

Kakioka Magnetic Observatory: Carrying the Spirit into its Next Century

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Abstract

The origin of magnetic observations by the Kakioka Magnetic Observatory (KMO) dates back to 1883, when hourly magnetic measurements were first initiated at Tokyo Magnetic Station. Established in 1913 following its relocation to Kakioka to secure a stable magnetic environment, KMO has since continuously monitored geomagnetic field variations for over a century without interruption. This achievement reflects a long-standing commitment, inherited across generations, to precise and continuous observation under all circumstances, as demonstrated by the uninterrupted continuation of measurements even through World War II and the Great East Japan Earthquake of 2011.

At present, as an auxiliary organ of the Japan Meteorological Agency (JMA), KMO provides high-quality geomagnetic data as the national reference, supporting applications such as space weather services, volcano monitoring, and magnetic field mapping. Its observatories—Kakioka, Memambetsu, and Kanoya—form part of the INTERMAGNET global network, contributing to both scientific research and operational services, such as Dst index derivation and global field modeling.

This presentation first reviews the historical development of KMO, including the original development of the KASMMER system in 1972, which marked a significant step in advancing automated geomagnetic observation and contributed to establishing KMO as a leading observatory. It then outlines its current activities, ranging from data denoising and traditional K-index scaling to the digitization of historical magnetograms and improvements in data accessibility through DOI-enabled services. Current challenges include environmental degradation due to urbanization and the discontinuation of some observations due to budget constraints. Finally, efforts will focus on strengthening geomagnetic observations at Syowa Station in Antarctica and advancing geomagnetic techniques for volcanic activity monitoring, now a key mission within JMA, as well as renewing aging instrumentation such as the Kakioka magnetic theodolite DI-72.

Keywords: History, Kakioka, Japan

The NAMRIA Magnetic Observatory of the Philippines

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Abstract

The NAMRIA Magnetic Observatory of the Philippines

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This presentation provides an overview of the operations, products, and future initiatives of the NAMRIA Magnetic Observatory, the national geomagnetic observatory of the Philippines.

The National Mapping and Resource Information Authority (NAMRIA), through its Hydrography Branch, operates the NAMRIA Magnetic Observatory, formerly known as the Muntinlupa Magnetic Observatory, to provide continuous geomagnetic observations and authoritative magnetic reference information for the Philippines. As an archipelagic nation, the Philippines requires regularly updated magnetic declination information to support the safe navigation of vessels and aircraft, hydrographic surveying, topographic mapping, and other geospatial applications. The observatory serves as the national reference for monitoring the secular variation of the Earth's geomagnetic field and maintaining the Philippine magnetic declination model, which forms the basis for the Philippine Isogonic Chart and other magnetic information products.

Continuous geomagnetic observations are carried out using the MUT-B and MUT-C magnetometer systems, integrating fluxgate and Overhauser magnetometers to acquire vector and scalar magnetic field measurements. Data are recorded at one-second intervals and processed into one-minute values following internationally accepted geomagnetic observatory practices. Data quality is maintained through regular absolute observations using a Theodolite Declination–Inclination Magnetometer (DIM). Through collaborations with Tierra Technica, the Institute for Space–Earth Environmental Research (ISEE) of Nagoya University, and Kyushu University, the observatory also supports international geomagnetic research through data sharing and collaborative monitoring activities.

To characterize the national geomagnetic field, NAMRIA conducts periodic Magnetic Repeat Station (MRS) surveys at 81 stations distributed throughout the Philippines. The integration of observatory and repeat station observations enables the periodic development of the Philippine magnetic declination model and the estimation of geomagnetic secular variation. During Epoch 2025, these datasets were used to produce the Philippine Declination Model 2025 and the Philippine Isogonic Chart 2025, providing updated magnetic declination information for new and existing nautical charts, civil aviation, engineering surveys, mapping, and other government applications. To improve public accessibility, NAMRIA also developed the PH Declination Calculator, which provides location-specific magnetic declination values nationwide.

Current initiatives include the modernization of observatory instrumentation, enhancement of data acquisition and management, strengthening of the national MRS network, relocation of the observatory to a magnetically suitable site, and the establishment of standardized data-sharing protocols. These efforts aim to improve data quality and accessibility, strengthen collaboration with government, academic, and scientific institutions, align with international observatory standards, and enhance the Philippines' contribution to regional and global geomagnetic monitoring.

Keywords: MAGNETIC OBSERVATORY, PHILIPPINE DECLINATION MODEL, MAGNETIC REPEAT STATIONS

Tsumeb Magnetic Observatory: Sustaining Long-Term Geomagnetic Observations in Southern Africa

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Abstract

The Tsumeb Magnetic Observatory (TSU), located near Tsumeb in northern Namibia, is an important long-term geomagnetic observatory within the southern African regional network. Operating since 1964, TSU provides continuous magnetic field observations from a strategically significant region influenced by the South Atlantic Magnetic Anomaly and by rapid spatial and temporal changes in the geomagnetic field. Its long data record supports studies of secular variation, geomagnetic jerks, magnetic storms, space weather effects, and regional field modelling. This presentation outlines the work being done to maintain high-quality absolute and variometer measurements. Emphasis is placed on observatory operations, data quality control, and alignment with INTERMAGNET standards. The workshop provides an opportunity to share experiences, discuss best practices, and explore pathways for enhancing observatory performance and regional capacity in geomagnetic observation.

Keywords: Geomagnetic observatory, INTERMAGNET, ,Tsumeb, South Atlantic Magnetic Anomaly,data quality control

Establishment/revival of new IIG observatories in Indian region

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Abstract

Indian Institute of Geomagnetism (IIG) maintains one of the most comprehensive geomagnetic observation networks in the low and mid-latitude regions by operating thirteen geomagnetic observatories. Strategically distributed from the magnetic equator to high northern latitudes, these observatories provide continuous measurements of the Earth's magnetic field, enabling investigations of solar-terrestrial interactions, ionospheric and magnetospheric current systems, geomagnetic storms, and long-term secular variation. IIG's observatory network encompasses equatorial, low-latitude, upto mid-latitude, which are useful for detailed characterization of regional magnetic responses associated with the equatorial electrojet, Sq current systems, substorms, and space weather disturbances. The observatories acquire high-resolution vector and scalar geomagnetic measurements following international standards.

Recently, the Magnetic observatory Hanle was revived in the campus of IIA, Hanle, Leh. Also, the establishment of Multi-Parametric Geophysical Observatory along with geomagnetic observations is in progress at Mussoorie, Uttarakhand. Efforts are ongoing for the establishment of a geomagnetic observatory in Kodaikanal, in the campus of IIA. In this presentation, the revival/establishment of these observatories along the scientific results will be presented.

Keywords: Geomagnetic Observatories India, IIG Magnetic Observatory

Geomagnetic Programme in Samoa

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Abstract

Since the establishment of the Apia Geomagnetic Observatory in 1902, its operations have evolved significantly, strengthening both the functions and core responsibilities of what is now the Samoa Meteorology Division under the Ministry of Natural Resources and Environment (MNRE). This progress has been made possible through technical capacity development, sustained international collaboration, and the commitment of local staff.

The geomagnetic programme plays a vital role in providing high-quality magnetic field data to international geomagnetic databases and supporting global research in geomagnetism. This presentation provides an overview of Samoa's geomagnetic programme, including the observatory's instrumentation, data acquisition systems, processing procedures, and routine operational activities. It also discusses recent challenges that have threatened the sustainability and continuity of the programme, including limited technical capacity, ageing infrastructure, and especially resource constraints.

The presentation highlights the importance of maintaining continuous geomagnetic observations at the Apia Observatory, one of the world's longest continuously operating magnetic observatories. Owing to its unique location in the central Pacific, the observatory provides valuable data for global geomagnetic monitoring and scientific research. Continued international cooperation and investment remain essential to ensuring the long-term sustainability of this important national and global asset.

Keywords: Geomagnetism, Apia Observatory, Samoa

Report from INTERMAGNET

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Abstract

Currently, 124 geomagnetic observatories belong to the International Real-time Magnetic Observatory Network (INTERMAGNET). Another 33 observatories have been contributing to INTERMAGNET at an earlier time. The network certifies the participating observatories and peer-reviews their data. It provides the infrastructure for near real-time data collection and distribution as well as for archival and data stewardship. INTERMAGNET is integrated into the World Data System of the International Science Council. In this presentation, the members of the INTERMAGNET Operations Committee (OpsCom) and Executive Council will report on INTERMAGNET and specifically on the discussions at the INTERMAGNET meetings in Rio de Janeiro in 2024, in Lisbon in 2025, and in Kyoto in 2026. Current priorities are to reduce the latency of the real-time data and to take in more members into OpsCom. The institutes operating INTERMAGNET observatories are welcome to nominate new OpsCom members. We will also report on planned changes to data formats and look forward to your feedback and questions on all aspects regarding INTERMAGNET.

Keywords: INTERMAGNET

Global Geomagnetic Observations and International Collaboration through the MAGDAS Project

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Abstract

Kyushu University has continuously operated a global geomagnetic observation network for more than 40 years since the 1980s. These activities are currently conducted under the MAGDAS (MAGnetic Data Acquisition System) Project, which is maintained and operated by the International Research Center for Space and Planetary Environmental Science (i-SPES), Kyushu University.

One of the distinctive features of the MAGDAS Project is its unique observational configuration, consisting of a north–south meridional chain extending approximately along a geomagnetic longitude of 210 degree, including Japan, and an east–west zonal chain extending along the geomagnetic equator. This configuration enables high-time-resolution observations of both the detailed propagation processes of magnetic disturbances from high-latitude regions to the equatorial region and the global characteristics of geomagnetic variations in the magnetic equatorial region.

Our observations are conducted primarily using ground-based fluxgate magnetometers. The high-quality data obtained from our observation network have contributed to numerous scientific achievements in research fields such as magnetosphere–ionosphere coupling, ULF waves, Sq variations, EEJ, and related phenomena.

In addition, we have released a new geomagnetic index, the EE-index, to accelerate the understanding of physical processes in the magnetic equatorial region. The index is continuously computed in near real time and published daily on our homepage. The EE-index consists of a global component, the Equatorial Disturbance Storm-Time (EDst) index, and local components, the Equatorial Upper (EU) and Equatorial Lower (EL) indices, computed for each observation station. EDst is defined as the mean value of variations in the horizontal magnetic field relative component observed at stations located on the nightside (18–06LT) among the stations distributed along the magnetic equatorial region. Furthermore, by subtracting EDst from the relative H-component data obtained at each equatorial station, the components corresponding to the Equatorial Electrojet (EEJ) and Counter Electrojet (CEJ) can be extracted. These components are defined as EU and EL, respectively. These indices provide valuable information for elucidating the states of solar–geospace coupling, magnetosphere–ionosphere coupling and atmosphere–ionosphere coupling in the magnetic equatorial region. Long-term and continuous studies using the EE-index are expected to significantly advance the understanding of the fundamental mechanisms underlying various geomagnetic phenomena occurring in the equatorial region.

The geomagnetic data and related index products maintained by the project are made publicly available not only through the project website, but also through inter-university collaborative projects, institutional repositories, and international cooperative frameworks for the operation and maintenance of ground-based magnetometers.

The MAGDAS Project is supported by a global network of international partners, and its activities are sustained through long-term collaboration with researchers around the world. To maintain and further strengthen these productive relationships, we promote joint research programs, capacity building at observation sites and at our research center, and the tangible return of research outcomes to our partners through the assignment of DOIs to datasets.

Keywords: MAGDAS, Equatorial Electrojet, International Collaboration

Modernizing Operational Geomagnetic Observatory Systems

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Abstract

Modernizing Operational Geomagnetic Observatory Systems

Operational geomagnetic observatories face the common challenge of renewing aging acquisition and processing infrastructure while maintaining established observatory practices, data quality, and uninterrupted operational capability. As instrumentation, telemetry, cybersecurity, and space weather requirements continue to evolve, modernization efforts must balance new technologies with the long-term stability expected of national observatory networks.

This presentation describes the CANMOS-HPRC stand-up pilot, an engineering workflow developed to modernize operational geomagnetic observatory systems through a modular, standards-aligned architecture and a structured validation process. Rather than redefining observatory operations or scientific products, the approach preserves existing observatory layouts, instrumentation practices, calibration procedures, and operational workflows while renewing the supporting acquisition, timing, processing, monitoring, and communications infrastructure.

Key aspects of the modernization include a unified system architecture supporting diverse analog and digital instruments, deterministic timing and standardized processing pipelines, and a commercial-off-the-shelf (COTS)-first design philosophy that minimizes custom hardware while providing a practical path for future instrumentation. To reduce deployment risk, complete observatory stand-up systems are assembled and pressure-tested at headquarters, enabling integrated validation of hardware, software, calibration, monitoring, fault recovery, and operational procedures prior to field installation. The initial deployment strategy replaces legacy systems at four pilot observatories using validated operational spare systems rather than extended parallel operation.

The presentation will discuss the engineering decisions, validation methodology, and early lessons learned from the stand-up pilot, with particular emphasis on developing sustainable, maintainable, and repeatable modernization practices applicable to operational geomagnetic observatory networks. The engineering approach presented may provide a practical framework for organizations undertaking similar observatory renewal initiatives while preserving continuity of long-term operations.

Keywords: Systems Modernization

Update on the geomagnetic observatory Neumayer Station III

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Abstract

The geomagnetic observatory Neumayer Station III is one of few geomagnetic observatories in Antarctica that deliver data to INTERMAGNET. The observatory is located in a tunnel in the slowly rotating and drifting shelf-ice. We previously reported that regular measurements of geographic north with a gyro are used to correct for the rotation and geomagnetic absolute measurements along the drift path are used to correct for the change in crustal field due to drift. Here, we report about a new gyro and a new strategy for absolute measurements on the drift path. In the Antarctic summer 2025/2026, the diameter of the ice-tunnel had to be increased by a dedicated digging machine, leading to a period of data loss. The previously installed auroral cameras and riometer receiver were moved into a permanent laboratory container fit for long-term deployment. We also installed a 3-component induction coil magnetometer with 500 Hz sampling rate and a VHF-receiver (with two 14 square meter sized loop antennas for North-South and East-West sensing) and a frequency range of 300 Hz to 48 kHz. Thus, we effectively measure the geomagnetic spectrum from DC to 48 kHz.

Keywords: Antarctica, Space Weather, Aurora

Geomagnetic observations and research in Arctic and Antarctic research institute.

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Abstract

The current geomagnetic field monitoring system in Arctic and Antarctic region was established by Arctic and Antarctic research institute (AARI) in 2008. Now it includes 8 geomagnetic observation sites near ROSGIDROMET stations in the Arctic: Barentsburg, Lovosero, Amderma, Dikson, Izvesty, Vise, Baranova, Tixie and 4 sites in Antarctic: Vostok, Mirny, Novolazarevskaya, Progress. The typical geomagnetic observation site is set in 200-300 m. of the main station working buildings. It consists of nonmagnetic building, with 4 pillars for magnetometers. The instrumentation includes 3 component flux-gate magnetometer oriented in EHZ coordinate system, inclinometer-declinometer and proton magnetometer. A complete set of instruments allowing absolute measurements is installed only in Amderma, Dikson, Tixie, Baranova, Vostok, Mirny, Novolazarevskaya and Progress stations. The rest of stations only include 3 component fluxgate magnetometer oriented in HEZ coordinate system, which allow measuring geomagnetic variations and calculate geomagnetic indexes K and AE. The collected data is transmitted to AARI servers via ROSGIDROMET satellite network system in real time. Some instruments are often malfunction, which cause data gaps and outliers. To resolve these issues, AARI specialists provide remote technical support to the station crews and conduct field maintenance trips. The obtained data is available on request through pgc@aari.ru.

Scientific research is carried out at AARI with use geomagnetic data obtained by AARI and data from other institutions. The MLT structure of DP11 and DP12 current systems were examined with use of SML indexes calculated for different MLT sectors. It was found that substorm sudden onset can occur either in a single MLT sector (usually before midnight) or in several MLT sectors (up to the extent of 20 –04 MLT). The displacement of maximal intensity to morning hours was found for higher substorm power. As a result, in case of the most power substorms the intensity of DP11 disturbances can reach maximum in the morning sector (02-06 MLT). And conversely, in case of the weak power substorms the maximum substorm intensity is fixed in the midnight sector.

Keywords: geomagnetic observatories, substorms

RECONSTRUCTION AND QUALITY CONTROL OF LONG-TERM GEOMAGNETIC DATA FROM KHOVD OBSERVATORY, WESTERN MONGOLIA

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Abstract

Khovd Observatory (HVD), located in western Mongolia, has provided continuous geomagnetic field observations since 2003 and has been part of the MAGDAS network since 2007. In this contribution, we present ongoing work to reconstruct and preprocess the HVD geomagnetic dataset for reliable scientific analysis and international data exchange. The historical records require systematic reconstruction, quality control, and standardization before use. The workflow includes compiling variometer records, integrating absolute magnetic measurements, correcting baseline variations, detecting and removing spikes and artificial steps, and converting the data into standard geomagnetic components. For these processes, we apply a combination of median filtering and the Hampel filter for spike and artefact removal, LOWESS (Locally Weighted Scatterplot Smoothing) to correct baseline variations, and custom Python scripts built on the ObsPy and GeoMagPy libraries for data handling and resampling. Outlier detection and correction follow a semi-automated approach combining statistical thresholds with manual review. Particular attention is given to linking absolute D, I, and F measurements with continuous variometer observations to recover stable H, D, and Z time series. The reconstructed data are resampled to minute and hourly values in accordance with international geomagnetic data standards. Preliminary results show that the HVD records contain valuable information on regional geomagnetic field variations and external magnetic disturbances. Several technical challenges remain, including instrumental drift, data gaps, timing problems, incomplete metadata, and changes in sensor configuration. Addressing these problems is essential for producing a reliable long-term geomagnetic dataset from western Mongolia. This work modernizes geomagnetic data processing in Mongolia and provides a basis for future studies of regional magnetic field variation, space weather effects, magnetic storms, and long-period electromagnetic induction. The reconstructed HVD dataset will also support the development of national geomagnetic data products and enhance Mongolia's contribution to international geomagnetic observation networks.

Keywords: Data processing, Geomagnetic observatory, Long-period induction

A Review of Absolute Magnetic Measurements Using Real and Synthetic Data – Part I

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Abstract

A Review of Absolute Magnetic Measurements Using Real and Synthetic Data – Part I

Absolute magnetic measurements are carried out with a Declination Inclination Magnetometer (DIM). This instrument is manually operated and requires a highly trained observer. To facilitate the observer's work, MinGeo developed a push-button DIM instrument and, later, an automatic DIM instrument. The former is called the Declination Inclination Digital Station (DS), and the latter is called the Automatic DS (ADS).

Although absolute measurement sequences, data processing, and evaluation methods have been well established over the past decades — making the procedure largely routine — certain aspects can still be improved.

Given the tight coupling between the measurement methods and the instrumentation, as well as the large volume of absolute measurement data now available from these new instruments, we conclude that the measurement methods themselves are worth expanding and refining.

In this paper, we focus on possible improvements in the data processing steps while also examining selected aspects of the measurement scheme. Among other things, we:

- summarize the benefits and drawbacks of the null (zero), close-to-zero (residual), and inverse methods;
- assess the validity of the residual method when residuals reach ± 1000 nT;
- demonstrate how extending the residual method with iteration and scale estimation improves the quality of spot baseline values;
- analyze the measurement situation in which the telescope is not perfectly horizontal during residual observations;
- briefly present a numerical absolute measurement evaluation method based on Levenberg–Marquardt (LM) optimization;
- investigate how increasing the number of measurement positions and sampled data points affects the results;
- examine the effect of temporal changes in the geomagnetic field at low, mid, and high latitudes on absolute magnetic measurement methods.

Keywords: Declination Inclination Magnetometer (DIM), Absolute geomagnetic measurements, Spot baseline values

Review of absolute magnetic measurements using real and synthetic data - Part II - Error-sensitivity analysis

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Abstract

Absolute geomagnetic measurements require high-precision non-magnetic instrumentation and specific environmental conditions. Commonly used measurement schemes efficiently eliminate some of the most frequent instrument errors, such as collimation error, magnetometer offset, sensor misalignments and circle eccentricity error. However, certain other possible instrument errors and field conditions can degrade the measurement accuracy.

We investigated several of these factors using both real measurements and simulations. The examined parameters included the magnetic gradient on the pillar, magnetometer noise and nonlinearity errors, higher-order sensor misalignments, angular positioning deviations from ideal horizontal and meridian angles, and prolonged measurement duration.

We compared baseline results obtained using one-second and one-minute variometer and scalar data, analyzed separately for quiet and disturbed days. In the case of one-second data, we also studied the impact of time-stamping mismatches between the DIM magnetometer and the variometer.

The analyses are based on evaluating the scattering of spot baseline points and, in case of synthetic data, on the easily verifiable absolute accuracy of the results.

One of the goals of these presentations is to initiate the standardization of absolute magnetic data processing methods. As part of it, we recommend that the magnetic community create synthetic datasets that anyone can use to test their algorithms. We are happy to share our testing data as well as our customized processing algorithms. Our methods are available in Python programs and partially in spreadsheet files, but our ultimate plan is to integrate them into the MagPy software package.

Keywords: Geomagnetic Absolute Measurement, Declination/Inclination Magnetometer (DIM), Spot baseline values

Geomagnetic observations conducted by the Geospatial Information Authority of Japan (GSI)

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Abstract

The Geospatial Information Authority of Japan (GSI) began geomagnetic surveys all over Japan around 1950 to understand the spatial distribution of the geomagnetic field and its temporal variation and has been observing the geomagnetic field in Japan for more than 75 years. Geomagnetic surveys had been carried out at approximately 100 first-order magnetic points and 800 second-order magnetic points, from Hokkaido to Okinawa in Japan. In addition, to continuously monitor the secular variation in the geomagnetic field, the Kanozan Geodetic Observatory (Kimitsu City, Chiba Prefecture) was established in 1962, followed by the Mizusawa Geodetic Observatory (Oshu City, Iwate Prefecture) in 1969. Since 1996, geomagnetic observation instruments have been installed nationwide (currently at 12 locations), continuously measuring the absolute value of the total intensity (F) and variations in the three geomagnetic components (H, D, Z). In today's geomagnetic surveys, observations are conducted using Overhauser and D/I magnetometer at reference magnetic points co-located with geomagnetic observation instruments. Then, difference in the total intensity (F) and baseline values of the three geomagnetic components (H, D, Z) between the geomagnetic observation instrument and the reference magnetic point are determined. Finally, by combining these survey results with geomagnetic observation data that have undergone processing such as removal of artificial noise, absolute geomagnetic values at a reference magnetic point are obtained. At the same time, corrections are applied for instrument drift and other sources of error to ensure the accuracy of the data.

GSI provides various types of data on its website, including absolute geomagnetic values at reference magnetic points (in IAGA2002 format) and raw data from geomagnetic observation instruments. In addition, it offers "Geomagnetic Charts", which show the distribution of the geomagnetic field in Japan, as well as information on geomagnetic declination (the angular difference between true north and magnetic north) for determining the accurate direction with a compass (indicated on topographic maps).

This presentation introduces an overview of geomagnetic observations conducted by GSI.

Keywords: Geomagnetic Observations

On the Diversity of K-Index Calculation Methods Across Magnetic Observatories

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Abstract

Since the introduction of the K index by Bartels in 1939, magnetic observatories have undergone a major transformation from analogue to digital data acquisition and processing. This digitalisation, while enabling the production of vast amounts of continuous magnetic field data, has also necessitated the automation of K-index derivation — a task originally performed by hand.

As observatories proactively implemented automated algorithms, numerous variations of Bartels' original method emerged. Menvielle et al. (1995) evaluated several of these methods against a reference set of hand-scaled K indices. However, in the three decades since, the landscape of methods in operational use has received little systematic attention, and documentation of the specific algorithms employed is often incomplete or absent.

This study surveys the variety of K-index derivation methods currently available and in use across observatories. We identify and categorise the key differences and quantify the impact of these methodological choices through systematic comparisons.

Our results highlight that differences arise depending on the method used, reinforcing the importance of proper metadata documentation. We argue that transparency regarding the algorithm employed is essential for the meaningful interpretation and intercomparison of K indices across the global observatory network and discuss possible steps toward greater harmonisation.

Keywords: geomagnetic activity, K index, magnetic field data

Digital preservation of the geomagnetic observatory data in Finland

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Abstract

Sodankylä and Nurmijärvi geomagnetic observatories in Finland have been producing digital data since 1990s. The last analogical recordings of La Cour variometers were stopped on 31 Dec 1995 in Sodankylä. The original analogical magnetograms were stored at the observatory archives in Sodankylä and Nurmijärvi. Nurmijärvi archives were later moved to FMI main archives. Photographic copies were made regularly on microfilm and microfiche, but until today the digital images of the magnetograms were not systematically produced. Only some major events have been reconstructed for scientific purposes. WDC Kyoto has produced digital images from Nurmijärvi magnetogram photographs available in their archives.

New resources for the digital preservation of the geomagnetic time series from Finland was granted to EPOS-Finland as a part of National Roadmap infrastructure program for 2025-2028. Digital images from the magnetograms of Sodankylä (1914-1995), Nurmijärvi (1950-1991) and Petsamo (1932-1933) are produced and the concept for producing numerical time series is developed. Previously, 1-minute values with 1nT resolution have been produced manually on the Hewlett-Packard digitization table from the original Nurmijärvi and Sodankylä magnetograms. This project extended 1 min data availability of Nurmijärvi back to 1976 and Sodankylä back to 1980. This data set can be used for validation of the production of the numerical time series. The Proof-of-Concept phase for digital preservation project has been established with the National Archives of Finland.

In this poster we present status of the geomagnetic observatories in Finland, results of the first tests in Proof-of-Concept project of the digitalisation at National Archives and project plan of the digital preservation of the historical geomagnetic data aiming to improve historical data resolution from hourly means to sub-minute level from Finnish geomagnetic observatories.

Keywords: historical data recovery,digital preservation,observatory

New developments on the Tatuoca magnetic observatory magnetogram digitization and data extraction project

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Abstract

The Tatuoca Magnetic Observatory (TTB), established in 1957, utilized classical variometers to monitor Earth's magnetic field for half a century. Operating until 2007, the observatory generated a vast collection of analog magnetograms. To preserve and extract the historical data contained within these physical records, the Tatuoca Project was formed as an interdisciplinary collaboration among archivists, information scientists, computer scientists, and geophysicists. This work presents ongoing efforts to develop an automated algorithm that fulfills two goals: (i) to digitize the magnetogram records correctly; (ii) to convert pixel curves into physical geomagnetic values, minimizing the need for manual supervision. The current methodology consists of three main stages: image processing, unit conversion, and validation. The image processing stage filters scanning noise and employs clustering and mathematical morphology to isolate the magnetic variation traces. The unit conversion stage translates coordinates from image pixels to original document millimeters, and ultimately to geomagnetic units using absolute calibration tables available in yearbooks. For validation, we selected a test day from the TTB record and compared it with the predicted magnetic curve from our approach. The preliminary results demonstrate that the algorithm successfully reconstructs the geomagnetic variation curve with high fidelity in non-complex scenarios where the data traces do not intersect. However, line crossing events remain a critical tracking challenge; local directional analysis, such as Principal Component Analysis (PCA), is currently being evaluated to resolve these topological ambiguities.

Keywords: digitization,magnetograms,geomagnetic variation

Digitization of analog magnetograms at the Kakioka Magnetic Observatory of the Japan Meteorological Agency

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Abstract

The Japan Meteorological Agency (JMA) has conducted long-term magnetic observations at Kakioka since 1913, at Memambetsu since 1952, and at Kanoya since 1958.

A large portion of these data is preserved as analog magnetograms, while digital minute values are available only from 1976 for Kakioka and from 1985 for Memambetsu and Kanoya.

For periods where only analog magnetograms exist, we first scan the records at high resolution to convert them into digital images, and then digitize the data using our original tracing software.

This digitization project started around 2010. To date, geomagnetic data have been converted into 7.5-second and 1-minute digital values for Kakioka from 1955 onward, and for Memambetsu and Kanoya from 1966 onward.

The project is ongoing, with the ultimate goal of digitizing all remaining analog magnetograms.

The tracing software has been continuously improved. For instance, at points where data curves intersect with each other or with horizontal baseline reference lines, unwanted components or the baseline reference lines can be masked by filling them with the background color.

In addition, when the data curves are faint, their visibility can be enhanced by adjusting contrast, enabling more reliable tracing. These improvements have enabled the digitization of complex magnetograms, such as those recorded during geomagnetic storms, which were difficult to process at the early stage of the project.

This report presents the current progress of the digitization effort and describes the methodology for converting analog magnetograms into digital data, with particular emphasis on cases involving significant geomagnetic disturbances using the developed tracing software.

Keywords: magnetograms, tracing, digital data

Geomagnetically induced currents (GIC) around Tokyo: From basic principles to future perspectives

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Abstract

Geomagnetically induced currents (GICs) are quasi-DC currents flowing in long grounded conductors such as power transmission lines and pipelines. They are driven by electric fields induced by time-varying current systems in the magnetosphere and ionosphere, so that a comprehensive understanding of GICs requires knowledge of the magnetospheric–ionospheric current systems, the ground resistivity structure, and the topology as well as the resistance of the conducting network. At high latitudes, large geomagnetic variations associated with auroral activity make GICs a recognized threat to power systems. A well-known example is the 9-hour blackout in Québec, Canada in March 1989 (Boteler, 2019, 10.1029/2019SW002278). Power grids at low and mid latitudes have often been considered relatively safe because of their distance from the auroral oval. However, observations challenge this view. A GIC with a peak amplitude of 129 A was recorded at a Japanese power plant during the October 2003 storm (METI, 2015, <https://dl.ndl.go.jp/info:ndljp/pid/11280903>), although no damage was reported. In this talk, we overview GICs at low and mid latitudes from fundamentals to future perspectives, focusing on the Tokyo region. First, we revisit the fundamentals. GICs are usually calculated by applying the Lehtinen–Pirjola (LP) formulation to the surface electric field. From first principles, the induced electric field driving GICs is best understood, through the differential form of Faraday's law, as the superposition of a downward-propagating electromagnetic disturbance of external origin and the field reflected from the conducting Earth. We also evaluate the conditions under which the induced electric field at typical transmission-line altitudes can be regarded as nearly the same as that at the ground surface. Second, we summarize the current understanding of GICs around Tokyo and of the geoelectric fields at Kakioka Magnetic Observatory (KAK). Statistically, large geoelectric fields at KAK appear during sudden commencements as well as storm main and recovery phases, with 100-year return levels of about 612, 442 and 456 mV/km, respectively, estimated by generalized extreme value distribution analysis (Zhang et al., 2022, 10.1029/2021SW002893). Since 2017, we have measured GICs at four substations connected to the 500-kV power grid around Tokyo. Large (>3 A), long-lasting (>45 min) GICs occur regardless of the storm phase, and the largest GIC observed during 2018–2024 was 30.7 A on 10 October 2024 (Watari et al., 2026, 10.1186/s40623-021-01422-3). The observed GICs are well represented by a linear combination of the two horizontal components of the geoelectric field at KAK, which can be obtained by convolving geomagnetic field variations with an appropriate galvanic tensor. This enables us to predict GICs from geomagnetic data. Applying this model to the geomagnetic field variations recorded at Colaba, India during the extreme storm of September 1859, we estimate that the geoelectric field at KAK could reach ~2.5 V/km (Ebihara et al., 2021, 10.1186/s40623-021-01493-2), corresponding to GICs of several hundred amperes. Finally, we discuss future perspectives, including extreme-event assessment, and improvements in the GIC modeling.

Keywords: Geomagnetically induced currents, Geoelectric field, Geomagnetic disturbances

Analysis of the geomagnetic storm of May 2024 at the Ebre and Livingston Island Observatories and of the GICs generated in the Spanish power transmission grid

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Abstract

This study analyzes the geomagnetic storm of May 10–12, 2024, using data from the Ebre Observatory (Spain) and the Livingston Island Observatory (Antarctica), together with modeling approaches to assess its impact on the Spanish power transmission grid. Geomagnetic field variations reveal significantly stronger disturbances at Livingston Island, because of its higher geomagnetic latitude, with peak rates of change of the horizontal magnetic field reaching 230.1 nT/min, compared to 74.4 nT/min at Ebre.

A statistical analysis based on a 46-year dataset (1980–2025) indicates that the storm corresponds to a return period of approximately 7.7 years at Ebre, ranking ninth in magnitude. In terms of modeled geoelectric field intensity, the event is less extreme, with a return period of 3.3 years. These results suggest that, while significant, the effects of the event were moderate compared to historical extremes.

To evaluate geomagnetically induced currents (GICs), the geomagnetic field data were combined with a 3D lithospheric electrical resistivity model to estimate geoelectric fields and resulting currents across the Spanish power transmission grid. The analysis shows that GICs were unevenly distributed, with maximum modeled values reaching 28.7 A in a substation, largely due to the alignment of transmission lines with the dominant electric field direction.

Results were partially validated using direct and indirect GIC measurements, showing overall agreement but also highlighting discrepancies likely related to grid configuration changes during the event. The findings confirm that the GICs generated were not negligible, although they did not pose a risk to the Spanish grid, unlike some recorded in grids at higher latitudes.

Keywords: Gannon storm, Mother's day storm, GIC

Modelling Natural Electromagnetic Induction in the Spanish Gas Pipeline Network

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Abstract

Electromagnetic induction poses a threat to long, earthed conductors, such as power grids, pipelines, railway tracks and communications cables. In this talk, we analyse the risk associated with natural induction in the pipelines of the extensive Spanish gas network, where excessive potential differences between the pipe and the nearby soil could undermine the measures applied by the responsible utility to prevent corrosion, thereby jeopardising the long-term integrity of the infrastructure.

The Ebre Observatory has a long tradition in studying and measuring geophysical quantities associated with Space Weather phenomena. Specifically, the geomagnetic field can provide a reliable geoelectric field when combined with a suitable resistivity model of the lithosphere, which is the basis for modelling the pipe-to-soil potential in the gas network. We present the theoretical basis of the method, along with the results achieved so far and the validation we are carrying out in parallel.

Keywords: Induction,Pipelines,Corrosion

The ESA-Project MagWatch3D

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Abstract

MagWatch3D is a feasibility study funded by the European Space Agency ESA. The study is led by Leomagnetics GmbH, a small German company and spin-off from GFZ. The project uses space weather observations, in this case geomagnetic observatory data, to investigate the feasibility of a future, commercially viable service to provide an actionable, data-based solution for ground infrastructure affected by space weather hazards such as Geomagnetically Induced Currents (GICs).

The MagWatch3D service has three main pillars: Firstly, it implements fair and traceable license agreements with geomagnetic observatories to use their real-time and archive data. Secondly, based on the geomagnetic observatory data and on 3-D subsurface electric conductivity models, regional and global models of the geomagnetic disturbance and the induced geoelectric fields are computed using a state-of-the-art data assimilation method. From this, GICs in infrastructure (power grids, pipelines, cables) can be reliably obtained. Thirdly, the observations and model values are distributed through an online service to end-users and stakeholders.

The benefits for participating geomagnetic observatories include payment of license fees for the commercial use of their data, automated feedback on data quality, and potential for scientific collaboration.

Keywords: space weather, geomagnetically induced currents, geomagnetic disturbance

Geomagnetic Observations in Malaysia and Their Applications to Space Weather Studies

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Abstract

Malaysia's geomagnetic observatories have undergone significant development over the past two decades. This presentation provides an overview of Malaysia's geomagnetic observatories and demonstrates how geomagnetic observations have been applied in equatorial space weather studies. The development began with the establishment of the first MAGnetic Data Acquisition System (MAGDAS) observatory at Langkawi in 2006 through a collaboration with Kyushu University. Since then, additional geomagnetic observatories have been established across Malaysia to support continuous monitoring of the equatorial region. Malaysia currently has six geomagnetic observatories located at Langkawi (LKW), Banting (BTG), Terengganu (TRE), Johor (JOH), Ranau (RAN), and Penang (PEN). These observatories are operated through collaborations between Kyushu University and Malaysian institutions, providing continuous geomagnetic measurements that support investigations of equatorial electrodynamics, geomagnetic disturbances, and other space weather phenomena. Geomagnetic observations from these observatories have been widely used in space weather studies, particularly to investigate the local response of the equatorial region to geomagnetic disturbances. One recent example is the extreme geomagnetic storm of 10–11 May 2024, during which observations from LKW, RAN, TRE, and JOH, selected based on data availability, were analysed to examine storm-time variations in the geomagnetic H component. Ionospheric disturbance dynamo (Ddyn) signatures were identified, with the strongest response observed at LKW, the station closest to the magnetic equator, whereas Ddyn signatures were not evident at JOH. These observations demonstrate the importance of multi-station geomagnetic measurements for understanding the regional response to extreme space weather events in the equatorial sector. The findings highlight the capability of Malaysia's geomagnetic observatories to support space weather research and continuous geomagnetic monitoring in the equatorial region. The continued development of geomagnetic observations in Malaysia provides a strong foundation for advancing national space weather monitoring capabilities, capacity building, and the development of a Malaysian local geomagnetic index based on long-term observations from these observatories.

Keywords: Geomagnetic observatories, Space weather, Ionospheric disturbance dynamo

Space weather and geophysical applications of geomagnetic data from a single station in the Philippines

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Abstract

The Philippines used to host six magnetometers of the MAGnetic Data Acquisition System (MAGDAS) network of the Space Environment Research Center (SERC), Kyushu University. One of the two remaining stations is in Davao (7°N, 125.4°E), maintained by the Manila Observatory (MO), formerly a MAGDAS Subcenter. The geomagnetic observations from this station have been widely used globally in understanding the response of the Earth's magnetic field to space weather events over the equatorial region, the equatorial electrojet (EEJ), and ultra-low frequency (ULF) emissions for earthquake precursor research. In this presentation, we showcase two main applications of geomagnetic data at MO. At the principal station of MO in Manila (14.64°N, 121.07°E), the Vertical Incidence Pulsed Ionospheric Radar (VIPiR) ionosonde is currently operational and is used to understand the occurrence of equatorial plasma bubbles (EPBs). The EEJ strength has been reported in many studies to be associated with EPBs. The MAGDAS Group developed the hourly EE-index from its network of magnetometers to quantify the EEJ strength and the calculated index in Davao station is used to analyze the relationship between the daytime/pre-sunset EEJ and EPB occurrences based on the 1-minute ionograms of the VIPiR during the equinoctial months of 2024 (March-April, September-October). EPBs are likely to be suppressed when the integrated daytime and pre-sunset EE-index is weak or negative (counter-electrojet). Since the Philippines is a tectonically complex region, another application of geomagnetic data is detecting anomalous electromagnetic signals in the ULF range (0.01-0.1 Hz) associated with earthquakes. The polarization ratio analysis method is applied to the 1-second geomagnetic data in Davao station within 300 days before and 30 days after the mainshock of the Mw 6.9 earthquake in Cebu, Philippines (epicenter: 11.16°N, 124.11°E) on September 30, 2025 at 13:35:43 UTC as a case study. The Single Station Transfer Function is employed to locate the source of the ULF anomalies and the epicenter of the earthquake lies within $\pm 22.5^\circ$ of the estimated azimuth of the ULF anomalies relative to the station on May 12, 2025, more than 140 days before the mainshock. Other anomalies are attributed to different seismic sources, such as the doublet earthquake (Mw 7.4 and Mw 6.7) in Davao Oriental on October 10, 2025. We have demonstrated the research capabilities of a single station in the Philippines and we aim to implement the same methodologies at the other station in Muntinlupa to campaign for a dense magnetometer network in the country.

Keywords: geomagnetic data, equatorial plasma bubbles, earthquake precursors

SOLAR WIND–MAGNETOSPHERE–GROUND MAGNETIC FIELD COUPLING DURING GEOMAGNETIC STORMS: A PRELIMINARY STUDY USING MONGOLIAN GEOMAGNETIC OBSERVATIONS

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Abstract

This study presents an early look at how changes in the solar wind, Earth's magnetic environment, and ground magnetic field disturbances in Mongolia are linked during geomagnetic storms. The goal is to link satellite data about the solar wind and space magnetic fields with magnetic measurements from Mongolian and nearby stations. As a first example, we study the magnetic disturbance from 5–6 December 2020. Solar wind details such as speed, pressure, magnetic field components, and the SYM/H index were taken from OMNI data, with additional satellite data used when available. Ground magnetic changes were studied using H, D, and Z components from MAGDAS and regional INTERMAGNET stations. MAGDAS data were averaged into one-minute values, and quiet-day baselines were used to find disturbance-related changes in the horizontal magnetic field. The first comparison shows that changes in solar wind and magnetospheric indices are generally seen in the ground magnetic records. A cross-correlation analysis between some solar wind factors and ground magnetic disturbances suggests a possible statistical link and a delay between solar wind changes and the ground magnetic response. However, this is an early finding because the study looks at only a few events and may be influenced by baseline choices, station locations, local time, missing data, and processing methods. This work establishes a method for future statistical studies of numerous geomagnetic storms. The next step will include a larger list of events, comparisons of different storm strengths, and a study of regional differences in magnetic responses across Mongolian stations. This will help better understand how the solar wind, magnetosphere, and ground magnetic field interact at middle latitudes and support the use of Mongolian geomagnetic data in space weather research.

Keywords: Geomagnetic storms, Solar wind coupling, Ground magnetic response

Applications of geomagnetic data obtained in the frame of MAGDAS and INTERMAGNET programs in Yakutia

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Abstract

Ground measurements of the full geomagnetic field vector in Yakutia in Yakutsk begin in 1932 during the 2nd International Polar Geophysical Year. Continuous observations of the geomagnetic field in Yakutia, conducted by the Institute of Cosmophysical Research and Aeronomy SB RAS under the INTERMAGNET program at the YAK station, began in 2008, and under the MAGDAS program at six stations (YAK, ZGN, TIX, KTN, CHD, and ZYK) since 2011.

The Institute was able to join the INTERMAGNET program thanks to the efforts of specialists from the GeoForschungsZentrum, Potsdam, Germany, and the MAGDAS program thanks to the efforts of staff from the International Center for Space Weather Science and Education, Kyushu University, Fukuoka, Japan.

The INTERMAGNET program uses a combination of vector magnetometers (a three-component fluxgate magnetometer, DI magnetometer) and scalar magnetometers (proton magnetometers based on the Overhauser effect) to measure the geomagnetic field. Geomagnetic field measurements under the MAGDAS project are carried out using identical three-component MAGDAS-9 fluxgate magnetometers. Both types of magnetometric systems have demonstrated stable performance in the harsh climatic conditions of Yakutia.

The report further presents the results of a study of geomagnetic Pc5 pulsations with periods of 150-600 seconds over 10 years (2012-2021) based on data from a chain of geophysical stations: Tiksi (71.41° N, 128.32° E), Zhigansk (66.47° N, 123.22° E), and Yakutsk (62.02° N, 129.44° E). The interannual, seasonal, and daily variations in the activity of Pc5 pulsations, as well as the predominant excitation frequencies of Pc5 pulsations, are considered.

Keywords: Ground geomagnetic field measurement, space weather, Pc5 geomagnetic pulsations

Pc1 pulsations simultaneously observed at the latitudinal induction magnetometer network and by the Swarm satellites

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Abstract

Pc1 geomagnetic pulsations are considered to be an electromagnetic ion cyclotron waves excited by the temperature anisotropy of plasmas in the magnetosphere. Previous satellite studies [Anderson et al., 1992; Usanova et al., 2012; Keika et al., 2013] reported that Pc1 pulsations are predominantly observed in the outer magnetosphere at $L > 7$ at daytime centered around 13–18 magnetic local time (MLT). They are seldom detected in the inner magnetosphere at $L < 4$. On the ground, MLT distribution of Pc1 pulsations at high- and mid-latitudes ($L > 4$) is similar to those of the satellite observations [Saito et al., 1969; Plyasova-Bakounina et al., 1996]. However, Pc1 pulsations at low-latitude ($L < 4$) show a completely different MLT distribution with the frequent occurrence at nighttime peaking at 03–06 MLT [Saito et al., 1969; Kawamura et al., 1981]. The occurrence rate of low-latitude Pc1 appears to be larger than that in the inner magnetosphere at $L < 4$. This implies that low-latitude Pc1 pulsations are not caused by direct entry of Pc1 pulsations from the magnetosphere to the ground along the geomagnetic field line, but due to waves indirectly propagated from the magnetosphere, although the indirect propagation path is still unclear.

We have been constructing a latitudinal network of induction magnetometers in the Russian Far East-Asia-Oceania sector (Russia, Japan, Philippines, and Australia) and successfully detected Pc1 pulsations in the wide latitudinal range from -21 deg to 64 deg geomagnetic latitude at 10–15 UT on March 25, 2023. This event was observed in the premidnight sector during the recovery phase of a large magnetic storm (SYM-H minimum = -163 nT). The Swarm satellites were flying near the same MLT and provided simultaneous measurements of geomagnetic field variations that are related to the Pc1 pulsations detected at low-latitude on the ground. In this talk, results of data analysis are presented and the propagating path of EMIC waves from their excitation region to low-latitude ground stations will be discussed.

Keywords: Pc1 pulsation, induction magnetometer

Automatic detection of SI/SSC in near-real time using a global network of magnetic observatories: results from 2 years of operations at solar maximum.

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Abstract

It is well known that the solar wind impacting the Earth's magnetosphere produces Sudden Impulses (SI) and Sudden Storm Commencements (SSC) that are detectable simultaneously at magnetic observatories located at any longitude on Earth. The service for rapid variations of the Ebro observatory (Spain) conducts a thorough analysis of magnetic field time series to produce the IAGA-endorsed list of SI and SSC events.

At the Institut de physique du globe de Paris we currently manage a network of 10 observatories located at different longitudes at mid and low latitudes: Chambon-la-For  t (CLF) in France, Tamanrasset (TAM) in Algeria, Ed  a (EDA) in Cameroon, Reunion Island (REU), Phu Thuy (PHU) and Da Lat (DLT) in Vietnam, Pamata  i (PPT) in Tahiti, Isla de Pasqua Mataveri (IPM) in Chile, Kourou (KOU) in French Guyana and Sop Niakhar (SOK) in Senegal. All these observatories produce data that are transmitted to our central servers in Paris within 5 minutes from acquisition, making them suitable for near-real time data processing and to detect space weather events.

On this basis we selected all SI/SSC events from 2009 to 2021, a time-period after 1-second data started being recorded at these magnetic observatories. Taking time-windows of 1801s centred at the SSC events for each observatory we constructed a database of classified events and we selected randomly other time-windows to constitute a database for training a machine learning classifier. We trained a specific classifier separately for each observatory. For the REU observatory, that started operations at the end of 2022, we used the same classifier as IPM, because we were not having enough events for training.

Since our network presents a large gap over the western Pacific, we added Guam (GUA) observatory (USGS) to our service.

We started a near-real time service to detect SI/SSC event and produce automatically an e-mail alert during the Spring of 2024. From 2024/04/08 to 2026/06/13 the service triggered 155 alerts, that include both SI and SSC events. In near-real time it is not possible to distinguish between impulses that will be followed by geomagnetic storm from those that will not be followed by a storm. We present several examples of both cases. Knowing that in the hours of disturbed solar wind conditions several impulses can happen, the system does not produce subsequent alerts occurring during the same day.

The list of detected events can be accessed at : https://www.bcmt.fr/DATABANK/PRODUCTS/SUDDEN_IMPULSE/
In that page reprocessed alerts are reuploaded the UT day following the initial alert, displaying magnetic time series over the complete day.

Keywords: Sudden Storm Commencement, Space Weather

Global analysis of geomagnetic observatories data quality.

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Abstract

Geomagnetic observatories are fixed locations on the Earth's surface dedicated to measuring the geomagnetic field over long periods. Historically, their data products were primarily used for secular variation inference and core field modelling. Since the beginning of the satellite era, and with the growing number of satellite missions in recent years, timely observatory data has become increasingly important for new data products and geomagnetic models. The INTERMAGNET network establishes standards for procedures and formats, and peer-review definitive data. Here, we present a global analysis of data quality across more than 140 observatories from INTERMAGNET and the WDC, spanning the past 20 years, with a particular focus on the near real-time distributed data. Similar to previous studies, we aim at identifying drift and jumps in the data by first removing models of e.g., magnetospheric sources and secular variation and by comparison with neighbouring observatories. We extend the analysis to reported and QD data and also compare QD data to definitive data.

Keywords: INTERMAGNET, Quality control

Evolution of the South Atlantic Anomaly's First Minimum and Second Minimum between 2014 and 2025 Using Swarm Satellite Data and the CHAOS-8.5 Model

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Abstract

A search for recent positions of the first and second minima of the SAA was conducted using the CHAOS -8.5 model. The geographic coordinates of the recent positions of the first and second minima were (59.70°W, 26.30°S) and (0.55°W, 40.60°S), respectively. The investigation of the evolution of these positions between 2014 and 2025 shows some movements, which are discussed in detail. The analysis of the temporal variation of the field, using the CHAOS-8.5 model and virtual geomagnetic observatories at satellite altitude above these positions, indicates positive secular acceleration (SA) resulting in a reduced rate of decrease of the field at the first minimum, while the second minimum shows a negative SA with an increasing rate of decrease of the field. The analysed PIL magnetic observatory data supports the observed trend of the temporal magnetic field variation at the first minimum. The extrapolation of the total field intensity, based on constant estimated SA values over the study period, indicates that the total field intensity value recorded at the second minimum will be smaller than the one at the first minimum after the epoch of 2041.1.

Keywords: South Atlantic Anomaly, Secular variation, Swarm satellite data

A Study of the Spatial Evolution of the South Atlantic Anomaly's Second Minimum Lobe Using a Regional R-SCHA Main Field Model (2014-2025)

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Abstract

Recent Swarm observations have revealed a second minimum of the South Atlantic Anomaly (SAA) in the southwest of Africa. A regional Revised Spherical Cap Harmonic Analysis (R-SCHA) model developed from Swarm satellite and ground-based observations provides a detailed representation of the geomagnetic field over the SAA's second minimum lobe between 2014 and 2025. This study investigates its temporal morphological evolution. The analysis focuses on quantifying changes in the length and width of the weak-field region, the orientation of the anomaly, and its rate of expansion throughout the study period. These geometric characteristics provide additional insight into the evolution of the second minimum beyond its position alone and help to characterize changes in its spatial structure. The results based on these morphological quantities are presented and discussed.

Keywords: South Atlantic Anomaly, SAA Second Minimum, Secular Variation

Models and forecasts of Earth's magnetic field derived from geomagnetic observatory data

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Abstract

Observations of the geomagnetic field taken at Earth's surface are processed to construct a set of continuous models of the geomagnetic field and its secular variation from 1956 to 2033. One of these models, the parent model, provides candidate main field models for the epochs 2020 and 2025 to the 14th generation of the International Geomagnetic Reference Field (IGRF). The secular variation candidate model for the period 2025 - 2030 is derived from a forecast of the secular variation in 2027.5, which results from a multi-variate singular spectrum analysis of the secular variation from 1960 to 2023. Apart from the parent model, we also derive models to higher spherical harmonic degrees than $\ell=14$ to study small scale features of the core field and its temporal variation. A comparison with a satellite-based field model indicates a good agreement for the core field, but shows significant differences for the secular variation, which probably could be explained by the different source geometry of the data. Our results suggest a strengthening of the meridional core flow in recent years and the existence of north-south oriented undulations in the radial component of the secular variation which may be related to the presence of waves in Earth's liquid outer core.

Keywords: Geomagnetic core field modelling, geomagnetic secular variation forecast, IGRF-14

Compass pad Calibration Rose: Winnipeg Airport Case Study

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Abstract

Abstract

This case study presents the methodology and field procedures used to establish and survey a Compass Calibration Pad (CCP) at the Winnipeg International airport utilizing modern GNSS surveying equipment integrated with magnetic survey instruments. The survey workflow combined Global Navigation Satellite System (GNSS), gradiometer data acquisition, and magnetic declination measurements, to accurately determine the spatial geometry and magnetic orientation of the calibration pad. A GNSS survey suite consisting of dual GNSS receivers, a control unit, and a Declination Instrument Module (DIM) was employed alongside a GEM GSM-19 Overhauser gradiometer and base magnetometer systems.

The survey commenced with the establishment of a magnetic base station recording, followed by a detailed gradiometer survey of the study area. While recording GNSS base station data, static and Real-Time Kinematic (RTK) GNSS observations were used to determine the precise coordinates of the CCP center and to stake calibration points according to the required radial geometry. Magnetic declination measurements were collected at the center and all survey calibration points using the declination method, incorporating multiple sensor orientations and repeated observations to improve accuracy and minimize systematic errors. Precise GNSS coordinates and azimuths were recorded for each point to ensure reliable spatial referencing.

The integrated survey approach enabled the accurate determination of magnetic north, calibration point positions, and local magnetic declination values while simultaneously characterizing the magnetic environment surrounding the CCP. The methodology demonstrates the effectiveness of combining high-precision GNSS technology with magnetic surveying instruments to establish robust compass calibration facilities suitable for geophysical, navigation, and calibration applications.

Keywords: Compass pad calibration

First Fully Automatic Magnetic Declinometer

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Abstract

We present the apparatus GYRODIF MKIII able to measure the magnetic declination unattended, which means that it is able to find the direction of the True North and the Magnetic North without any human intervention and compute the angle between these two directions, which is the magnetic declination.

The International Association of Geomagnetism and Aeronomy (IAGA) organizes every other year a workshop where geomagnetic instrumentation is tested for its absolute accuracy. We report here on a participation in Vassouras magnetic observatory (Brazil) workshop of in the XXth IAGA Workshop on Geomagnetic Observatory Instruments, Data Acquisition and Processing. Official results of the workshop warrant an independent certification of the participating instruments performance.

The GYRODIF MKIII is essentially a robotized non-magnetic theodolite with fluxgate and gyroscopic sensors.

The measurement system is described in detail as well as the data processing.

An observation session during the workshop is run over several days on the observatory reference pillar A. This allows comparison with the observatory declination reference via the in house magnetic variometer and proton magnetometer data.

The analysis of the data by the workshop organizers shows that the GYRODIF MKIII was able to provide the values of magnetic declination with an accuracy better than 0.01° .

Keywords: Automatic DIfux, True North seeking

Ten Years of Automated Absolute Magnetic Observations with an AutoDIF at the Conrad Observatory: Stability, Validity, and Lessons Learned

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Abstract

Establishing reliable observatory baselines has traditionally depended on manual absolute measurements mostly using a Declination/Inclination (DI) determination with mounted fluxgate magnetometers on theodolites. Over the past decade, however, automation has emerged as a viable solution to increase data temporal resolution and reduce human operational costs. This study presents a comprehensive analysis of 10 years of continuous automatic DI measurements collected at the Conrad Observatory (Austria) using an AutoDIF system. We evaluate the long-term stability and validity of the automated system by directly comparing its output against a robust parallel dataset of traditional manual measurements.

Our analysis focuses on the drift characteristics of the automated pier, environmental temperature dependencies, and the reliability of the instrument's robotic positioning. The 10-year data comparison demonstrates that the automatic system tracks baseline variations with high precision, successfully capturing fluctuations and long-term trends. Discrepancies between manual and automated data remain well within acceptable international data quality standards, with the automated system showing remarkable mechanical and electronic stability over the decade-long operational lifetime.

Key lessons learned from this extended deployment highlight the critical importance of regular, albeit less frequent, manual validation gaps, stringent humidity/temperature control of the sensor environment, and proactive monitoring of pier stability. In conclusion, the results definitively demonstrate that automatic DI measurements are mature, highly reliable, and fully suitable for constructing and maintaining definitive geomagnetic observatory baselines. This milestone paves the way for fully autonomous observatory operations in remote or harsh environments without sacrificing data integrity.

Keywords: Geomagnetism, Instrumentation, Absolute measurements

A new AutoDIF automatic diflux generation

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Abstract

. After several years of operation, and in order to meet the needs of new projects, it was decided to completely redesign the AutoDIF mkII. Its strengths were identified so they could be retained and refined. The weaknesses of this version were analyzed so they could be corrected and the instrument's reliability improved. In this paper, we will discuss the improvements made to the design of the DIFlux automatic AutoDIF and the strengths highlighted in this new AutoDIF mkIII version. Finally, we will compare the measurements taken by the two automatic instruments with those taken using a conventional manual theodolite.

Keywords: DIFlux,automatic

Automation of the Belgian magnetic observatories

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Abstract

The Royal Meteorological Institute of Belgium has been developing automated instruments for absolute declination and inclination measurements for many years. However, the Dourbes (DOU) and Manhay (MAB) magnetic observatories continued to be operated using conventional manual measurement procedures. This situation is now being addressed through the deployment of third-generation Autodif instruments at the RMI-operated observatories.

The Dourbes Observatory now uses a laser-based Autodif MK3 as its reference absolute instrument. This significantly reduces the need for manual measurements with the Boif-TD6J-NM/FLM5 theodolite, although they are still performed periodically for quality control and validation purposes.

At the Manhay Observatory, the decision was made to install a Gyrodif MK3 equipped with a fiber-optic gyroscope (FOG) capable of directly measuring the Earth's rotation. This choice was motivated by the site's specific configuration as well as previous experiences with vandalism, making a fully autonomous system particularly advantageous.

The Princess Elisabeth Antarctica (PEA) Observatory will also be equipped with a Gyrodif MK3 to comply with current international standards. The installation is scheduled for the next Antarctic campaign.

Keywords: Absolute measurement, automation

Improved baseline control via high-frequency absolute geomagnetic measurements

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Abstract

Geomagnetic observatories typically perform absolute measurements once or several times a week using a manually operated DIM instrument. This measurement frequency is usually sufficient to maintain the variometer's baseline.

With the advancement of automatic absolute instruments, both the number of samples within absolute measurements, and the frequency of complete absolute measurements can be easily increased. These capabilities open new avenues for observatory geomagnetic checks and, consequently, for improving absolute magnetic data quality.

High-temporal-resolution baselines obtained from automatic measurements can effectively capture temperature effects, as well as other baseline variations showing diurnal, multi-hour, or multi-day periodic patterns that can originate from electromagnetic disturbances or other environmental sources.

In addition, automated optical angular readings, both horizontal and vertical, and a specialized theodolite compensator tests provide means to verify the physical stability of the pillar and the theodolite on the pillar.

We present brief yet insightful examples from some test sites and observatories where Mingeo's automatic instrument, the ADS, performed near-continuous absolute measurements. We will also discuss how the continuous baseline can be refined by processing measurement data with a sliding window over the absolute measurement positions.

Keywords: Geomagnetic Absolute Measurement, Automatic DIM, Baseline

Measurement biases caused by local magnetic field inhomogeneity in geomagnetic observatories

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Abstract

One of the fundamental requirements of geomagnetic observatories is to provide a measurement environment free from artificial magnetic disturbances. Although the selection of the observation site and the construction of observatory facilities generally reflect careful planning and professional expertise, certain geological conditions (e.g., a volcanic island) may impose unavoidable constraints. Under such circumstances, the geomagnetic field may exhibit significant spatial inhomogeneity, which can affect the performance of some measuring instruments. For example, signal degradation of proton magnetometers in the presence of strong magnetic gradients is well known.

This study presents experimental results obtained in the presence of externally generated magnetic field gradients. Magnetometers performing measurements over an extended spatial volume were investigated, including DIM (Declination–Inclination Magnetometer) and dIdD systems. Both systems sample the magnetic field over a finite spatial volume and may therefore be sensitive to field inhomogeneities.

The study investigates how external magnetic gradients are reflected in DIM and dIdD measurement products and evaluates whether gradient characteristics can be inferred from the observations.

An inhomogeneous magnetic field was generated using a dedicated coil system, producing controlled magnetic gradients in the range of 0–200 nT/m. Preliminary results reveal significant variations in calculated parameters commonly assumed to be constant, including coil constants, offsets, and angular correction terms. These observations suggest that magnetic field gradients may influence not only the measured geomagnetic elements but also the instrument constants estimated during calibration procedures.

These findings are particularly relevant for geomagnetic observatories located in geologically complex environments, where natural magnetic field gradients may affect the stability of instrument calibration parameters and consequently the quality of absolute geomagnetic measurements.

Keywords: geomagnetic gradient, geomagnetic observatory measurement

Optimization of Amorphous Wire for Low-Noise MI Sensors

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Abstract

In recent years, outer space has been increasingly utilized in modern society through activities such as the operation of artificial satellites. The region of space surrounding Earth in which these satellites orbit, known as geospace, has become an important subject of research. The magnetic environment of geospace is influenced by factors such as the solar wind and can have significant impacts on human activities; therefore, it is important to understand and monitor it. One approach to investigating this environment is ground-based geomagnetic measurement using magnetic sensors. Such measurements require high sensitivity to detect even small variations in the geomagnetic field, and highly sensitive observations using superconducting quantum interference devices (SQUIDs) have been reported [1]. However, SQUIDs require cryogenic environments and are costly, making it challenging to achieve measurements that are simultaneously inexpensive, simple, and highly sensitive.

We develop and commercialize magneto-impedance (MI) sensors based on the magnetic impedance effect. This sensor is a magnetic sensor that utilizes an amorphous wire in the sensor head and the MI effect, whereby the impedance changes rapidly in response to an external magnetic field when excited at high frequencies. In terms of performance, MI sensors exhibit high sensitivity, with noise levels on the order of tens of pT/ $\sqrt{\text{Hz}}$ at 1 Hz, and offer advantages such as compact size, low cost, low power consumption, and fast response. These sensors have previously been applied to auroral observations, where magnetic field fluctuations associated with auroral pulsations were successfully detected [2]. MI sensors are therefore considered promising for achieving inexpensive, simple, and highly sensitive geomagnetic measurements, and further improvements in sensitivity are under development.

In this study, we attempted to reduce sensor noise by controlling the geometry of the amorphous wire used as the sensor head. Sensor elements with varying wire diameters and lengths were fabricated, and their effects on sensor characteristics were investigated. The results confirmed that noise decreases with increasing wire diameter and aspect ratio (length-to-diameter ratio). These findings suggest that further reductions in noise can be achieved by optimizing wire diameter and aspect ratio. The details of the experiments will be presented.

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Keywords: Magnetic sensors, Noise reduction

Development of small-sized, single-axis fundamental mode orthogonal fluxgate magnetometer for DI determination in the geomagnetic absolute measurement

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Abstract

The geomagnetic absolute measurement is achieved by measuring the total magnetic field as well as determining the declination (D) and inclination (I) angles of the field. A scalar magnetometer, typically a proton magnetometer, is used to measure the total magnetic field, while a single-axis fluxgate magnetometer mounted on a theodolite is utilized for DI determination. The DI determination process requires sophisticated operation where accurate magnetic field readings from the single-axis fluxgate magnetometer and precise rotation of the theodolite are critical. Conventional commercially available single-axis fluxgate magnetometers for DI determination still have room for improvement in terms of performance and usability. For example, large fluctuations in the measured values and limitations in the display range hinder the smooth and accurate determination of angles from symmetrical, opposite-polarity outputs. In addition, a large sensor head mounted on the theodolite can make its operation clumsy.

Japan Aerospace Exploration Agency (JAXA) has been developing new kind of small-sized and highly precise fluxgate magnetometers called “fundamental mode orthogonal fluxgate (FM-OFG)” for space applications, such as those applicable to magnetic testing of spacecraft components and those as spacecraft-borne instruments for in-situ magnetic field measurements in space. FM-OFG employs a rod type sensor head simply built with a very thin amorphous wire core and a pickup coil wound round it. Unique current of sinusoidal AC superposed on DC is directly passed through the wire core for the excitation. Owing to the DC component in the excitation, magnetization in the wire core does not undergo polarity reversal unlike conventional fluxgates, suppressing Barkhausen noise. FM-OFG therefore exhibits low-noise performance around $10 \text{ pT/Hz}^{1/2}$ at 1 Hz even with the small-sized sensor head. JAXA has also improved FM-OFG sensor’s temperature stability, achieving output offset drift as low as $0.013 \text{ nT/}^\circ\text{C}$. FM-OFG’s practicality as a space-grade magnetometer was proven in the Japanese sounding rocket mission launched in 2025, with a successful triaxial observation of geomagnetic field during the suborbital flight.

Based on those heritages, the authors are now adopting a customized single-axis FM-OFG for DI determination at geomagnetic observatories. Newly developed FM-OFG sensor heads, which are 30 mm and 47 mm long, together with a dedicated compact FM-OFG electronics unit, has demonstrated its practicality for DI determination at Kakioka Magnetic Observatory (Hirahara et al., this workshop). We report on the details of hardware designs and performance evaluations of the developed FM-OFG magnetometer.

Keywords: Magnetometer, Fluxgate

New Fluxgate sensors for the FGM-FGE magnetometer.

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Abstract

Since 1989, DMI and DTU Space (Technical University of Denmark) have produced approximately 400 FGM-FGE three-axis fluxgate magnetometers based on the Pandect LDC/A/20 fluxgate sensor, which is no longer manufactured. To replace it, DTU Space has developed a similar sensor. The primary goal is to provide a drop-in replacement for failed sensors in older FGM magnetometers without requiring hardware changes, while also enabling use in new FGM-FGE magnetometers with equal or improved performance.

We began by developing several sensor-holder designs based on the dimensions of the original Pandect sensor. We also tested and processed different core materials to achieve performance equal to or better than that of the Pandect sensor.

Recent tests have shown promising noise and stability performance, which will be presented.

We aim to start, or resume, production of the FGM-FGE magnetometer in 2027, after the sensor has been product-matured and additional long-term tests have been completed at different observatories.

Keywords: Fluxgate Sensor, FGM-FGE, Vector magnetometer

The first performance results of the prototype of a self-calibrating optical vector magnetometer

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Abstract

Optically pumped magnetometers are used in many applications such as geophysics, space research and biomedical applications due to their high absolute accuracy and high sensitivity.

The authors' team develops and builds optically pumped scalar magnetometers for scientific space missions. Until now, four instruments have been launched. Three are in Earth orbits and one is on its way to Jupiter on board ESA's JUICE satellite. For all these missions, the scalar magnetometer is used as a reference for the calibration of fluxgate magnetometers (vector instruments).

Building on this know-how and the already developed technologies, the authors are currently developing an optically pumped vector magnetometer based on a zero-magnetic field effect in atomic vapours, the so-called Hanle effect.

Similar to a fluxgate, the Hanle instrument utilises a feedback system (three orthogonal feedback coils powered by three feedback current sources) for external magnetic field compensation to maintain the zero-magnetic field condition within the atomic vapour. The three-dimensional vector components of the external magnetic field are determined from the feedback coils' gain factors and their respective electric feedback currents used for field zeroing. In contrast to a fluxgate magnetometer, this zero-magnetic field marker is drift-free since it only depends on the natural properties of the atomic vapour. Thus, a Hanle instrument offers higher long-term stability as well as higher sensitivity.

In addition to the vector measurement mode, the team integrated their absolute scalar magnetometer scheme as a second instrument mode. This allows measuring the magnetic field magnitude at the vector measurement location, enabling self-calibration of the gain and non-orthogonality of the feedback system.

The goal of this technology development is to replace both the fluxgate as well as the absolute scalar magnetometer with a single, self-calibrating optical vector magnetometer. For future space missions, this single instrument will reduce the size, weight and power consumption while simultaneously increasing the measurement quality.

This instrument is highly suitable for geomagnetic applications, where it can serve as a variometer with increased long-term stability, making it ideal for use in observatories. Its sampling rates, up to several hundred Hz, combined with its high sensitivity, enable it to overlap with the frequency characteristics of a search coil magnetometer.

The presentation will show first results of the prototype of the optical vector magnetometer operated in the Conrad Observatory in Austria as well as in the test facilities at the Space Research Institute in Graz.

Keywords: Optically pumped magnetometer, Vector measurements

Geomagnetic Field Measurements with the next-generation Optically Pumped Potassium Sensor

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Abstract

This study evaluates a new, robust second-generation laser-driven, single-sensor potassium magnetometer prototype for long-term, high-sensitivity, low-noise (< 0.05 pT/ $\sqrt{\text{Hz}}$) observatory measurements. Such Optically Pumped Magnetometer (OPM) sensors are widely used in a variety of Earth-field sensing applications, including mineral exploration, mapping of near-surface hazards, and space missions. Since they rely on quantum measurements, OPM sensors have a number of important advantages when it comes to sensitivity, accuracy, and signal bandwidth. Although these sensors often need to be heated, their total power consumption is low and their disturbing influence on nearby sensors is very limited, making them highly suitable for Earth-field measurements. Here we present data from OPM sensors using potassium vapour in an observatory environment, the underground Conrad Observatory near Vienna, Austria.

In this work, we focus on two core aspects. First, we evaluate the rigorous testing and operational validation of a newly developed, second-generation potassium sensor prototype designed by GEM Systems for permanent observatory deployment. Building on lessons from initial iterations and 11 years of continuous data since 2015 from a GSMP-20S3 system, this updated version is driven by a stabilized laser instead of a plasma lamp. Featuring enhanced structural ruggedness and a refined design, this fully operational prototype achieves an ultra-low noise level of less than 0.05 pT/rt-Hz, a flat noise spectrum into the sub-mHz range, and an absolute accuracy of well under 0.1 nT. We present initial comparison results of this robust new system against both the long-running GSMP-20S3 potassium baseline and other standard observatory magnetometers like GSM-90 Overhauser data.

Second, we focus on the practical application of these ultra-high-sensitivity potassium systems in advanced signal investigation and source determination. By analyzing the high-resolution scalar and spatial data, we demonstrate how the exceptional femto-Tesla sensitivity and gradiometric capabilities are utilized to identify localized electromagnetic noise within the observatory environment. We detail the methodology used to successfully separate these anthropogenic, near-surface disturbances from true, distant geomagnetic signatures. This dual focus underscores both the structural readiness of the new laser-driven prototype and the distinct operational advantages of quantum OPM sensors for precise signal diagnostics in modern geomagnetic observatories.

Keywords: Geomagnetism, Field Strength, Instrumentation

Qeqertarsuaq (GDH) Observatory: A Century of Geomagnetic Observations

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Abstract

The Arctic observatory Qeqertarsuaq (IAGA code: GDH) celebrates its 100th anniversary this year. The town of Qeqertarsuaq is located on Disko Island, off the west coast of Greenland, at a geomagnetic (Quasi-Dipole) latitude of 74.42°. Owing to the sparse distribution of nearby observatories, GDH occupies a strategically important location for monitoring high-latitude geomagnetic variability. Its long-term data record provides crucial observations of Earth's magnetic field and supports studies including geomagnetic secular variation, geomagnetic activity, and long-term solar–terrestrial variability. In this poster, we present an overview of the observatory's history, including its buildings and relocation outside the town in response to population growth, the evolution of its instrumentation from the analogue to the digital era, and its magnetic field records from 1926 to the present day, including examples of extreme events. We also highlight the value of the century-long record for studies of geomagnetic variability and illustrate the observatory's continuing contribution to the global geomagnetic observatory network.

Keywords: Geomagnetic Observatory, Arctic observatory, Geomagnetic data

Panagyurishte Geomagnetic Observatory (PAG): Ninety Years of Continuous Geomagnetic Observations

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Abstract

The Panagyurishte Geomagnetic Observatory (PAG) is the oldest continuously operating geomagnetic observatory in the Balkans, providing uninterrupted observations of the Earth's magnetic field since its inauguration in 1937. Established by the Geographic Institute of the Bulgarian Ministry of Defence, the observatory has successfully preserved the continuity of geomagnetic measurements through profound political and societal transformations, including World War II, the post-war period, the socialist era, and the transition to a democratic society after 1989. Since 1961, PAG has been operated by the Bulgarian Academy of Sciences and today is an important asset of the National Institute of Geophysics, Geodesy and Geography (NIGGG-BAS).

Over its ninety-year history, the observatory has undergone several major technological upgrades, evolving from analogue variometers and photographic recording systems to fully digital instrumentation. A significant milestone was achieved in 2007 when PAG became a member of the INTERMAGNET network following modernization of its instrumentation and observatory infrastructure in cooperation with the GFZ Helmholtz Centre for Geosciences. Since then, the observatory has routinely delivered high-quality minute-resolution definitive and quasi-definitive geomagnetic data to the international community, contributing to global geomagnetic field modelling, space weather monitoring and geomagnetic hazard studies.

Besides its primary geomagnetic mission, PAG has gradually evolved into a multidisciplinary geophysical monitoring site. The observatory hosts a permanent GNSS station that forms part of the Bulgarian national geodetic infrastructure and contributes to regional geodynamic studies. A broadband seismic station installed at the site supports national and international seismological monitoring efforts. In addition, PAG hosts an Ultra-Low Frequency (ULF) magnetometer which is a part of the SEGMA international monitoring network, extending the observatory capabilities towards investigations of magnetospheric processes and space weather phenomena. The co-location of these instruments provides valuable opportunities for integrated studies of lithospheric, atmospheric and near-Earth space processes.

Recent activities at PAG are focused on our new, one-second system and its compliance with modern INTERMAGNET recommendations for one-second geomagnetic data production. The observatory has implemented a new acquisition system based on LEMI-025, GSM-90F vector and scalar instrumentation and MARTAS (Geosphere Austria) software and enabling continuous acquisition and archiving of one-second data. These developments aim to enhance the observatory's capability to support investigations of ultra-low-frequency geomagnetic pulsations, sudden storm commencements, geomagnetically induced currents and other space weather phenomena requiring high temporal resolution.

At the same time, PAG faces increasing challenges associated with anthropogenic disturbances caused by the continuing expansion of the nearby town of Panagyurishte and associated industrial and transport infrastructure. Urban growth has resulted in elevated electromagnetic noise levels and poses a long-term risk to maintaining the exceptionally quiet magnetic environment required for observatory operations. Continuous assessment of the local magnetic environment is therefore necessary to document ongoing changes and to evaluate the long-term viability of the observatory site.

Keywords: Geomagnetic observatories, INTERMAGNET, One-second geomagnetic data

A Multi Step Revival of Phu Thuy Magnetic Observatory, Vietnam

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Abstract

The Phu Thuy (**PHU**) magnetic observatory, one of two key INTERMAGNET Magnetic Observatories (IMOs) in Vietnam, faced severe operational threats in recent years. Recurrent lightning strikes caused heavy damage to electrical equipment and persistent disturbances from nearby construction activities resulted in significant gaps and steps, compromising the rapid variation-data essential for external field studies. Successive typhoons greatly damaged the sensor and absolute huts. With no alternative sites available, observatory closure was under serious consideration.

Recognizing the scientific value of PHU geomagnetic data, the BCMT Scientific Council recommended a concerted effort to restore the observatory data acquisition chain to INTERMAGNET standards. The revival process involved multiple critical steps: upgrading obsolete equipment, transitioning to solar power and GSM transmission to mitigate lightning risks, physically separating power system components (batteries, regulators, and fuses) from the sensor pavilion to eliminate high-current interference, and rebuilding the absolute measurement hut to ensure structural, magnetic integrity and safe working conditions to observers.

The successful implementation of these measures, completed in December 2025, restored PHU compliance with INTERMAGNET standards and provided a model for other remote geomagnetic stations facing similar challenges, particularly those situated in regions with intense lightning activity, such as Vietnam.

Keywords: Geomagnetic observatory, INTERMAGNET standards, data quality

Advances in the IGP Magnetic Station Network

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Abstract

The IGP magnetic station network has undergone significant expansion over the past four years, with the installation of four new permanent variometer stations across mainland France.

Strategically located far from anthropogenic magnetic disturbances and co-located with existing multi-instrumental sites, these stations enhance the spatial coverage and scientific value of geomagnetic observations in the region.

Each station is designed to adapt to site-specific constraints. The stations feature both scalar and vector magnetometers, with yearly absolute measurements for higher precision data acquisition. Special attention was given to temperature stability, employing passive solutions to minimize thermal drift and ensure data integrity.

This expansion was achieved within a constrained budget, balancing cost-effectiveness with technical performance. Key lessons learned include compromises between solar and mains power, the importance of site-specific adaptations, and the self-imposed challenge to meet the rigorous standards of INTERMAGNET for magnetic observatories. The network now provides a valuable dataset for studying geomagnetic field variations, contributing to both regional and global research efforts and is intended to expand further with a minimum of two additional stations.

Keywords: variometer stations, geomagnetic monitoring

Long-Term Geomagnetic Monitoring at Syowa Station, Antarctica: Toward Publication of High-Quality One-Second Data and Participation in INTERMAGNET network

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Abstract

Magnetic observations at Syowa Station began in 1957. Following several relocations and temporary interruptions during the early years, continuous measurements have been maintained at the present site since 1966. Only a limited number of Antarctic observatories have sustained long-term geomagnetic monitoring, and Syowa Station—located at auroral latitudes—provides a valuable record of decades from a high-latitude region strongly influenced by magnetospheric activity. In 2026, absolute one-second geomagnetic data at Syowa Station will be released, which is expected to broaden opportunities for international scientific use of the data.

Meanwhile, several issues must be addressed in preparation for future participation in INTERMAGNET. A primary challenge concerns the stability of the fluxgate magnetometer. During the austral summer, tiltmeters indicate substantial variations in the tilt angle of the sensor, which affect baseline stability. Furthermore, analyses of baseline values and ΔF ($= (H^2 + Z^2)^{0.5} - F$) reveal instances of output instability that cannot be fully explained by environmental factors. These issues degrade the accuracy of definitive data and limit the reliability of long-term analyses.

To address these problems, improvements to both data processing methods and the observational system are underway. First, baseline interpolation procedures are being refined to better account for seasonal variations and tilt-related effects, thereby improving long-term stability. Second, a plan to introduce a suspended-type fluxgate magnetometer is considered, as it may reduce tilt-induced and mechanical influences, leading to more stable baseline values and output signals.

In addition to these efforts, a long-term initiative is planned to finalize and release definitive fluxgate data back to 1981, when digital recording was started. This initiative is expected to further promote international use of the long-term geomagnetic datasets from Antarctica and other high-latitude regions.

Keywords: magnetic observatory, Antarctica, One-Second Data

Operational Status of the Cheongyang Geomagnetic Observatory and Long-term Geomagnetic Field Variation Analysis over the Korean Peninsula

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¹

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Abstract

The Cheongyang Geomagnetic Observatory has been operated to monitor long-term geomagnetic field variations over the Korean Peninsula and has submitted geomagnetic observation data and definitive data to INTERMAGNET since 2014. As the only INTERMAGNET observatory in Korea, it continuously improves its observation system to produce high-quality geomagnetic data that meet international standards. In 2022, an automated absolute observation system(AutoDIF) was introduced for stable and efficient determination of geomagnetic declination and inclination. In 2025, the observatory's aging instruments were completely replaced to enhance the long-term stability of geomagnetic observations. This study presents the current operational status of the Cheongyang Geomagnetic Observatory and analyzes long-term geomagnetic field variations over the Korean Peninsula using definitive data collected from 2014 to 2025. To evaluate the reliability of the observed geomagnetic variations, the results were compared with the International Geomagnetic Reference Field (IGRF). The comparison was used to assess the reliability and applicability of the Cheongyang geomagnetic data for monitoring regional geomagnetic field variations.

Keywords: magnetic,geomagnetic,cheongyang

Geomagnetic mapping of the Czech Republic and its actual update

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Abstract

Czech Republic belongs to varied geological structure of Central Europe, at most at stable tectonic plate. From the point of view of geomagnetism, we record some significant anomalous regions in different orographic structures.

The dominant anomalies are caused by thick layers of Cambrian volcanic rocks with a high content of magnetite. Generally, we register the most anomalous areas in the Barrandian (central part of Bohemia extended to South-West border of the Czech Republic), then, in the Ore mountains in the North-West border region and also in the East Moravia where we record some anomalous elements in the flysch region (outer bow of the Carpathian Mts. structure) and also in the lowland of South Moravia.

Czech geomagnetic network consists of 199 geomagnetic measurements sites, with about 30 kilometres spacing. The sites have been stabilized by means of granite boundary stones. Within this primary network, seven repeat stations have been selected and measured with 2 - year step.

Measurements of the vertical and horizontal components were carried out in 1957-58. The network was reoccupied in 1976-78 and 1994-96, when the measurements of components D, H and Z were completed by the measurement of the total field F.

Aeromagnetic survey in Czechoslovakia was carried out since the 1950s. However, we focus only on the territory of the Czech Republic, for which we can provide data.

The last primary network update had started in 2019. The prospections showed out, that about one third (60 primary stations) had been destroyed because of vandalism, stealing or agricultural mechanization traffic.

In the Barrandien anomalous zone, the partial damage of the measurement network aggravates the zone boundaries determination. Nevertheless, the anomaly zone has been precised by the aeromagnetic survey.

Some cases, we lost the measurement sites in the anomaly area, in other cases, the anomaly area is covered but the neighbour sites are destroyed. Similarly, we lost a significant part of the anomalous zone in the East Moravia. Because of intensive agricultural land-use, many of the sites covering this part of the country were destroyed.

Currently, we finalize the measurement of the preserved boundary stones.

Through the aeromagnetic survey, terrain gradiometric prospections and the absolute measurements at the preserved sites, we precise the generalized geomagnetic map of the Czech Republic.

Hand-to hand with Military Geographical and hydrometeorological Institute, the geomagnetic map of Czech Republic with aeromagnetic survey is updated by the overlay of the in-situ geomagnetic absolute measurements at the geomagnetic network.

Currently, we precise the geomagnetic map by fusion of the aeromagnetic survey with the in-situ measurement. Now, we are finalizing the preserved sites and, then, during the map improvement, potential thicken sites can be selected. Finally, we update the isolines for the all components in the precised geographic coordinates.

Keywords: geomagnetic mapping, primary network, repeat stations

Reconnaissance and Site Validation for Zimbabwe's First National Geomagnetic Observatory

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Abstract

The establishment of a National Geomagnetic Observatory is a critical milestone for Zimbabwe's integration into the global geomagnetic research community. This study presents the findings of the Phase 2 reconnaissance survey, conducted to validate a proposed site in Gokwe for the country's first permanent magnetic observatory. A comprehensive survey was performed over a 1-hectare area, involving precise setting out of a 10 m x 10 m grid using a Trimble GNSS and a detailed gradient survey conducted with an Overhauser GSM-19T magnetometer. The results reveal a remarkably homogeneous magnetic field across the entire surveyed plot, with a total variation of only 30 nT relative to the mid-latitude baseline and no evidence of significant local magnetic anomalies. This low magnetic gradient, comparable to established observatory sites such as Easter Island (20 nT/m) and consistent with INTERMAGNET recommendations, confirms the site's suitability for hosting a high-quality geomagnetic observatory. The validation of this magnetically clean site marks a significant milestone, enabling the next phase of land acquisition and infrastructure development. This project will not only advance Zimbabwe's space science capabilities but also enhance the global coverage of the INTERMAGNET network for improved geomagnetic forecasting and research.

Keywords: Geomagnetic Observatory ,Space Weather ,Gradient Survey

Development of an Automatic Geomagnetic Observatory on Socorro Island, Revillagigedo Archipelago, Mexico

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Abstract

This contribution presents the on-site surveying, historical measurements, and project development for the installation of an Automatic Magnetic Observatory on Socorro Island, located in the Revillagigedo Archipelago, Colima, Mexico, in the Pacific Ocean. Due to its insular location, approximately 700 km off the Mexican coast, the implementation of this observatory will expand data coverage in a region with scarce instrumentation, thereby contributing to the continuous monitoring of the Earth's magnetic field and the strengthening of the national geomagnetic observation infrastructure.

This project is the result of a collaboration between the Magnetic Service (Servicio Magnético - SMag) of the Institute of Geophysics at the Universidad Nacional Autónoma de México (UNAM) and the Centre de Physique du Globe de Dourbes of the Royal Meteorological Institute of Belgium (RMI). Additionally, the project is being developed in coordination with other UNAM geophysical services: the National Mareographic Service (SMN) and the Satellite Geodesy Service (SGS), that together with the stations managed by the National Seismological Service (SSN), aims to establish a multiparametric observation site to enhance national capabilities for the study and tracking of geophysical phenomena.

The activities carried out during the surveying site visit to Socorro Island are described, including the assessment of site conditions for the installation, the instrument performance tests conducted at the Dourbes (DOU) and Teoloyucan (TEO) Magnetic Observatories. Furthermore, the infrastructure, instrumentation, power supply, and data transmission systems to be utilized for the installation during 2027 are detailed.

Keywords: Geomagnetic observatory, Socorro Island

MAG-SWE-DAN - Magnetometer Stations Network covering Scandinavia and Greenland

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Abstract

The MAG-SWE-DAN project aim to narrow the existing gaps in ground magnetometer coverage in Scandinavia by establishing 10 geomagnetic stations in Sweden, Denmark and Greenland and extending the temporal sampling of four additional stations in the Faroe Islands, Greenland and Denmark. All stations provide near-real time data to monitor the geomagnetic conditions, thereby expanding the existing Space Weather monitoring system. In this work we present on the data quality, data availability and show examples of extraordinary space weather events captured by the network.

Keywords: Variometer network, Space Weather

Magnetic Field Observations and Data Processing for a Long-Period Magnetotelluric Survey in the North Island, New Zealand

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Abstract

Magnetotelluric (MT) surveys require reliable magnetic field observations over a wide period range to estimate electromagnetic responses related to subsurface electrical structures. In this study, we present magnetic field observations and data processing procedures from a regional-scale long-period MT survey conducted in the North Island of New Zealand. The survey was carried out in the Hikurangi subduction zone across the transition zone between the southern end of the Taupo Volcanic Zone and the adjacent non-volcanic region. A total of 28 MT sites were deployed during four field campaigns between July 2023 and January 2024. Three-component magnetic field data were acquired using LEMI-417M instruments with a sampling interval of 1 s. Two-component electric field measurements were also collected for MT response estimation. The recorded electromagnetic time-series data were processed to estimate MT response functions. Time-series processing was performed using the BIRRP code with a remote reference technique to reduce the effects of local noise. The processed data provided stable responses over periods ranging from several seconds to several tens of thousands of seconds. Representative induction vectors at selected sites, derived from the processed magnetic field data, are presented to demonstrate the characteristics of the obtained electromagnetic responses. The results demonstrate that the acquired magnetic field data are suitable for evaluating electromagnetic responses over a broad period range. This study provides an example of magnetic field observations and data processing procedures for a regional-scale long-period MT survey, offering practical insights into long-period magnetic field observations and subsequent electromagnetic data processing.

Keywords: Magnetotellurics, Magnetic field observation, Data processing

Ground-based Geomagnetic Observations on Volcanic Jeju Island: A New Installation Approach to Mitigate Underground Magnetic Field Effects

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Abstract

During the solar maximum, enhanced solar activity has increased the occurrence of geomagnetic storms, emphasizing the importance of accurate and reliable space weather monitoring systems. Severe geomagnetic storms associated with coronal mass ejections (CMEs) can disrupt technological infrastructure, including global navigation satellite systems (GNSS), communication networks, and power systems. To mitigate the impacts of space weather hazards, Korea Space Weather Center (KSWC) provides operational space weather forecasts and alerts based on continuous monitoring of solar-terrestrial environments. To improve domestic geomagnetic monitoring capability, KSWC established a new geomagnetic observatory on Jeju Island in December 2023. Unlike conventional geomagnetic observatories typically installed in underground environments, Jeju Observatory was constructed as an above-ground facility approximately 1 m above the surface due to the unique volcanic geological characteristics of Jeju Island, where subsurface magnetic properties may affect geomagnetic measurements. The observatory consists of an absolute measurement room, a scalar observation room, and a vector observation room, enabling continuous monitoring and calibration of geomagnetic field variations. The geomagnetic data collected during 2024-2025 demonstrated stable baseline performance, satisfying the quality requirements for INTERMAGNET membership, with annual baseline variations maintained within ± 5 nT. The observatory successfully detected geomagnetic field responses associated with intense geomagnetic storms, including G4-level events. This study presents the operational performance of Jeju above-ground geomagnetic observatory, focusing on the characteristics of geomagnetic variations under strong space weather conditions. In addition, the installation strategy, data quality assessment, and ongoing preparation process for INTERMAGNET membership are discussed.

Keywords: Geomagnetic Storm, Geomagnetic observation, Space Weather

Key milestones at the Fúquene Geomagnetic Observatory, Colombia (2024–2026)

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Abstract

The Fúquene Geomagnetic Observatory (FUQ), operated by the Geographical Institute Agustín Codazzi (IGAC) in Colombia, is one of the few geomagnetic observatories in northern South America and fills an important observational gap between the KOU, HUA, and SJG observatories. Its location at low magnetic latitude makes FUQ particularly valuable for studies of ionospheric processes and a promising candidate for future inclusion in the Dst index. The observatory has a long history of contributing to Equatorial Electrojet (EEJ) research in collaboration with the HUA observatory and provides valuable observations for characterizing the South Atlantic Anomaly and improving the regional coverage of global geomagnetic field models (Alva Carmona et al., 2025).

At the beginning of 2024, FUQ geomagnetic data archived at the World Data Centre (WDC) covered the period 1955–2013, although observations continued until 2022. Instrument failures between 2020 and 2022, including the destruction of the variometer system by two lightning strikes in 2022, interrupted geomagnetic measurements and prompted a major recovery and modernization effort.

Between 2024 and 2026, four major milestones were achieved. First, the observatory underwent a major modernization with the installation of FGE and LEMI-025 fluxgate variometers, WiDIF magnetometers for absolute observations, and GSM-19 proton precession magnetometers. The British Geological Survey donated the FGE variometer, while the remaining instruments were acquired by IGAC. These upgrades enabled continuous geomagnetic monitoring following international standards.

Second, historical analogue observations acquired between 2014 and 2020 were recovered, digitized, quality controlled, and processed into definitive geomagnetic data. The resulting datasets were submitted to the World Data Centre, extending the availability of Colombian geomagnetic records and preserving seven years of previously inaccessible observations.

Third, digital geomagnetic monitoring and processing procedures were implemented using xMagPy 2.0 (Leonhardt et al., 2025). One-minute geomagnetic measurements were processed following INTERMAGNET recommendations, including baseline determination, DeltaF evaluation, and quality control. In 2026, an application for INTERMAGNET membership was submitted and is currently under evaluation.

Finally, the modernization program strengthened research and capacity-building activities. Undergraduate projects focused on characterizing the Solar Quiet (Sq) current system using FUQ data and on developing near real-time geomagnetic activity indices and web-based space weather applications based on the MARTAS and MARCOS Python packages (Leonhardt et al., 2025). These initiatives represent the first steps toward establishing operational space weather services in Colombia.

The achievements accomplished during 2024–2026 mark a new stage in the history of FUQ. The recovery of historical records, modernization of instrumentation, implementation of internationally recognized processing methodologies, and progress toward INTERMAGNET membership will restore access to high-quality geomagnetic observations from Colombia for the international scientific community.

Keywords: Analogue and digital data processing, Geomagnetic Observatory, Space weather index

From Historical Records to Near Real-Time Geomagnetic Monitoring: Local K-Index Implementation at Fúquene Observatory, Colombia

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Abstract

Ground-based geomagnetic observatories are essential for regional space-weather monitoring, particularly in equatorial and low-latitude regions, where geomagnetic disturbances exhibit distinct behavior. This work presents the development of SIAPV, an integrated system for the acquisition, processing, validation, and visualization of geomagnetic information from the Fúquene Geomagnetic Observatory (FUQ) in Colombia.

The study focuses on estimating the local K index from both historical records and near-real-time data to support space-weather research and operational monitoring in Colombia. For the historical series, the Finnish Meteorological Institute Linear Elimination Method was adapted to FUQ records. The workflow includes signal preprocessing, outlier and spike removal, gap treatment, estimation of the regular solar variation curve, and calculation of three-hour disturbance amplitudes.

For near-real-time processing, operational procedures based on the approach used by the Royal Meteorological Institute of Belgium were implemented while preserving the principles of the original Linear Elimination Method. The system incorporates automated data acquisition, quiet-day curve estimation, quality-control flags, and continuous calculation through sliding time windows. The acquisition architecture integrates one-second vector observations from a LEMI-025 magnetometer and scalar total-field measurements from a GEM Systems GSM-19 magnetometer.

Evaluation of three geomagnetic storm events showed that the operational local K index reproduces the temporal variability observed in reference indices, with correlation coefficients ranging from 0.740 to 0.968 and coefficients of determination of up to 93.8%. The equatorial location of FUQ and its proximity to the South Atlantic Anomaly give this work particular scientific relevance. SIAPV contributes to strengthening geomagnetic monitoring in a region with limited operational products and substantial potential for Sun-Earth and space-weather studies.

Keywords: Geomagnetic monitoring, Local K index, Near-real-time processing

Quality Improvement of 2024–2025 Definitive Geomagnetic Data at the Cheongyang (CYG) Observatory Following INTERMAGNET Quality Assessment

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Abstract

The 2024 and 2025 definitive geomagnetic datasets from the Cheongyang (CYG) Observatory were reprocessed to improve their quality following the INTERMAGNET quality assessment. Additional reprocessing included baseline re-fitting, restoration of geomagnetic storm signatures, review of outliers, consideration of observatory events, and updates to the accompanying documentation. Initially, all available absolute observations were included in the baseline fitting. During the quality review, several observations that degraded baseline continuity were identified and excluded from the final fitting. The H, D, and Z baseline components were represented using cubic spline interpolation to improve baseline continuity. Geomagnetic storm signatures that had been removed during the automatic quality-control procedure were restored after comparison with neighboring observatories and K indices to preserve genuine geomagnetic variations. Observatory events, including lightning-induced disturbances, instrument replacement, and data gaps, were also reviewed and documented during the reprocessing. The accompanying documentation was also updated to describe the temperature correction procedure that had already been applied during the production of the 2024–2025 definitive datasets, following the method proposed by Martins et al. (2024). The revised processing improved baseline continuity, data consistency, and the overall quality of the definitive datasets, addressing the principal issues identified during the INTERMAGNET quality assessment. This case study demonstrates how feedback from the INTERMAGNET quality assessment can be effectively incorporated into the reprocessing of definitive geomagnetic data. The improved processing strategy will be extended to historical definitive datasets (2018–2023) at the Cheongyang Observatory to improve the consistency and long-term reliability of the observatory record.

Keywords: Geomagnetic Observatory, Data Reprocessing, Quality Control

Triaxial Fluxgate Magnetometer Scalar Parameter Estimation for Magnetic Observatories Purpose

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Abstract

Continuous, high-precision monitoring of Earth's geomagnetic field at magnetic observatories is fundamental to modern geophysics. These observations provide crucial data for separating field contributions originating from the core, the crust, and the outer ionospheric-magnetospheric region, as well as for updating global reference models—such as the International Geomagnetic Reference Field (IGRF)—and analyzing critical space weather phenomena. To ensure stable and reliable vector measurements, triaxial fluxgate magnetometers require routine, high-precision calibration of their fundamental instrumental parameters, particularly the scale factors for all three components. However, a significant research gap remains regarding a standardized, systematic methodology universally adopted for the dynamic calibration of these scale factors in triaxial fluxgate magnetometers. Instead, observatories often rely on semi-empirical approximations or baseline observations, which may struggle to maintain accuracy during highly dynamic geomagnetic periods. To overcome this limitation, we present a methodology based on a non-linear inversion framework utilizing the Levenberg-Marquardt optimization algorithm. The algorithm iteratively minimizes the mathematical discrepancy between vector observations and the field intensity simultaneously measured by an independent scalar magnetometer at the same location. To prevent numerical instability and physically implausible parameter fluctuations, the objective function incorporates custom regularization functionals, combining mathematical smoothness penalties with absolute-value constraints. As a key component of our research, we investigate the application of numerical differential operators to enhance calibration performance during extreme space weather events. As next steps, robust and precise synthetic tests will be performed to comprehensively evaluate and validate the numerical performance, stability, and convergence of the developed algorithm under controlled scenarios before its application to real observatory datasets.

Keywords: Geomagnetism, scale factors, non-linear inversion

A new data acquisition system for remote and temporary magnetic measurements

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Abstract

Geomagnetic measurements in remote environments are limited by power and network infrastructure requirements, as well as data retrieval. This work presents the development of a portable data acquisition system designed to log and transmit combined fluxgate and proton precession magnetometer (PPM) measurements.

The system integrates precise timing with low-power data logging and MQTT telemetry for data transfer. By removing the dependency on fixed infrastructure, this system enables flexible deployment in remote locations, including temporary installations and campaign-based variometer measurements, offering off-grid, battery-powered deployments. The design supports simultaneous fluxgate and PPM measurements, expanding capabilities beyond variometer stations.

Initial testing focussed on validation of core system performance in a field environment. The tests aimed to evaluate 1) the robustness of data recording and transmission in realistic conditions, 2) latency of data delivery via MQTT, and 3) temporal stability of continuous data acquisition over extended deployment periods.

This development provides a pathway toward more flexible geomagnetic data collection, supporting both research campaigns and operational monitoring. This approach may also offer improvement towards near-real-time data access from remote sites, without reliance on permanent infrastructure, while expanding measurement capability through combining fluxgate and PPM measurements.

Keywords: instrumentation,data acquisition,portable

A DIY Approach to Reverse Engineering the Pandect LDC/a/20 Fluxgate Sensor

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Abstract

The Danish Meteorological Institute (DMI) and later the Technical University of Denmark (DTU) have historically produced the FGM vector magnetometer based on the Pandect LDC/a/20 fluxgate sensor. However, the sensor became obsolete in 2020, and DTU's stock was fully exhausted by 2024. To sustain FGM production, a project was initiated to develop a viable replacement.

The core components of a fluxgate sensor include the housing, coils, and magnetic core material. The original Pandect sensor design was analyzed to identify alternative materials and manufacturing methods for each component. The primary objective was to design a direct, drop-in replacement suitable for both new instruments and legacy repairs.

Following extensive trials, a promising design and fabrication process was established for the housing, coils, and magnetic core. Initial testing demonstrates that the performance of the new sensor closely matches that of the original Pandect unit.

The new fluxgate sensor is scheduled for production in 2027, with new FGM magnetometers becoming available shortly after. Furthermore, the insights and manufacturing expertise gained from this project can be applied to other custom sensor designs and applications in the future.

Keywords: Fluxgate sensor, FGM, Pandect LDC/a/20

Performance and Operational Evaluation of a New Single-Axis Fluxgate Magnetometer for DI-Meter Applications.

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Abstract

A new single-axis fluxgate magnetometer developed for use in a DI meter (Murata et al., this workshop) has been evaluated through experimental observations to assess its operational performance. The sensor is based on the Fundamental Mode Orthogonal Fluxgate magnetometer (FM-OFG), originally developed by the Japan Aerospace Exploration Agency (JAXA) for spacecraft applications. Owing to its compact size, lightweight design, and low-noise characteristics, the FM-OFG is a promising candidate for ground-based absolute geomagnetic measurements.

In this study, the magnetometer was deployed in a DI-meter system and tested at the Kakioka Magnetic Observatory. Its performance was evaluated through comparison with existing single-axis fluxgate magnetometers currently used for the absolute measurements. The results indicate that the proposed sensor achieves sufficient accuracy for absolute geomagnetic observations.

In addition to sensor performance, practical aspects of operation were investigated. A newly designed mounting mechanism enabled precise and repeatable axis adjustments, allowing both horizontal and vertical alignment to be performed entirely from above. This configuration significantly improves measurement efficiency and ease of operation.

Furthermore, the processing unit incorporates a microcontroller, providing a flexible and extensible system architecture that enhances usability.

We report the results of operational testing and discuss the current status of the system.

Keywords: Magnetometer, Fluxgate, Absolute measurement

Calibration of Vector Magnetometers over a Wide Dynamic Range at the Conrad Observatory

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Abstract

Vector magnetometers tend to exhibit a variety of errors. These include non-orthogonal sensor axes, incorrect scaling, offset errors, and misalignment of the magnetometer's sensing axes relative to the device's body axes.

This work presents a calibration procedure designed to precisely determine the 12 calibration parameters associated with the errors mentioned above. The procedure relies on the Merritt coil system at the Conrad Observatory, which is capable of actively compensating Earth's magnetic field and applying arbitrary fields. Calibration of the coil system's scale factors and alignment of its magnetic axes are prerequisites for the magnetometer calibration. An Overhauser magnetometer is used to determine the scale factors for large fields, while a calibrated fluxgate sensor with known linearity is used to extend this measurement down to lower field strengths that are inaccessible to the Overhauser instrument. The alignment of the coils relative to survey markers in the observatory is determined with a non-magnetic fluxgate theodolite.

To calibrate a magnetometer using the coil system, fields are applied along the three known coil axes. From the response of the magnetometer that is placed inside, the scale factors as well as the orientation of the sensing axes can be computed. To determine the misalignment of the sensing axes relative to the body, the orientation of the body must be measured precisely. The magnetometer under test is therefore mounted on a non-magnetic optical bench. Accurate positioning on the bench is ensured with dowel pins. The orientation of the cubic mirror that is fixed to the optical bench can be tracked using theodolites equipped with autocollimator optics. By combining this procedure with a standard offset measurement, the 12 calibration parameters described above can be determined.

This presentation also outlines the test setup and results from the calibrations of a classical fluxgate magnetometer and a newly developed optical vector magnetometer.

Keywords: Calibration, Vector Magnetometer, Non-Orthogonality

DIMOVER: Development of compact highly uniform bias magnetic systems for vector-scalar Overhauser magnetometers

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Abstract

Ensuring ultra-high magnetic field uniformity within compact volumes is a critical metrological challenge in the development of advanced geophysical instrumentation, particularly for Overhauser vector-scalar magnetometers such as the DIMOVER system. These sensors are increasingly integrated into non-magnetic theodolite complexes to provide precise azimuthal referencing and metrological support for magnetic navigation, directional drilling operations, and vector Declination-Inclination (DI) measurements at magnetic observatories and secular variation observation points.

The proposed methodology synthesizes optimal discrete coil configurations by first parameterizing the continuous linear winding density using even-order Legendre polynomials, which inherently guarantees axial symmetry. To ensure physical realizability and suppress non-physical high-frequency oscillations in the winding profile, the inverse problem is solved using Tikhonov regularization. The resulting continuous density profile is normalized and transformed into a probability density function. The exact spatial coordinates of a predetermined number of discrete coil turns are then derived via inverse transform sampling based on the cumulative distribution function (CDF).

The core computational engine relies on heavily vectorized evaluations of the Biot-Savart law, utilizing complete elliptic integrals of the first and second kinds to accurately model the magnetic field of individual circular loops. To maintain computational efficiency and low memory overhead during the exhaustive multi-parameter search, the algorithm employs block-wise matrix multiplication when constructing the influence matrices. The optimization routine systematically explores the parameter space—spanning the total number of coils, polynomial expansion order, and regularization hyperparameters—to minimize the standard deviation of the normalized axial magnetic field within a predefined target uniformity volume. Results demonstrate that this integrated optimization approach yields compact solenoid configurations that significantly outperform classical analytical designs in terms of field uniformity per unit volume.

To optimize the uniformity of the magnetizing field, the proton precession signal was simulated; its decay time is a critical factor in ensuring the sensitivity of the Overhauser magnetometer. The use of a new type of combined receiving and polarizing coil for the Overhauser sensor enabled the localization of the precession signal generation in the center of the magnetic system, where maximum uniformity of the magnetizing field is achieved. The sensor consists of four coils with winding polarities configured as -+-, unlike standard coils with a +- configuration, which do not generate the proton precession signal in the central region.

An experimental prototype of a 26-turn solenoid with dimensions of $\varnothing 50 \times 100$ mm has been tested. It provides a signal decay time exceeding 5 s within the $\varnothing 30 \times 45$ mm active volume of the Overhauser sensor under a magnetizing field of 10,000 nT, achieving a sensitivity of at least 0.02 nT/√Hz.

The developed system was mounted on a 3T2KP non-magnetic theodolite telescope to measure declination and inclination angles, integrated with a geomagnetic field module utilizing DIMOVER technology. This approach is expected to complement and verify the metrology of fluxgate DI-flux theodolites.

Keywords: vector Overhauser magnetometer, fluxgate magnetometer, secular variation, magnetic observatory, magnetometer, uniform magnetic system

A new automatic instrument at LIV

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² Observatori de l

Abstract

We report here the first tests performed with the new automatic instrument that will soon be deployed at the Livingston Island (LIV) Geomagnetic Observatory.

In 2018, a Gyrodif MK2 was installed at the Livingston Island GeoMagnetic Observatory. Based on the Autodif MK2 platform, the instrument was equipped with a fiber-optic gyroscope (FOG) for true north determination. Its purpose was to compensate for the absence of an observer during the austral winter, when the Antarctic station is closed. Unfortunately, the ambient magnetic field adversely affected the accuracy of the gyroscope, preventing the instrument from achieving the declination accuracy required by the Intermagnet standards.

A Gyrodif MK3 will now replace the previous system. It incorporates a military-grade fiber-optic gyroscope whose sensing fiber is protected by magnetic shielding, significantly reducing the influence of the ambient magnetic field on true north determination. Furthermore, the separation between the different observatory buildings ensures that no magnetic interference occurs between the instruments.

Preliminary measurements have been carried out at the Dourbes (DOU) and Manhay (MAB) Magnetic Observatories. The results show excellent agreement with conventional theodolite-based absolute measurements, with residual differences remaining within 1 nT for all magnetic field components.

Following a final validation campaign at the Ebre Magnetic Observatory (EBR), the instrument is expected to be shipped to Livingston Island before the end of 2026.

Keywords: Automatic DIFlux, Autodif, Gyrodif

Application of magneto-impedance (MI) sensor to geomagnetic field measurements for magnetoseismology

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Abstract

Magneto-impedance (MI) effect was discovered about 30 years ago and a micro-size magnetic sensor that utilizes this effect becomes commercially available. Nosé et al. (2022, doi: 10.1029/2022JA030809) made some modifications to the commercially available MI sensors to cover the dynamic range of the geomagnetic field. For the period of March 30 to April 27, 2018, they conducted experimental observations of geomagnetic field variations with the MI sensors at the Mineyama observatory in Japan. Data obtained with the MI sensors are compared with those from the fluxgate magnetometer (FGM) that has been working at the observatory. Results showed that the MI sensors can record geomagnetic field variations such as geomagnetic storms, Sq variations, low-latitude positive bays, SSC, and geomagnetic pulsations with a peak-to-peak amplitude of < 1 nT that are also detected with the FGM. This study revealed that the MI sensor can measure the geomagnetic field variations in a period from a few tens of seconds to a few hours.

Using MI sensors, Raspberry Pi, low-cost 24-bit A/D converters, and stable power supply circuits, we developed a magnetometer with approximately \$4,000, which is named MIM-Pi (MI sensor Magnetometer with Raspberry Pi). Because of its low cost, MIM-Pi provides an opportunity to construct a dense observation network of geomagnetic field. We are now deploying MIM-Pi in Kanto-Tohoku area. When we apply the magnetoseismology method to the data from such dense observation network, it will be possible to monitor fine structures of the plasma mass density distribution in the inner magnetosphere.

Keywords: magneto-impedance sensor, magnetoseismology

High-Sensitivity LTS-SQUID Magnetometer Systems for Continuous Geomagnetic Monitoring: Design, Performance, and Geophysical Applications

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Abstract

Since 2016, we have been developing highly sensitive magnetometer systems based on low-temperature superconducting SQUIDs (LTS-SQUIDs) and conducting geomagnetic observations. We currently operate two observation systems of the same design, which achieve a noise level of 20–30 fT/√Hz at 0.1 Hz. The temperature drift of the system, which is mainly attributed to that of the data logger, has been reduced to less than 4 μV/°C, corresponding to a magnetic-field drift of approximately 0.2–0.3 pT/°C.

Each observation system consists of a cryostat for storing liquid helium, a three-axis SQUID magnetometer, Flux-Locked Loop (FLL) electronics, and a 27-bit data logger with a sampling frequency of 200 Hz. The entire system is battery-powered, with a total power consumption of approximately 3.5 W. The liquid helium holding time of the cryostat is approximately one month. Observation data are transmitted via telemetry every 10 minutes. In addition, the system is equipped with a remote-reset function that enables recovery of SQUID FLL operation when it is interrupted by transient disturbances such as lightning-induced noise.

Using these systems, we have successfully observed a variety of geophysical electromagnetic phenomena within this frequency range. For example, Schumann resonances generated by global lightning activity have been clearly detected from the fundamental mode up to the seventh or eighth harmonic. Similarly, ionospheric Alfvén resonances (Ionospheric Alfvén Resonance: IAR), characterized by distinctive spectral structures below 1 Hz, have also been clearly observed. In addition, geomagnetic transfer functions derived from observations at multiple sites show site-dependent characteristics that reflect differences in electrical conductivity structures.

During the earthquake swarm activity on the Noto Peninsula from 2022 to 2023, comparative observations were conducted at sites located near and far from the source region. As a result, magnetic-field variations suggestive of piezomagnetic effects associated with crustal stress changes were detected only at the site near the source region.

Although LTS-SQUID systems require liquid helium for operation, their high magnetic-field resolution over a broad frequency range makes them effective tools for detecting diverse electromagnetic phenomena associated with the Earth's interior, crust, ionosphere, and atmosphere.

In this presentation, we introduce our LTS-SQUID magnetometer systems, summarize their performance, and demonstrate their capabilities through representative observational results obtained from long-term field observations.

Keywords: LTS-SQUID magnetometer, Geomagnetic transfer function, Piezomagnetic effect

Determination of K-index using a machine-learning-based method

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Abstract

The K-index, introduced by Bartels in 1939, quantifies geomagnetic activity in three-hour intervals and had traditionally been derived by hand-scaling from analog magnetograms. In the late 1980s, several computer-based methods for determining the K-index were developed. Among these, the IAGA recognized four methods as producing official observatory K-index, and as a result, most geomagnetic observatories today have adopted computer-based determination. KAK, MMB, and KNY, operated by the Kakioka Magnetic Observatory (KMO), are the only observatories in the world that continue to determine the K-index by hand-scaling.

Comparisons among well-trained observers show agreement rates exceeding 80%, whereas agreement among computer-based determinations reaches only about 70% at best. The fact that the accuracy of computer-based methods does not match that of hand-scaling is the reason why KMO has not adopted automated determination. However, it is not guaranteed that KMO will be able to continue producing well-trained observers in a stable manner in the future. Therefore, the objective of this study is to develop a new computer-based method with high accuracy in preparation for a possible transition to automated determination.

The limitation of conventional computer-based methods is likely due to their inability to fully reproduce the flexible judgment of well-trained observers. To address this issue, we attempted to reproduce the skills of well-trained observers using machine learning.

The reported K-index is taken as the larger of the K-indices read from the two horizontal components. At KAK, hand-scaled values for both the H and D components have been archived since 1989. Therefore, we attempted to train a gradient boosting decision tree to predict the hand-scaled values of the H and D components separately using KAK data from 1989 to 2019. The input features included not only parameters manually extracted from one-minute data, such as amplitude of three-hour ranges, but also variables representing season and local time. In addition, the model directly estimates the K-index from these features without explicitly estimating the quiet-day curve. This omission of the quiet-day curve estimation is a key difference from conventional computer-based methods. As a result of the training, accuracy rates of 80% for the H component and 83% for the D component were achieved. These results are comparable to the level of agreement observed among well-trained observers using hand-scaling. However, the accuracy for $K = 1$ and 2 is relatively lower than for other values. This is likely because $K = 1$ and 2 represent relatively quiet geomagnetic activity levels, where separation from the quiet-day curve is most difficult, making features harder to capture. Improving the accuracy for these values remains an important issue for future work.

Keywords: geomagnetic index, machine learning

A Regional K-index for Chile: Space Weather Monitoring with Integrated Professional and Low-Cost Magnetometers

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Abstract

Ground-based magnetometers are essential for space weather monitoring, enabling the derivation of geomagnetic indices used in regional alert systems. While ongoing deployment efforts aim to address latitudinal gaps in global sensor coverage, particularly in Chile, translating these local measurements into a standard K-index remains challenging. Traditionally, K-indices are derived from certified, highly stable geomagnetic observatories. Chile, however, lacks such infrastructure, relying instead on an expanding network that mixes scientific-grade and low-cost magnetometers with highly variable noise levels and calibration baselines.

To address these limitations, we developed a data processing pipeline to derive a real-time regional K-index from this mixed-sensor network. The pipeline automates quiet-day curve (QDC) estimation using the method of Verhulst et al. (2021) and applies smoothing and quantile-matching techniques to harmonize data across different instrument types. The pipeline's output was compared against the global K_p and regional K_{sa} indices. Our results show that integrating low-cost sensors, when supported by robust calibration algorithms and reference-grade anchor stations, offers a viable and cost-effective alternative for regional space weather monitoring, despite the inherent noise limitations of the instruments.

Keywords: Space Weather, Magnetometer, K-index

Near-Real-Time Computation of Local Geomagnetic Disturbance Index (Dlat) at Fúquene Observatory

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Abstract

The constant monitoring of the geomagnetic field is fundamental to understanding the dynamic interactions between the Sun and Earth's magnetosphere. These interactions can generate geomagnetic storms triggered by coronal mass ejections and high speed wind streams, which reduces GPS accuracy and compromises air safety. Indicators such as the **Dst index** measure changes in the horizontal component (H) of the geomagnetic field at the equator, using a small set of stations spread across different longitudes. However, the limited number of stations can introduce regional bias and an insufficient temporal resolution. Leading to the development of local indices like **Dlat**, which uses data from a single observatory to achieve higher time resolution and estimate disturbances within a specific geographic latitude band.

Thanks to the modernization of equipment at the **Fúquene magnetic observatory**, we present the first real time geomagnetic data connection for Colombia. This was achieved using open source software that allows data to be displayed and processed. Within the infrastructure of the system, we implemented a local storm disturbance index (**Dlat**) following the method of **Love and Gannon**. This index includes data from 1957–2018 and an operational, near real time (NRT) version with a one minute resolution.

A key feature of both versions is the combined use of techniques like time domain and frequency domain to eliminate the quiet day solar variation (Sq). The method takes advantage of the physical processes associated with specific Fourier harmonics, which allows for careful identification and separation of the Sq signal before extracting the disturbance series. Afterwards, the magnetic latitude correction was then applied using the **14th generation IGRF model** evaluated at **FUQ**.

For the historical method, the results were validated using the **Kyoto Dst index** with Pearson's correlation and analyzing the mean squared error during the storm events that occurred between 1957 and 2018. For high magnitude storms like in the year 1989, a correlation coefficient of **0.94** and a root mean square error of **18.6 nT**. For the NRT method, validation was done against the **USGS observatory network**, demonstrating strong agreement during storm periods recorded in 2026, such as the January 20 storm. Showing a strong correlation with the **San Juan Observatory (SJG)**, with a coefficient of **0.984** and a root mean square error of **11.0 nT**. Largely due to the fact that SJG has the closest magnetic latitude to Fúquene within this network.

These results support the viability of calculating a regional disturbance index for mid-equatorial latitudes and strengthen FUQ's role as an active node in global geomagnetic monitoring, particularly in space weather studies and research on the **South Atlantic Anomaly**.

Keywords: Geomagnetic disturbances, Dst index, Fúquene Observatory

Publication of the Geomagnetic Charts of Japan for the Epoch 2025.0

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Abstract

The Geospatial Information Authority of Japan (GSI) has conducted geomagnetic surveys all over Japan since around 1950 to understand the spatial distribution of the geomagnetic field and its temporal variation. Geomagnetic surveys had been carried out at approximately 100 first-order and 800 second-order magnetic points, from Hokkaido to Okinawa in Japan. Since 1996, geomagnetic observation instruments have been installed nationwide (at 12 locations as of today), continuously measuring the absolute value of the total intensity (F) and variations in the three geomagnetic components (H, D, Z). In today's geomagnetic surveys, observations are conducted at reference magnetic points, using Overhauser and D/I magnetometer. Then, difference in the total intensity (F) and baseline values of the three geomagnetic components (H, D, Z) between the geomagnetic observation instrument and the reference magnetic point are determined. Finally, absolute values at the reference magnetic point are obtained by adding the survey results to the data from the geomagnetic observation instrument.

Based on these observation results, GSI updates "Geomagnetic Charts" that show the geomagnetic distribution in Japan every five years. Each chart represents the geomagnetic state as of 00:00 UTC on January 1st of a certain year, referred to as "Epoch yyyy.0". Currently, GSI is preparing to publish the next charts, the "Geomagnetic Charts for the Epoch 2025.0", by the end of 2026. The charts represent the geomagnetic distribution in Japan as of 00:00 UTC on January 1, 2025.

As in previous charts, the "Geomagnetic Charts for the Epoch 2025.0" are created using the "Geomagnetic Spatiotemporal Model", based on principal component analysis, to calculate geomagnetic variations at any location from a reference date to an any given time. Using geomagnetic observation data from GSI and the Japan Meteorological Agency (JMA), temporal functions representing time variation and spatial functions representing spatial distribution are derived to construct the model. To improve accuracy in northern Hokkaido, the data from the Wakkanai observation site will be newly incorporated. Geomagnetic variations calculated from this model are added to past geomagnetic survey results at approximately 900 first-order and second-order magnetic points, enabling the estimation of geomagnetic values at these points for any epoch. These calculated values, together with annual mean values from geomagnetic observation data and marine data (IGRF), are used to generate gridded data using Green's function spline method, from which the Geomagnetic Charts are drawn.

The Geomagnetic Charts for the five geomagnetic components (declination, inclination, total intensity, horizontal intensity, and vertical intensity) along with declination tables will be published on the GSI website and GSI Maps. In addition, based on the gridded data used to create these charts, a web service will be provided to allow users to obtain geomagnetic values (Epoch 2025.0) at any location in Japan.

Keywords: Geomagnetic Charts

Observation of the Geomagnetic Secular Variation in the Urals near the Arti Observatory

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Abstract

The Arti (ARS) geophysical observatory, located on the western slope of the Ural Mountains (Russia) is one of nine INTERMAGNET observatories in Russia. The observatory has maintained a continuous series of geomagnetic observations since 1836 (190 years this year). Notably, the nearest INTERMAGNET-standard magnetic observatories are located at least 1,000 km away. Another historical observatory, founded in 1829 in Kazan (600 km from Arti), is currently operational, but has not yet joined the INTERMAGNET network.

Magnetic observatories serve not only to monitor rapid magnetic field variations and to record magnetic storms, but also to study the dynamics of slow changes in geomagnetism (secular variation). It is generally accepted that secular variation consists of several components: a global-scale contribution (the westward drift of the field); changes in the so-called «centres of secular variation» (SV foci at the core surface) at depths of several thousand kilometers, which produce variations in field components over distances of thousands of kilometers within relatively short periods of 5–20 years; and changes driven by processes in the Earth's crust, such as geological structure, tectonics, geochemistry, and other phenomena. The latter mechanism generates secular variation anomalies of a local or regional scale. To study these processes in greater detail, a network of secular variation stations is typically organized in addition to a permanent observatory. The observatories of the Urals were also engaged in studying secular variation at repeat stations between 1887 and 1939; the network of stations was located in the Urals, Western Siberia, and Kazakhstan. Since 2006, we have been developing a modern network of repeat stations to investigate secular variation anomalies in the vicinity of the Arti Observatory. The network design and measurements have been carried out in accordance with the IAGA guidelines for magnetic repeat station surveys (Jankowski & Sucksdorff, 1996). To date, 36 stations have been surveyed across an area of 5,000 km². Some of the stations are situated within the Manchazh regional gravimagnetic anomaly, which has deep-seated sources. Since the discovery of this anomaly, its source has been investigated by many researchers, and the nature of its magnetization remains a subject of debate. Measurements have generally been performed annually, with a few exceptions. Some stations were lost over time, some were relocated, and new ones were established to increase the detail of the survey. The measurement methodology has evolved over the years. From 2007 to 2017, measurements were carried out using a cesium magnetometer – a Scintrex SM-5 gradiometer – at heights of 1 m and 2 m above the ground. Starting in 2025, an Overhauser magnetometer – the POS-2 gradiometer – has been employed. Between 2014 and 2022, the vertical component of the geomagnetic field was measured using a ZT POS-3 Overhauser component magnetometer.

A repeat station on the ground consists of a prepared site equipped with a special non-magnetic pillar for placing the magnetometer. A special adapter (tribrach) is screwed onto the top of the pillar, and the POS-3 instrument is mounted on it. The instrument sensor is positioned at a height of 0.2 m above ground level. Data processing involves calculating the differences between the magnetic field values measured at each station and the values synchronously recorded at the observatory by the standard POS-1 magnetometer. Finally, the mean values of the differences are calculated; these constitute the final result.

We compare the obtained data with the calculated values from the WMM, EMM, and IGRF models. The comparison results enable an in-depth study of the regional dynamics of secular variation anomalies and confirm the reliability of the magnetic field observations at the observatory.

Keywords: geomagnetic secular variation, repeat stations, Urals

Detection of the South Atlantic Anomaly Using Magnetic Field Data Observed by the Arase Satellite

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Abstract

The South Atlantic Anomaly (SAA) is a region where the Earth's internal magnetic field is locally weakened, and its location and spatial structure change over time due to the secular variation of the geomagnetic field. In this study, we identified the SAA using magnetic field data observed by the Arase satellite and investigated the annual variation of its center location.

Arase travels in an elliptical orbit, and we used magnetic field data with a measurement range of $\pm 60,000$ nT obtained near perigee from 2017 to 2024. First, data acquired at altitudes between 450 and 1,000 km were extracted. Because the geomagnetic field intensity varies significantly with altitude, the observed magnetic field data were normalized to an altitude of 450 km using the altitude dependence of the geomagnetic field intensity calculated from the International Geomagnetic Reference Field (IGRF) model. The SAA region was then identified from the normalized magnetic field intensity, and its center location was determined using a weighted-average method. The annual motion of the SAA center was quantitatively evaluated by applying a linear fit to its yearly variation.

For data acquired between 450 and 1,000 km altitude, the SAA center was found to move southward at $0.028^\circ/\text{year}$ and eastward at $0.093^\circ/\text{year}$. The same analysis was then performed by extending the upper altitude limit to 1,500 km and 2,000 km. With an upper altitude limit of 1,500 km, the SAA center moved southward at $0.150^\circ/\text{year}$ and westward at $0.012^\circ/\text{year}$, while with an upper altitude limit of 2,000 km, it moved southward at $0.054^\circ/\text{year}$ and westward at $0.069^\circ/\text{year}$.

These results demonstrate that magnetic field observations obtained near the perigee of the Arase satellite can be used to identify the SAA and investigate its temporal variation. The results also indicate that the estimated direction and rate of motion of the SAA center depend on the altitude range used in the analysis.

Keywords: South Atlantic Anomaly, Satellite observation, IGRF model

Broadband magnetotelluric and Network-MT measurements in a seismogenic zone around western Ibaraki Prefecture

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Abstract

A seismically active area exists to the northeast of the Tokyo metropolitan area, specifically, around western Ibaraki Prefecture. There exists a cluster of plate boundary earthquakes on the Philippine Sea (PHS) slab in this area. Above the plate boundary, a supraslab earthquake cluster is located at depths of 25–35 km. A previous seismological study suggested that the upward fluid migration in the overlying continental slab, which follows the slow slip events on the PHS slab, could trigger supraslab earthquakes. The subsurface fluid is thought to play an important role in earthquake generation. To elucidate the subsurface fluid distribution and its influence on seismic activity, it is crucial to reveal the electrical resistivity structure since the electrical resistivity is sensitive to the interconnected fluids in rocks. In Ibaraki Prefecture, we conducted the Network-magnetotelluric (MT) measurements from December 1991 to May 1993. In addition, above the supraslab earthquake cluster, we conducted a broadband MT measurement from November 2025 to December 2025. The Network-MT method, which utilizes commercial telephone lines to measure the electric field, has high sensitivity to deep structures, down to the subducting slabs and below. On the other hand, the broadband magnetotelluric method offers higher resolution to the crustal structure. We calculated the response functions from the two datasets using the robust remote reference multivariate regression S-estimator. The magnetic field at Kakioka Magnetic Observatory was used as the predictor variable to estimate the Network-MT response function. The magnetotelluric response functions obtained from the two datasets show some consistent features, such as a continuous increase in the apparent resistivity with increasing period at periods longer than around 1 s. This feature is also consistent with the MT response function at Kakioka Magnetic Observatory. The increase in the apparent resistivity with depth may reflect the increase in resistivity from the shallow sedimentary layer to the basement, and further to subducting slabs. Induction arrows (Parkinson convention) obtained from our broadband MT data, as well as those from the data of Kakioka Magnetic Observatory, point southward at periods of longer than several hundred seconds. Along the southwestern border of Ibaraki Prefecture, there are boundaries in gravity anomaly and seismic velocity, and the southern area shows a low gravity anomaly and low velocity. The gravity anomaly is thought to be due to differences in the thickness of the sedimentary layer, whereas some previous works have ascribed the low-velocity anomaly south of the boundary to the serpentine mantle wedge above the PHS slab. The southward induction arrow implies that there is a lateral difference in the subsurface electrical resistivity across the boundary, and the southern area is relatively conductive. We plan to estimate the three-dimensional resistivity structure from the shallow crust to the subducting slabs using the combined inversion method of broadband MT and Network-MT data.

Keywords: Network-MT method, Magnetotellurics, Electrical resistivity structure

Broadband Magnetotelluric Survey for Unveiling the Magma Reservoir Beneath Mount Asama, Central Japan

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Abstract

Mount Asama is a stratovolcano located in central Japan and is one of the most active volcanoes in Japan. Due to its volcanic activity and potential volcanic hazards, it is important to understand the subsurface magma plumbing system beneath the volcano. Information regarding location and size of magma chamber is important for understanding and forecasting eruptive behaviour. Previous geophysical and geological studies have suggested the existence of magma reservoir beneath Mount Asama (Takeo, et al., 2006; Aizawa, et al., 2008; Aoki, et al., 2009; Nagaoka, et al., 2012; Usui, et al., 2017). Several seismic observations indicate that the possible magma chamber located northwest of the summit. Additionally, earlier studies have revealed that the possible magma structures associated with hydrothermal fluids and volcanic conduits beneath the volcano. However, the exact location and geometry of the magma reservoir remain unclear. Moreover, most previous studies mainly focused on relatively shallow structures, leaving the deeper part of the volcanic system insufficiently understood. The Magnetotelluric (MT) method, which is highly sensitive to electrically conductive material, is suitable for imaging volcanic subsurface structures. In this study, we conducted a broadband MT survey at Mount Asama in 2018 to investigate the deep resistivity structure beneath the volcano to reveal conductive anomalies potentially associated with the magma reservoir. The measurements were conducted using 8 sites that recorded the data from 5 June to 28 June 2018 and 11 sites that recorded the data from 11 September to 3 October 2018 distributed in the western region of Mount Asama to cover the potential extent of the magma reservoir inferred from the seismic studies. As a note, several data records from some sites are unavailable due to unexpected measurement interruptions or other operational disturbances. The time series data are processed using the robust transfer function TRACMT code (Usui, et al., 2024; Usui, et al., 2025). The MT observation data was acquired using three sampling rates, 32Hz, 1024 Hz, and 32768 Hz. For the 1024 Hz dataset, the MT responses at several stations (ASW020, ASW100, ASW110, ASW140, and ASW145) were significantly affected by strong artificial noise, resulting in poor-quality responses. Therefore, these stations were excluded from the three-dimensional inversion. For the 32768 Hz dataset, no dedicated reference site was available, so station ASW030 was used as the reference for the September–October observations, while station ASW080 was used for the June observations. Preliminary processing of the 1024 Hz data using the TRACMT code shows apparent resistivity ranging from 10 to 100 $\Omega\cdot\text{m}$, suggesting the presence of a conductive body beneath the western region of Mount Asama. Additionally, the 32768 Hz data provide reliable responses up to approximately 1 kHz, with apparent resistivity values ranging from 0.1 to 1000 $\Omega\cdot\text{m}$. Subsequently, three-dimensional inversion is performed using the FEMTIC code (Usui, 2015; Usui et al., 2017), which employs the finite-element method with unstructured tetrahedral elements to include the topography.

Keywords: Magnetotelluric, Magma reservoir, Mount Asama

The Role of Geomagnetic Observation in the Volcano Monitoring of the Japan Meteorological Agency

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Abstract

The Japan Meteorological Agency (JMA) has been carrying out volcanic observations for more than a century, including the monitoring and evaluation of volcanic activity and the dissemination of related information (Yamasato, 2005). Although the observation network has gradually improved by incorporating lessons learned from past disasters, the catastrophic eruption of Ontake Volcano in 2014 highlighted the inherent complexity of phreatic eruptions. These eruptions are often characterized by a lack of clear mechanical precursors, emphasizing the need for new approaches to disaster mitigation.

Following this event and in line with recommendations from the Coordinating Committee for Prediction of Volcanic Eruption (2014), JMA has strengthened its integrated assessment framework based on multi-parameter observations. Continuous geomagnetic observation has become an important component of this framework. In Japan, many studies in volcanic electromagnetism have provided the scientific basis for these developments, particularly by clarifying temporal variations in the geomagnetic field associated with subsurface thermal activity (Hashimoto, 2005).

Thermal inputs from magma or hydrothermal fluids can cause demagnetization of surrounding rocks, a process known as thermal demagnetization. As a result, detecting localized geomagnetic variations offers an effective way to evaluate shallow thermal processes that may trigger phreatic eruptions. However, geomagnetic observations can typically detect signals only within about 1 km of the source. This requires observation stations to be installed near hazardous summit craters, where instruments are exposed to severe weather conditions and corrosive volcanic gases. In addition, extracting weak volcanic signals from geomagnetic noise—such as secular variation, upper-atmospheric disturbances, and local fluctuations—remains a technical challenge. Because of these practical and analytical difficulties, volcano-magnetometry has traditionally played only a supplementary role.

More recently, however, the accumulation of knowledge in geomagnetism, combined with the growing need to detect early signs of phreatic eruptions following the Ontake disaster, has led to the expansion of monitoring efforts. As part of ongoing technological developments to track the shallow thermal state of volcanic edifices, observational data have been steadily increasing (Volcano and Earthquake Department, JMA, & Kakioka Magnetic Observatory, JMA, 2022).

In this presentation, we introduce the continuous geomagnetic observation systems developed since the 2014 Ontake eruption. We also report temporal variations in total magnetic intensity in relation to volcanic activity at Kusatsu-Shirane, Izu-Oshima, and Meakandake volcanoes, where long-term observations have been conducted by the Kakioka Magnetic Observatory, along with methods for reducing geomagnetic noise.

Keywords: volcano, phreatic eruption, thermal demagnetization

Long-Term Variations of Total Magnetic Intensity at Izu-Oshima Volcano

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Abstract

At Izu-Oshima Volcano, periodic eruptive activity has been suggested, highlighting the need for early detection of precursory phenomena. Geomagnetic total intensity observations have reportedly captured magnetic field changes beginning approximately five years prior to the 1986 eruption, indicating their effectiveness for volcanic monitoring.

In this study, we investigate long term variations of the geomagnetic total intensity on Izu-Oshima island to detect volcanic signals. Daily values of the total intensity in and after 2000 were collected at 14 observatories. The geomagnetic secular variation was obtained from CHAOS-8 model. Variations related to ionospheric and magnetospheric disturbances were estimated by referring to the geomagnetic field at Kakioka and the long term trends were extracted by a Kalman filter procedure. Those trends are supposedly variations of volcanic origin for 25 years from 2000.

The trends monotonically increase on the order of several tens of nanotesla at most of observation sites between 2000 and 2024. We divide the 25-years time period from 2000 into 3 time periods: Period 1 (2000-2007) for large variations near the summit, Period 2 (2008-2017) for increasing trend at nearly all sites, and Period 3 (2018-2024) for relatively small variations.

We check whether the trend can be explained by thermal magnetization/demagnetization of rock inside the volcano. An optimum magnetization/demagnetization source were determined for the 3 time periods so that the residuals between the trend and calculated total intensity become the minimum. Results indicate the presence of a magnetized region in the shallow subsurface on the northwestern side of the summit during the period from 2000 to 2007. The total intensity variations prior the 1986 eruption were observed at the same area around summit. This suggests that magnetic field changes reported both before and after the 1986 eruption can be explained by thermal demagnetization and magnetization in the same region.

In contrast, the estimated thermal sources at Periods 2 and 3 could not sufficiently explain the large trend at the coastal area of the island. We tried sources at a shallow part around the summit and a deeper part outside the summit near a known crustal deformation source. Identifying causes of the trend after 2008 remains a subject of a future study.

Keywords: Geomagnetic total intensity , Volcanic signal

Geomagnetic changes associated with volcanic activity at Shinmoedake Volcano, Japan, detected through repeated aeromagnetic surveys

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Abstract

Shinmoedake is one of the most active volcanoes in Japan. Recently, at the beginning of 2011, Shinmoedake volcano had magmatic eruptions such as sub-Plinian and Vulcanian type eruptions. The gushed lava covered the crater, and the original crater lake disappeared. After ceasing activities of volcanic eruptions, we conducted surveys repeatedly nine times almost every or every other year so far, and notable temporal changes are detected just around the crater of Shinmoedake volcano by gaining magnetization due to cooling of lava in the crater at the eruptions.

After the 2011 eruption, the cooling rate just follows the square root of elapsed time from the eruption, and thus the cooling is simply done by thermal diffusion at the surface of lava. In 2017-2018, Shinmoedake erupted again, and additional lava was gushed, and the geomagnetic temporal variation went off the previous diffusion curve, but the magnetic field abruptly changed due to this event. It is because gushed molten lava was cooled down and gained magnetization to drastically increase a magnetic dipole moment. After the events, the dipole moment came to lie on another diffusion curve again. Very recently, in 2025, Shinmoedake erupted again. However, the magmatic deposit is found to be very minor, and new lava does not appear on the surface. Geomagnetic field does not show an abrupt change either unlike the 2018 event, and this data also indicate the magma did not ascend very much and did not give a major effect on the increase of the magnetic dipole moment.

In this paper, we show the result of the magnetic field in Shinmoedake volcano observed by aeromagnetic survey and its time variations at three volcanic events.

Keywords: aeromagnetic survey, geomagnetic change, volcanic eruptions

Long-Term Continuous Electromagnetic Monitoring Before, During, and After a Large Earthquake: The 2024 Noto Earthquake (Mw 7.5) in the Epicentral Area

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Abstract

On January 1, 2024, a large intraplate earthquake (Mw 7.5) struck the northern part of the Noto Peninsula in north-central Japan, causing widespread damage due to strong ground motions and a tsunami. Prior to this catastrophic earthquake, an intense earthquake swarm and localized non-steady crustal deformation had been continuously observed since late 2020 in this non-volcanic region. The swarm activity persisted, producing several M-5 class earthquakes—including an M 6.5 event on May 5, 2023—before culminating in the Mw 7.5 mainshock.

To detect changes in the subsurface resistivity structure associated with variations in seismic activity, we established an continuous electromagnetic field observation network covering the clusters of the swarm activity starting in late FY2022. Our observation network consists of two types of broadband electromagnetic field instruments (ELOG-MT and ELOG-Dual, manufactured by NT System Design) that measure five components of the electromagnetic field (three magnetic and two electric) and two components of the electric field, respectively. The systems record data at sampling intervals of 15 Hz, 150 Hz (from 13:00 to 21:00 UTC), and 2400 Hz (from 15:00 to 20:00 UTC). Continuous observations started at the end of FY2022 with one 5-component station and five 2-component stations. Ultimately, a total of four stations successfully acquired long-term electromagnetic field records spanning the pre- and post-earthquake periods for both the May 5, 2023, M 6.5 earthquake and the January 1, 2024, Mw 7.5 earthquake. This continuous monitoring system successfully recorded invaluable data directly above the hypocenter throughout the entire preparation and rupture phases of the mainshock.

In this presentation, we report on the temporal variations of the Tipper, defined as the ratio of the vertical to horizontal components of the geomagnetic field. We will discuss the observed changes in the Tipper in relation to the migration of crustal fluids and the stress accumulation process leading up to and during the 2024 Noto Earthquake.

Keywords: Continuous electromagnetic monitoring, Tipper, The 2024 Noto Earthquake

Multiparametric Analysis of Geomagnetic Precursors Associated with the October 1, 2022 Tarutung Earthquake (Mw 5.8) Using Ground Surface ULF Signals and Swarm Satellite Data

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Abstract

This study analyzes geomagnetic and ionospheric anomalies as potential short-term precursors to the Mw 5.8 Tarutung earthquake on October 1, 2022, in North Sumatra, Indonesia. Ground-based data from the SMG geomagnetic station were analyzed using the Power Spectral Density (PSD) and Single Station Transfer Function (SSTF) methods to monitor fluctuations in the Ultra-Low Frequency (ULF) polarization ratio (Z/H). Observations from the European Space Agency (ESA) Swarm satellite were combined to examine the residual ionospheric magnetic field after subtraction from the International Geomagnetic Reference Field (IGRF) model. To confirm the seismic origin, the Disturbance Storm Time (Dst) index was used to filter out geomagnetic storms and solar radiation. The analysis revealed two prominent ULF anomalies on September 8 and September 24, 2022, with polarization amplitudes of -3.503 nT and 2.053 nT, respectively, and lead times of 23 and 7 days, respectively. This anomaly was validated with the Dst index and SWARM data within the Dobrovolsky radius ($\rho \approx 380\text{km}$), which confirmed that pre-seismic stress was localized within the Renun segment of the Great Sumatran Fault. Satellite swarm analysis validated this finding, identifying synchronized daily magnetic residuals in the ionospheric E component. This anomaly is related to the microcracking process in the subduction zone of the Renun segment of the Sumatran Fault, indicating a lithosphere-atmosphere-ionosphere coupling phenomenon. This study demonstrates the effectiveness of an integrated approach for tectonic earthquake precursor detection, supporting the development of earthquake prediction systems for disaster mitigation in vulnerable areas such as Tarutung.

Keywords: Tarutung Earthquake, ULF Signals, Swarm Satellite

Applications of magnetometer - based techniques from laboratory materials research to geophysical monitoring

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Abstract

Applications of magnetometer - based techniques from laboratory materials research to geophysical monitoring

This study explores the application of magnetometer - based sensing techniques in both materials science and geophysical monitoring, specifically, it investigates the detection of weak electromagnetic signals generated during the mechanical failure of geomaterial composites. It examines the relationship to principles used in geomagnetic monitoring systems such as the International Space Weather Initiative and the International Center for Space Weather Science and Education Magnetometer Network. Laboratory experiments involve subjecting mortar specimens to compressive and impact loading while monitoring possible magnetic field emissions using multiple magnetic sensors and acoustic instruments. The study also considers challenges common to both laboratory-scale and geophysical magnetic measurements, including signal attenuation, sensor interference, and data interpretation. Analysis of the magnetic field components of the electromagnetic radiation (EMR) emissions resulting from the fracturing of the mortars revealed significant time lags of about 1 – 3 seconds between the measured peaks of acoustic and EMR emissions. Analysis of geomagnetic field data from the Magnetic Data Acquisition System (MAGDAS) deployed at the Davao, Philippines station from June to August 2010 revealed significant earthquake precursors occurring from between 22 to 24 days before the July 23, 2010 Moro Gulf Earthquakes. By comparing methodologies used in structural material monitoring and geomagnetic observation, the research aims to evaluate the feasibility of adapting magnetometer - based approaches for fracture detection and stress monitoring in engineered materials. The work contributes to interdisciplinary research linking geophysics, materials science, and electromagnetic sensing, with potential implications for nondestructive testing, and future earthquake precursor studies.

Keywords: earthquake precursors

Toward a Comprehensive Database of Solar Flare Effects (SFE)

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Abstract

Kakioka Magnetic Observatory reports geomagnetic phenomena such as sudden storm commencements (SSC), sudden impulses (SI), and solar flare effects (SFE). SFE is a phenomenon that appears as an enhanced Sq variation, primarily caused by increased ionospheric conductivity due to solar flares (see Curto, 2020 and references therein). As SFE is one of the earliest geomagnetic responses to a solar flare, it can serve as an important indicator of solar flare reaching the Earth.

Our observatories have compiled lists of SFE events observed at Kakioka (as well as Memambetsu and Kanoya) since 1957. However, these lists are limited to the events in Japan and are not suitable for global analyses. Although the Ebro Observatory provides records of SFE observed at observatories around the world through its data portal, the available information is limited to event start times, station names, and event classifications. For statistical analyses, additional information such as peak time, amplitude, and related parameters are required. Furthermore, incorporating information on the corresponding solar flares would significantly enhance the utility of the database. In this study, we are developing an SFE database for statistical analysis. Solar flare data are derived from GOES event list and the catalog of Plutino et al. (2023). For SFE events, we use data from approximately 15 INTERMAGNET observatories, covering the period from 2000 to 2020. In this workshop, we will discuss the current progress in database development and remaining issues.

Keywords: Solar Flare Effects

Statistical Analysis of Geomagnetic Variations due to Soft X-ray/Extreme Ultraviolet Radiation During Solar Flares Using Magnetometer

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Abstract

The Solar Flare Effect (SFE) is a transient geomagnetic variation caused by a sudden enhancement of ionospheric conductivity due to excess solar electromagnetic radiation, primarily soft X-rays and extreme ultraviolet (EUV) emissions, during a solar flare. Ground-based magnetometers record these variations across different geomagnetic components: the horizontal northward (X) and eastward (Y) components (often integrated into the horizontal magnitude H), and the vertical downward component (Z). Traditionally, the SFE has been interpreted simply as a temporary, localized augmentation of the Solar Quiet (Sq) current system. However, recent studies, including Hudson et al. (2025), have demonstrated that hodogram analysis of geomagnetic vectors reveals a more complex temporal evolution, suggesting the superposition of multiple independent current systems. Hodogram enables to follow two geomagnetic vectors over time.

To elucidate the precise physical mechanisms driving the SFE, this study investigates the SFE on a global scale. We utilized high time-resolution geomagnetic data from global observation networks, specifically INTERMAGNET and SuperMAG, alongside solar spectral data from the Solar Dynamics Observatory (SDO) Extreme ultraviolet Variability Experiment (EVE) and the GOES satellites. By deriving global equivalent current systems and conducting detailed hodogram analyses of the geomagnetic vectors across various latitudes and local times, we systematically tracked the spatiotemporal evolution of SFE currents during X-class flares.

Our global analysis identified general SFE responses. Notably, we observed widespread SFE variations that exhibit temporal evolutions highly correlated with EUV emissions (e.g., He II 30.4 nm, Ly α 121.5 nm), which typically reach their peak intensity earlier than soft X-rays. Furthermore, horizontal (X-Y) hodograms across multiple stations revealed abrupt changes in the geomagnetic vector direction during the flare progression. We found that these directional shifts precisely coincide with the transition from the EUV-dominated phase to the soft X-ray-dominated phase.

We attribute these complex morphological changes to the altitude-dependent ionization processes in the ionosphere. Soft X-rays penetrate deeply into the lower E region (peaking at approximately 105 km), where Hall conductivity governs the current flow. Conversely, EUV emissions are absorbed at higher altitudes in the upper E region (approximately 130 km), where Pedersen conductivity is dominant. Because these distinct solar emissions peak at different times, the Hall and Pedersen currents are enhanced with a temporal phase shift. The time-differenced activation of these altitude-dependent current systems directly modulates the direction and magnitude of the integrated magnetic vector observed on the ground. Ultimately, our global equivalent current and hodogram analyses demonstrate that the SFE is not merely an amplified Sq current, but a dynamic superposition of multiple current systems driven by spectrally and temporally distinct solar emissions.

In this presentation, we will detail our methodology for extracting SFE magnitudes and outline the general and unique characteristics of these geomagnetic responses. Our primary discussion will then focus on whether ground-based magnetometers genuinely capture the signatures of the Pedersen current.

Keywords: Geomagnetic Solar Flare Effect, solar Extreme Ultraviolet / soft X-ray, Electric conductivity

Capturing Geomagnetic Storms: From Observatory Data to Auroras and Space Weather Hazards

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Abstract

The Scott Base Geomagnetic Observatory (SBA), operated by Earth Sciences New Zealand, has provided continuous measurements of Earth's magnetic field in Antarctica since 1957. As part of the global INTERMAGNET network and supported by Antarctica New Zealand as a long-term science programme, SBA contributes to international datasets used in space weather research, ionospheric and deep Earth studies, and practical applications such as navigation and digital compass correction. Despite this, the purpose of geomagnetic observatory data is not always clear to non-specialists involved in Antarctic operations.

This work addresses that gap by communicating geomagnetic observations through a familiar phenomenon: the aurora. High-resolution magnetic data are often perceived as abstract “wiggles” with little intuitive meaning. By aligning magnetic field measurements with time-stamped auroral imagery, distinct features in the data – such as geomagnetic storms and substorms – become visible and tangible.

Geomagnetic storms result from interactions between charged particles from the Sun and Earth's magnetic field, our natural shield in space. Guided along magnetic field lines into polar regions, these particles disturb the field and drive rapid fluctuations. During periods of high solar activity, coronal mass ejections (CMEs) can intensify space weather and extend its effects to mid-latitudes. While producing spectacular auroras, these events can also impact communications, navigation, and power systems.

By linking observatory data to auroral observations and technological impacts, this approach provides an accessible way to understand space weather and its hazards. It positions SBA not only as a scientific instrument within a global network, but also as a practical tool for communication and outreach, making space weather visible, understandable, and relevant.

Keywords: Scott Base Geomagnetic Observatory (SBA), Aurora photography, Space Weather