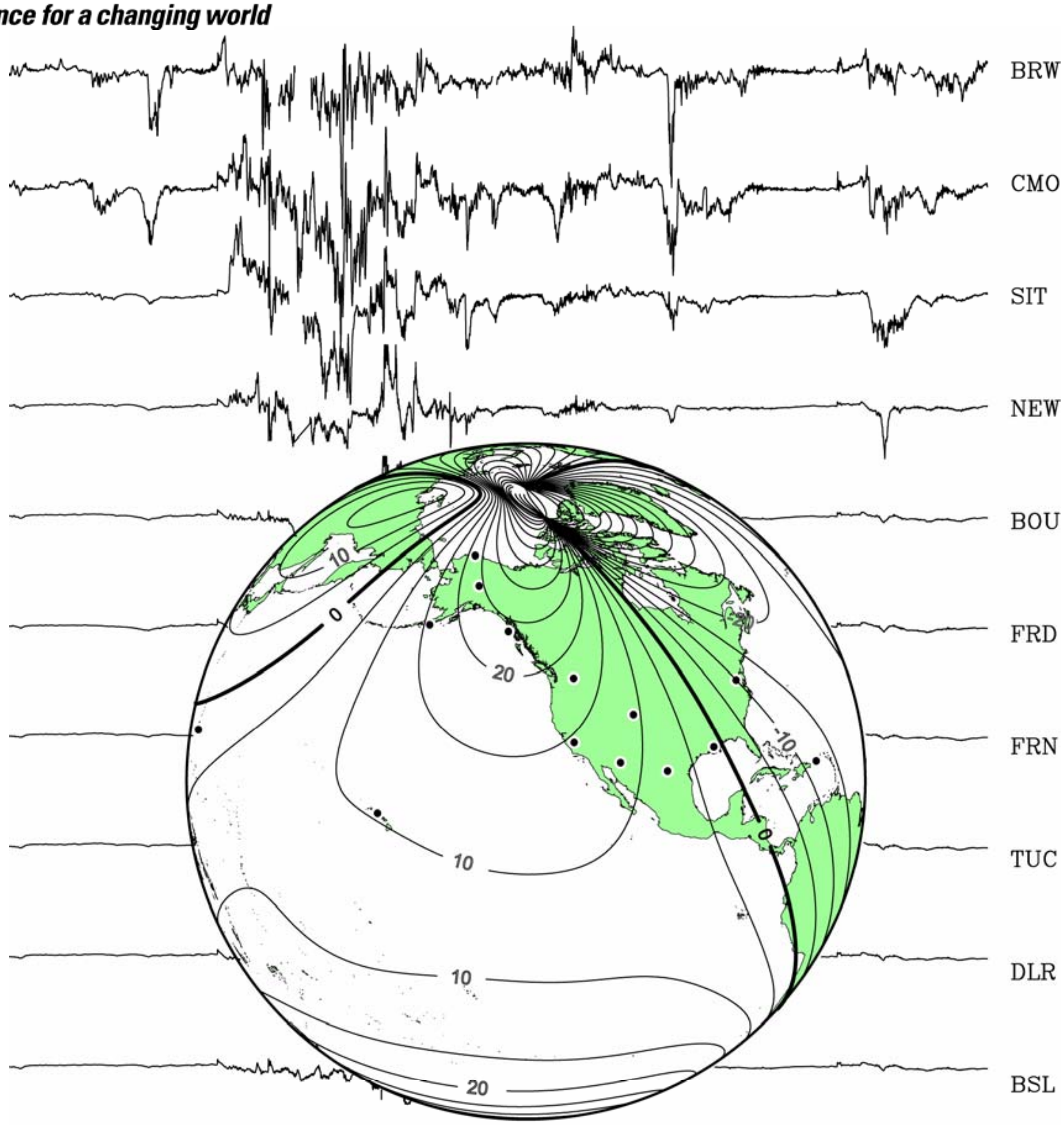

NATIONAL GEOMAGNETISM PROGRAM: CURRENT STATUS & FIVE-YEAR PLAN, 2006-2010

JEFFREY J. LOVE

Open-File Report 2006-1352

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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Cover Page Explanation

The satellite perspective map seen on the cover depicts the magnetic declination (degrees east) for the year 2000 as approximated by the International Geomagnetic Reference Field (IGRF). The black dots represent the locations of USGS geomagnetic observatories. The stack plot of data depicted behind the globe is of the horizontal component of the magnetic field recorded at USGS observatories during the magnetic storm of March, 12-16, 1989.

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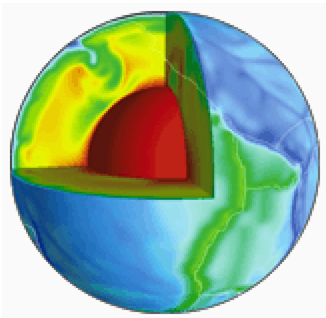
EXECUTIVE SUMMARY

The U.S. Geological Survey's Geomagnetism Program serves the scientific community and the broader public by collecting and distributing magnetometer data from an array of ground-based observatories and by conducting scientific analysis on those data. Preliminary, variational time-series can be collected and distributed in near-real time, while fully calibrated, absolute time-series are distributed after processing. The data are used by the civilian and military parts of the Federal Government, by private industry, and by academia, for a wide variety of purposes of both immediately practical importance and long-term scientific interest, including space-weather diagnosis and related hazard mitigation, mapping of the magnetic field and measurement of its activity, and research on the nature of the Earth's interior and the near-Earth space environment. This document reviews the current status of the Program, in terms of its situation within the Government and within the scientific community; summarizes the Program's operations, its staffing situation, and its facilities; describes the diversity of uses of Program magnetometer data; and presents a plan for the next 5 years for enhancing the Program's data-based services, developing products, and conducting scientific research.

CONTENTS

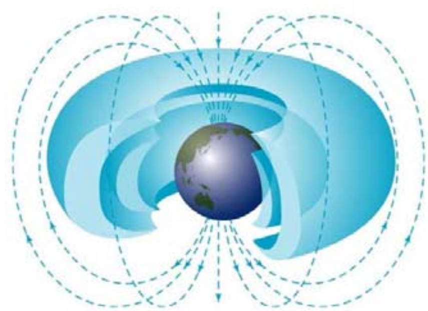
I. INTRODUCTION

SCIENTIFIC SUMMARY



The geomagnetic field is generated by electric currents located in many different parts of the Earth (Parkinson, 1983; Jacobs, 1987; 1987, 1989, 1991; Courtillot and Le Mouel, 1988). In the outer core, the main part of the geomagnetic field is sustained by a naturally occurring dynamo. In the mantle, currents can be induced by time-dependent variations in the ambient magnetic field. In the crust, the field has both induced and permanent components. Oceanic fluid currents and tides can induce magnetic fields. In the ionosphere and magnetosphere, electric currents are sustained through a complicated interaction with the Sun, the heliomagnetic field, and the solar wind of charged particles. The many different, and sometimes remote, sources of the Earth's magnetic field each contribute to the total field at any one particular location, with the very different physical processes in each domain giving rise to a wide variety of temporal variation. Therefore, through the analysis of the time-series of the magnetic field from different geographic locations, the different source regions, be they below or above the Earth's surface, can be studied for the purposes of scientific knowledge and understanding.

The monitoring and analysis of the geomagnetic field is also important for practical applications, some of which have been in use for centuries. The magnetic field can be used for orientation, navigation, and mineral and oil exploration. Of more recent interest, the infrastructure and activities of our modern, technologically-based society can be adversely affected by rapid magnetic-field variations during magnetic storms, when radio communication can be difficult or impossible, global positioning systems can be degraded, satellite electronics can be damaged, satellite drag can be enhanced, astronaut and high-altitude pilots can be subjected to increased levels of radiation, pipeline corrosion can be enhanced, and electric power grids can experience voltage surges causing blackouts. The aurorae seen prominently at higher latitudes are beautiful visual manifestations of storm-time geomagnetic activity. Given the plurality of geomagnetic-related effects and applications, it is not surprising that the communities concerned with geomagnetic data are numerous and diverse.



HISTORY OF THE PROGRAM

The U.S. Geological Survey's (USGS) Geomagnetism Program has, for many years now, monitored the Earth's magnetic field through a network of observatories and conducted scientific analysis on magnetic data. The Program traces its origins to the Reorganization Act of 1843 in which Congress authorized the creation of a coastal survey agency, as part of the Treasury Department, that was responsible for geomagnetic surveys among other things. The 19th century saw the establishment of relatively short-lived magnetic stations, and the production of declination maps for the United States and Territories. With the purchase of Alaska, coastal surveys became an increasingly higher priority, and in 1889 the Coast and Geodetic Survey, with a Division of Terrestrial Magnetism, was established. The first essentially permanent geomagnetic observatories were established under the Division's leadership of Drs. Louis A. Bauer and John A. Fleming: the Cheltenham, Maryland, observatory was established in 1900, subsequently moved to the Fredericksburg, Virginia, site in 1956; the Sitka, Alaska observatory was established in 1901 and that of Honolulu, Hawaii in 1902. Soon after these observatories became operational, Program scientists observed that the Sitka and Honolulu magnetometers were also sensitive to local earthquakes, so seismometers were installed at the sites. In part, because of this co-location of instruments, the magnetic and seismological work in the Coast and Geodetic Survey were united in 1925 under the Division of Geomagnetism and Seismology. Over the years, the Geomagnetism Program has evolved in response to the needs of the country and in response to changes in the Nation's various Federal agencies. In 1903 the Coast and Geodetic Survey was transferred to the newly organized Department of Commerce (DOC), and in 1970 the Survey became part of the National Oceanic and Atmospheric Administration (NOAA). In 1973 the USGS of the Department of the Interior (DOI) assumed responsibility for the National Geomagnetism and Seismology Programs.

CURRENT SITUATION

Today, Geomagnetism is one of four USGS Geologic Discipline Programs, in addition to the Earthquake Hazards, Global Seismographic Network, and Landslide Hazards Programs, represented by the USGS Central Region Geologic Hazards Team in Golden, Colorado. Geomagnetism is a self-contained national program within the USGS, with facilities and personnel located in all three regions of the USGS. The Program has 10 full-time staff and an annual appropriation (FY05) of $2 million with additional reimbursable funding totaling approximately $0.3 million. The Program's 14 observatories are equipped with modern digital acquisition systems and are designed to produce long time-series of stable, one-minute-average magnetometer data having high accuracy and resolution. The Program collects, transports, and can disseminate these data in near-real time, and it also has significant data-processing and management capacities. The operational and developmental activities of the Geomagnetism Program are, in an abstract sense, similar to those of the Seismology Programs, which are also concerned with the treatment of time-series of data collected from remote sites. Because of similar operational philosophies, opportunities for sharing infrastructure and software, and common interests in time-series and statistical data-analysis methodologies, the Geomagnetism Program benefits from being situated within the Geologic Hazards Team. From a scientific standpoint, however, the Geomagnetism Program retains its own specialized niche within the Team and the USGS.

ACCOMPLISHMENTS AND ONGOING PROJECTS

Over the past 5 years, Geomagnetism Program staff have refocused their efforts on the operations concerned with the magnetic observatories and the data they produce. Through the hard work of the staff, a number of important objectives have been accomplished. Specifically, a new observatory, the Shumagin geomagnetic observatory in the Aleutian Islands, has been opened. Because of its remote location, the installation of Shumagin was time-consuming and logistically challenging. This observatory fills a gap in the global geographic distribution of observatories; it is now producing very good data, and in the coming years it will prove to be a valuable asset for the Program by improving the capacity for magnetic-field monitoring. Shumagin uses the new personal-computer, Internet-based, data-acquisition and transportation system, which is now being deployed at the other observatories as well. This new acquisition-transportation system delivers data in real time, and it is easier to operate and modify than the older systems. Once the data are received in Golden, a new in-house developed, interactive, graphical software package is used to process the data. The Program has a new Web site, providing more information to the public about operations, data, and services, along with educational and scientific material. The Program now has a formal memorandum of agreement (MOA) with the U.S. Air Force (USAF) concerning the near-real-time delivery of magnetometer data, and several MOAs have been put into place concerning operations and different legal issues at the individual observatories. Operational and developmental accomplishments are documented in published papers and abstracts given in Appendices A and B.

With respect to ongoing projects, staff are developing a number of important new operational components that will improve the Program's data service. For example, the new data-acquisition system is being modified to produce one-second average data, and when the system is made operational the Program's data will be of significantly higher temporal resolution than the current one-minute data. In order to improve the fidelity of acquisition systems, a coil-calibration facility is being installed at the Boulder observatory site, and when this is completed, staff will be able to carefully calibrate their magnetometers. An Oracle database is being developed that will help staff manage the Program's voluminous data, serve as an interface between the data-transportation and processing systems, and facilitate the dissemination of data through the Program's Web site and other specialized delivery tools. All of these developments will improve the quality of service to the scientific community and, ultimately, expand the Program's customer base.

Research is being pursued on magnetometer-calibration theory, data-processing theory, and the analysis of magnetic observatory data. The calibration and processing projects are directly related to the Program's ongoing development of a coil-calibration system and the need for enhanced processing of observatory data, both of which are needed to improve the data quality in order to satisfy the ever-more-stringent needs of the user community. The data-analysis project, sometimes broadly described as a geomagnetic-hazard map, consists of a statistical analysis of the spatial and temporal characteristics of rapid magnetic-field variations, particularly those occurring during magnetic storms. Some of this analysis is concentrated on indices - generic measures of magnetic-field activity widely used within the scientific community - while other parts of the analysis are concentrated on variation in the magnetic-field vector itself. Since the data-analysis project is of fundamental relevance to a broad range of subjects within geomagnetism, both applied and academic, the project will help Program staff to interface with a broad base of existing and potential customers. Research results are documented in Appendices A and B.

CHALLENGES AND OPPORTUNITIES

Geomagnetism is relevant to the broadest definition of the Earth sciences, one that encompasses the solid Earth, the oceans, the atmosphere, and the space environment in which the Earth resides. As a result, the Geomagnetism Program has opportunities to collaborate with scientists and programs that come from several different Federal and State agencies and a wide variety of private organizations and academic institutions to conduct work pertaining to the entire dimension of the planet and of increasing importance to our modern, technologically based society. The science of all of these different domains is rapidly progressing and constantly changing. In order to continue to serve the scientific community, then, the Program must remain abreast of developments in magnetometers, observatory operations, and data transportation, processing, and management. Scientific research and related product development must also be supported. This will enhance the interface with the communities using the Program's data, ensure that observatory operation and data production standards are both necessary and sufficient, and will improve the profile of the Program.

In order to take advantage of opportunities, and to succeed at attaining important internal objectives, the Program must be adequately supported by the bureaucratic infrastructure of the USGS, and it must be provided with sufficient staffing and funding. The regional and matrix-type structure of the USGS presents the Program with a number of challenges, because it is a national program with staff and facilities in all USGS regions. The Program needs to hire a few more staff, particularly since several are now eligible for retirement. Finally, financial resources are limited, but the Program has significant potential, and a modest increase in funding would dramatically improve the operations and enable the Program to conduct significantly more research and product development.

II. PROGRAM MISSION

The mission of the USGS Geomagnetism Program is to monitor the Earth's magnetic field through an array of ground-based magnetic observatories; to provide high temporal resolution records of magnetic field variations covering long timescales; to disseminate magnetic data to various governmental, academic, and private institutions; and to conduct research into the nature of geomagnetic variations for purposes of scientific understanding and hazard mitigation. The Program is an integrated part of a network of plans and initiatives that exist within the USGS, the Department of the Interior (DOI), other Federal Government departments, academia, private industry, and the international scientific community and its organizations.

GOVERNMENT PROGRAMS, PLANS, INITIATIVES

Within the United States, the Geomagnetism Program is an integral part of the Federal Government's National Space-Weather Program (Tascione, and others, 1995). Ground-based observatories provide an effective and relatively economical means of monitoring the near-Earth space environment, and Geomagnetism Program staff coordinate their data service with space-weather programs supported by NOAA, the Department of Defense (DOD), primarily through the Air Force, the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and other governmental institutions. The Geomagnetism Program contributes the largest part of the ground-based monitoring effort associated with the National Geomagnetic Initiative called for by the National Research Council of the National Academies of Science (Brett, and others, 1993). The Geomagnetism Program's mission is consistent with the DOI's *Strategic Plan* (Norton, 2003) for serving the public by advancing knowledge through scientific leadership and informing decisions through the application of science in order to safeguard lives, property, and assets. Within the USGS, the Geomagnetism Program's mission is consistent with the objective of providing the Nation with reliable, unbiased information to describe and understand the Earth and to minimize loss of life and property from natural disasters. The Geomagnetism Program's mission is consistent with the USGS *Strategic Plan* (Groat, and others, 2000) for describing, documenting, and understanding natural hazards and their risks, and since geomagnetic activity can adversely affect modern, technological infrastructure, the mission of the Geomagnetism Program is consistent with the Bureau's recent programmatic emphasis on urban hazards. Finally, within the Geologic Discipline of the USGS, the Geomagnetism Program's mission is consistent with the *Science Strategy* (Bohlen, and others, 1998) and its stated goals of conducting geologic hazard assessments for mitigation planning and for providing short-term prediction of geologic disasters and rapidly characterizing their effects.

INTERNATIONAL PROGRAMS AND INITIATIVES

Internationally, the Geomagnetism Program staff work closely with foreign national geomagnetism programs under the auspices of the International Association of Geomagnetism and Aeronomy (IAGA), which itself is part of the larger International Union of Geodesy and Geophysics (IUGG). The Program's operations and research elements fall under IAGA's Division 5, Geomagnetic Observatories, Surveys and Analyses, but because of the diversity of applications associated with magnetic observatory data, all of IAGA's Divisions are of relevance to the Geomagnetism Program. The Program's operations are closely linked to Intermagnet, a consortium of national geomagnetism programs having the mission of supporting the worldwide monitoring of the Earth's magnetic field and the promotion of the usage of magnetic observatory data for practical applications and scientific research. The Program's research element applies to the American Geophysical Union (AGU) Sections of Geomagnetism and Paleomagnetism, and Space Physics, and the Focus Groups of Nonlinear Geophysics, and Structure of the Earth's Deep Interior (SEDI). On the very largest of governmental scales, the USGS is becoming more involved with the Group on Earth Observations System of Systems (GEOSS), a high-level international initiative concerned with advancing understanding of the Earth system across all physical and biological dimensions. The Geomagnetism Program's involvement in GEOSS would also come through Intermagnet if it chooses to become a participating organization in GEOSS. Finally, with respect to notable historical international initiatives, several of the Program's observatories were established in the 1950s as part of the International Geophysical Year (IGY) campaign, and now, some 50 years later, the Program has the opportunity to be involved with the International Polar Year (IPY), the International Heliophysical Year (IHY), and the Electronic Geophysical Year (eGY).

III. EXPERTISE AND CAPABILITIES

The Geomagnetism Program's 10 full-time employees are its most important asset, and their hard work and contribution are deserving of recognition and support from the Leadership of the Team and the USGS. Addressing staffing needs is the Program's highest priority. Most of the Program's staff are in operations and development with a small research element. The tasks of all Program staff are mutually interdependent, and work must be coordinated and carefully planned so that the Program's mission is a success.

CURRENT STAFFING SITUATION

Operations and Development

The responsibilities of the Program's operational and developmental staff can be roughly divided into three separate tasks: 1. Observatory operations: seven Program staff members maintain the existing 14 observatories, work to upgrade the data-acquisition systems at each observatory, secure agreements with collaborating parties at each observatory, and expand the observatory network when it is needed. Three of these staff are stationed in Golden, two are stationed in Alaska, and one each in Guam and Fredericksburg. Personnel within this task also provide magnetometer calibration services and airport compass-rose surveys. 2. Data acquisition and transportation: one Golden-based Program staff member is responsible for developing the acquisition and data transportation system used by the Program. The same individual is responsible for much of the operational software development undertaken by the Program. 3. Data processing and management: one Golden-based Program staff member is responsible for processing and managing the magnetometer data once they are received from the observatories. Related responsibilities of these staff include data archiving and data dissemination.

Scientific Research and Product Development

One permanent Program staff member, the Group Leader, conducts research on the Earth's magnetic field. In the past, most of this research has been with the internal part of the geomagnetic field but has gradually expanded to include the external field as well. The Program has recently benefited from the presence of a USGS Mendenhall postdoctoral scientist, who is working with the Group Leader on the statistical analysis of observatory data, a project often described as a geomagnetic hazards map. The Group Leader is working on a related project of mapping the magnetospheric equatorial ring current in space and time, a project that is fundamental to an understanding of storm-time, magnetic-field activity.

FUTURE STAFFING NEEDS

Operations and Development

There is a great deal of technical expertise among the Geomagnetism Program's staff, but due to increasingly stringent demands and expectations being placed on the Program's data service, the overall technical-skill level of the Program's operational and developmental staff mix needs to be continuously enhanced. With respect to specific staffing requirements, additional experience and abilities in electronics and computer science are a critical need. Several of the Program's staff are currently eligible for retirement, and, overall, the demographics of the staff need to be factored into future plans in order to ensure operational continuity. Moreover, two of the Program's observatories are currently manned by full-time staff members, while the remaining observatory operations are supported by part-time contractors. The Program will benefit from a continued transition to more automated operations, but hands-on involvement by experienced operational staff members is essential for maintaining delicate magnetometer systems. Indeed, in other similar national geomagnetism programs the relative numbers of technical staff devoted to observatory operations exceed those of the USGS. In order for the Geomagnetism Program to maintain its existing observatory network and to make improvements and advancements required to keep pace with changing demands, the Program needs to hire at least one full-time, formally trained engineer.

Scientific Research and Product Development

In order to make full use of the substantial and ongoing investment in observatory infrastructure and operational personnel, the Program needs to expand its research activities. An additional Geomagnetism Program research staff member would enable the Program to efficiently exploit the information content of the data that it is already producing and which are currently being successfully used by other outside agencies. The additional research activities include conducting basic research into the broad range of subjects within geomagnetism, developing new and useful products derived from the Program's own data, and interfacing with the scientific community. In addition, internal use of observatory data will help with operations, by providing feedback to the operational staff as to the characteristics and qualities of the data being produced and, more generally, of their necessity and sufficiency. Specifically, the Program needs to hire one full-time researcher and also needs to have ongoing support for an occasional postdoctoral fellow.

IV. FACILITIES AND OPERATIONS

The primary operational and developmental responsibilities of the USGS Geomagnetism Program are concerned with the Program's magnetic observatories and the data that they produce. The observatories support modern digital acquisition systems designed to produce long time-series of stable magnetometer data having high accuracy and resolution. The Program collects, transports, and can disseminate these data in near-real time, and it also has significant data-processing and management capacities. By necessity, the observatory network and everything associated with handling the data are technologically elaborate, consisting of many finely tuned components, each of which needs to be maintained and operated in careful synchronization. It is important that the operations be streamlined when possible, but it is also important that the operations be modernized and even expanded so the data service provided by the Geomagnetism Program is enhanced.

OBSERVATORY NETWORK

The Geomagnetism Program currently operates 14 magnetic observatories, a network that stretches from Guam in the western Pacific, to San Juan in the eastern Caribbean, to Barrow on the north shore of Alaska (see cover graphic). There are eight observatories in the lower continental United States (and Puerto Rico), four in Alaska, and two observatories in the Pacific. The geographic distribution of the Program's observatories has been determined by the need to monitor the geomagnetic field on a global scale, primarily for purposes of space-weather diagnosis and main field modeling and mapping, as well as the practical issues of availability of land, communication and operational logistics, and the locations of observatories operated by other foreign-national programs.

Geomagnetism Program Observatories.

Observatory	Code	Latitude	Longitude	Established
Barrow AK	BRW	71.32	203.38	1949
Boulder CO	BOU	40.14	254.76	1961
College AK	CMO	64.87	212.14	1948
Del Rio TX	DLR	29.49	259.08	1982
Fredericksburg VA	FRD	38.20	282.63	1956
Fresno CA	FRN	37.09	240.28	1980
Guam	GUA	13.59	144.87	1957
Honolulu HI	HON	21.32	202.00	1902
Newport WA	NEW	48.27	242.88	1966
San Juan PR	SJG	18.11	193.85	1903
Shumagin AK	SHU	55.35	199.54	2003
Sitka AK	SIT	57.06	224.67	1901
Stennis MS	BSL	30.35	270.37	1986
Tucson AZ	TUC	32.17	249.27	1910

OBSERVATORY INFRASTRUCTURE

Most Program observatories consist of a set of temperature-controlled buildings designed to protect the magnetometer systems and minimize their baseline drift. Buildings housing magnetometer are made of nonmagnetic materials, and all buildings are situated on a plot of land of sufficient size, 30 acres or more, to help insulate the operations from outside magnetic interference. The basic sensor package operated at each observatory consists of a triaxial fluxgate magnetometer, which gathers variational vectorial data, a proton magnetometer, which measures the absolute intensity of the magnetic field, and a theodolite, on whose telescope is mounted a small fluxgate. To preserve orientation, each sensor is mounted on a stable pier anchored deep into the ground. Acquisition systems are supported by electronic modules and computer systems. Electric power is often an issue at the observatories; their relatively remote locations means that power is not always stable and so uninterruptible power systems are installed, and some of the observatories are outfitted with backup generators. Because of the sensitivity of the magnetometers, artificial ground currents are a concern and care must also be taken in establishing electrical grounds. Finally, each observatory is served by telephone and satellite communication links; most of the observatories now also have Internet service, with Internet installation a continuing effort at the remaining sites.

Panoramic view of the San Juan, Puerto Rico, observatory site.

DATA ACQUISITION

The fluxgate and proton magnetometers are operated continuously in time, with electronic data-acquisition systems producing digitally filtered, one-minute average data. Each observatory is visited by a Program employee or contractor once a week so that absolute measurements can be made using a theodolite; these data are also used for correction, during data processing, of the baselines of the one-minute fluxgate data. The Program's currently operational data-acquisition system, or data-collection platform (DCP), has served the Program well for some 15 years or so, but it is now being replaced by a new more flexible, personal-computer-based, data-collection platform (PCDCP). This new acquisition system is being modified to produce one-second data, a substantial increase in temporal resolution that requires the surmounting of a number of difficult obstacles concerning accuracy, resolution, and timing. All of these systems rely upon a good set of magnetic sensors. Unfortunately, the fluxgate-sensor response function is insufficiently linear to produce data meeting some customers” stringent needs. It is for the purpose of measuring sensor-response nonlinearity that Program staff have begun to develop a coil-calibration facility at the Boulder observatory site. When this is made operational, Program staff will be able to calibrate their magnetometers so that the data can be acquired with improved fidelity.

DATA TRANSPORTATION

One-minute data are transmitted in near-real time to Program headquarters in Golden, Colorado, by a series of satellite linkages. This transmission system has served the Program well for many years now, but it is relatively delicate, being prone to interference from other users, and the fact that the data must be transmitted regularly within certain windows of time means that the data are not received in real time (satellite transmissions are delayed by 12 to 24 minutes). Many of these problems are being eliminated with the Program’s new Internet-based, data-transportation system (MagWorm), a modification of a highly successful system developed by USGS seismologists (EarthWorm). This new system allows for two-way communication between each observatory and Golden, it makes data-delivery essentially instantaneous, and it is extremely robust, allowing for real-time system reconfiguration and even brief interruption without data loss. The combination of the new data-acquisition system’s diagnostics and real-time two-way communication with the observatory will make routine operations and remote troubleshooting much more efficient

DATA PROCESSING

Fluxgate data received in Golden in near-real time are variational or “preliminary” meaning that they are arbitrary to within a baseline offset, which itself may have a slow drift. This raw data also has occasional spikes and step offsets. Absolute or “definitive” one-minute time-series are obtained through data processing, using specialized, in-house-developed software (MagProc). The data-processing software was designed using modern programming techniques and principles, and it provides dynamic, interactive graphical displays for the user, thus making the production of the Program’s final definitive data much more efficient. Preliminary variometer data are cleaned, and adjustments are made for fluxgate baseline drift by using the absolute measurements made with the proton magnetometer and theodolite. Fully calibrated, absolute time-series of magnetometer data is one of the flagship products of an observatory program. Unfortunately, because of the labor involved, absolute data cannot be produced in real time; but because of their high quality, absolute observatory time-series of data set the standard for ground-based magnetometer measurement.

DATA MANAGEMENT

An Oracle database is being developed to improve the Program’s data management capabilities, accommodating both the ongoing production of one-minute and the expected influx of one-second data. When complete, the database will be fully integrated with the data-transportation systems and processing software, as well as the Program’s Web site. Program staff are working to archive old Program data that were collected prior to routine data storage on CDs. Hourly mean data from Program observatories have been produced for over a century; minute data were first produced with the introduction of digital data-acquisition systems in 1975.

Current Observatory 1-Minute Data Standards.	
Magnetic resolution	0.1 nanotesla (nT)
Temporal resolution	1 minute
Absolute time-series accuracy	5 nT
Variational time-series availability	12 to 24 minutes after acquisition
Absolute time-series availability	Within one year of acquisition, but often sooner

DATA DISSEMINATION

Program data are disseminated in two forms: variational data in near-real time, and definitive data, after processing and within one year of initial acquisition. Near-real-time data are disseminated to customers via direct links, automatic email, ftp, and increasingly over the Internet through the Program's Web site. Definitive data are disseminated through CDs produced in cooperation with Intermagnet, which also helps promote the dissemination of magnetometer data generated by national programs in other countries. Program data are also available from the Intermagnet Web site and from the World Data Centers (described below). Program staff are working to improve the capacity for inspection and retrieval of both old and new data via the Program's Web site.

FACILITIES MANAGEMENT

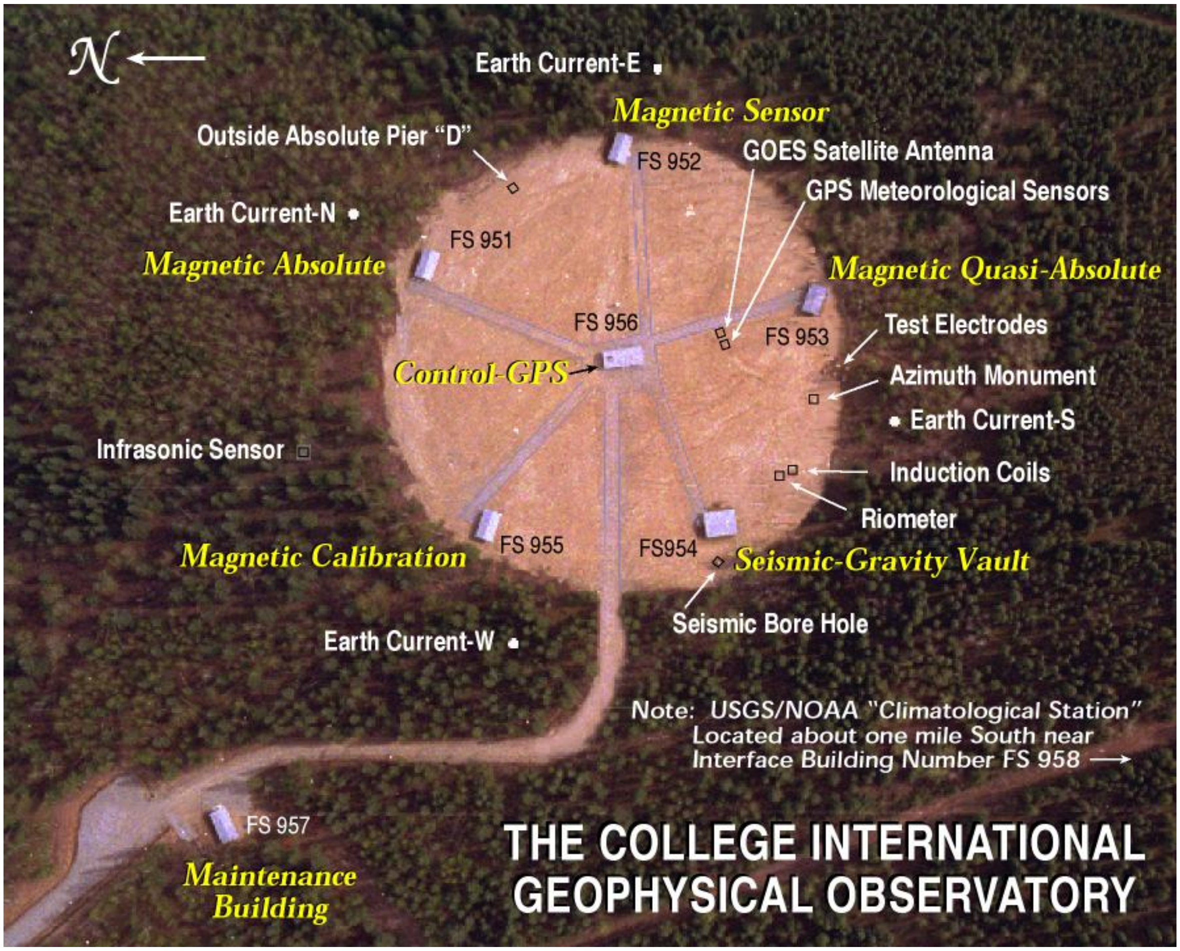
Oversight of the observatory facilities rests with Golden-based personnel from the Program and from the Central Region Geologic Hazards Team. This approach works well because of the day-to-day proximity of the personnel involved and the resulting ease of communication. But on a broader scale, the USGS also has a regionalized structure for facilities support, with Eastern, Central, Western, and Alaskan parts, and a matrix style of management, meaning that the supervisory structure is not parallel with the flow of money. The regionalization and matrix structures present a number of challenges to the Geomagnetism Program. One is simply the number of people that are involved. With facilities in all of the regions, Program staff must explain the purpose of facilities requests to each region separately, thereby increasing that effort by an amount approximately equal to the number of regions. Another challenge is the lack of standard operating procedures among the regions. So, for example, although some facility maintenance funds are available through the three different regions, the process of securing and spending regional funds, and even knowing how much funding is available, varies from region to region. Finally, the fact that some facilities are supported by regional staff that are relatively far removed from Program headquarters means that communication is inefficient. All of this adds significant complexity to the day-to-day responsibilities of Program staff.

V. PARTNERSHIPS

The Geomagnetism Program has many operational partnerships, covering a wide range of issues, including the usage of property, the operation of Program observatories, and the support of allied geophysical operation. Terms of the partnerships are formally defined through memoranda of agreements (MOAs). Establishing and refining these written documents have been priorities for the Program's staff over the past 5 years.

LAND AND PROPERTY

The only Program observatories located on USGS property are Fredericksburg and San Juan. The Guam observatory is on property owned by the U.S. Air Force. The Sitka and Barrow observatories are on property owned by the Bureau of Land Management (BLM). The Boulder observatory is on property owned by the Department of Commerce's National Telecommunications and Information Agency (NTIA). The Stennis observatory is on the grounds of NASA's Stennis Space Center. The Del Rio and Tucson observatories are on National Park Service (NPS) property. The Fresno and Newport observatories are on U.S. Department of Agriculture (USDA) Forest Service (USFS) property. The Honolulu observatory is on NOAA property. The College observatory is on University of Alaska Fairbanks (UAF) property, and the Shumagin observatory is on property owned by the Shumagin Native Corporation (SNC).



Aerial view of the University of Alaska's College International Geophysical Observatory site, including the USGS College Geomagnetic Observatory.

OBSERVATORY OPERATIONS

Other cooperative agreements are concerned with the conduct on, and operational support of, the observatories. Specifically, the Barrow and Honolulu observatories are operated with the assistance of NOAA, the Stennis observatory is operated with the assistance of NASA, and the College observatory is operated with the assistance of UAF. The Department of Energy (DOE) provides some communication link support at Barrow. Program staff at the Guam observatory assist the NOAA tsunami warning program. The Geophysical Institute of the University of Alaska has assisted the Program with the construction of a coil-calibration facility currently being developed on the Boulder observatory site.

ALLIED OPERATIONAL SUPPORT

In addition to geomagnetic operations, some of the observatory sites support other types of geophysical operations. Perhaps most prominently, the College observatory is situated on the College International Geophysical Observatory (CIGO), which was originally designed by USGS Geomagnetism Program staff and which supports seismic, global positioning system (GPS), and infrasound operations, in addition to several different types of geomagnetism projects and operations. The CIGO site and the Guam and San Juan observatories support bore-hole seismometers of the Global Seismographic Network (GSN). The Fredericksburg and Newport observatories support seismometers for the USGS Advanced National Seismic System (ANSS). The Fredericksburg observatory site is used extensively by NOAA’s National Geodetic Survey. The Newport observatory supports an infrasound facility operated by the University of California under contract from the DOD’s Defense Threat Reduction Agency and according to the terms of the Nuclear Test Ban Treaty. Finally, the USGS Biological Resources Discipline (BRD) uses some of the buildings on the Guam observatory site. Again, these multifaceted projects are defined by MOAs established with the USGS and its Geomagnetism Program.

Summary of Operational Partnership Agencies at Each Observatory.

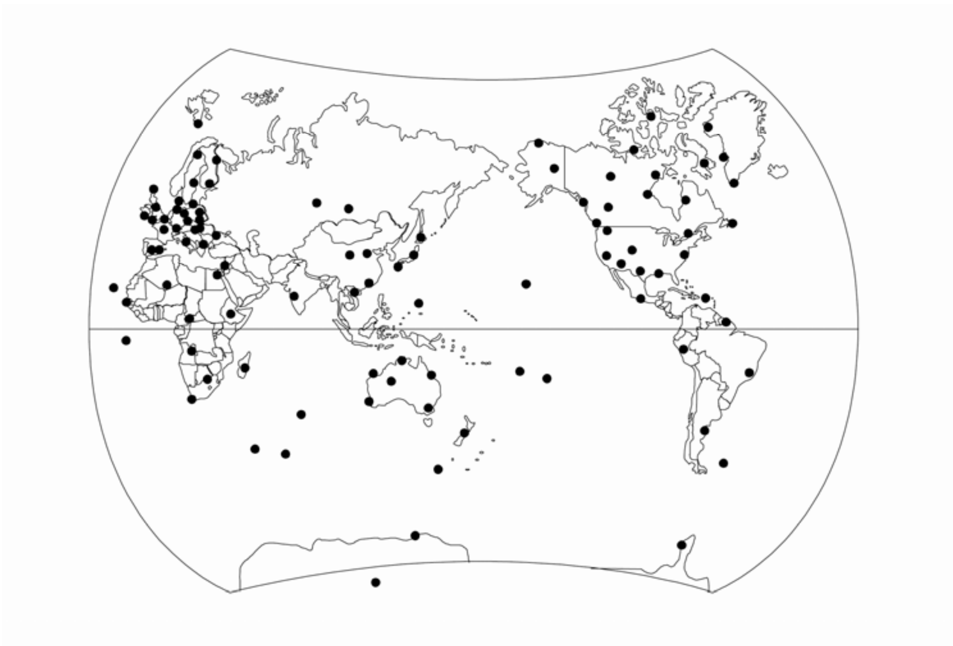
Observatory	USGS Partners			Other Governmental Partners								Other	
	ANSS	GSN	BRD	DOI BLM	DOI NPS	USDA USFS	DOC NOAA	DOC NTIA	NASA	DOD	DOE	UAF	SNC
BRW				X			X				X		
BOU							X	X				X	
CMO		X										X	
DLR					X								
FRD	X						X						
FRN						X							
GUA		X	X				X			X			
HON							X						
NEW	X					X				X			
SJG		X											
SHU													X
SIT				X			X						
BSL									X				
TUC					X								

VI. RELATED PROGRAMS

GROUND-BASED MAGNETOMETERS

Observatory Programs

There are about 150 magnetic observatories operated world wide, producing data with various temporal cadences, delivery rates, and wide-ranging absolute quality. Approximately 100 of these observatories are part of Intermagnet and, therefore, meet common minimum operational standards. Most observatories are operated by governmental agencies and are situated on corresponding national territories and colonies. For example, the British operate observatories on Ascension Island and in the Falklands, the French operate observatories in the southern Indian Ocean, and the Danes operate observatories in Greenland. The most notable exceptions to this rule are the observatories operated in Antarctica, which is not part of any nation. The USGS Geomagnetism Program, with its array of 14 observatories, makes an important contribution to the international observatory community, and the Program has an important leadership role within Intermagnet. With respect to outreach and support, the French, British, Belgians, and Japanese have particularly active programs for enhancing observatory operations in developing nations.



Map of the geographic distribution of Intermagnet observatories as of 2004.

Variational Programs

In addition to the world wide observatory network, there are a number of important variational magnetometer stations and arrays. Generally speaking, variational stations are not operated according to the same strict standards as observatories; they generally only support fluxgate or induction magnetometers, and there is little or no compensation for the drifting baselines of those instruments. The data are appropriately described as variational in that they are useful for studying the time-dependent variation of the magnetic field over timescales less than a day or so. Variation stations are often operated as parts of specific campaigns; they are not usually operated in the "permanent" sense of an observatory. Variation stations do not, therefore, contribute very much to the long-term operational efforts of government agencies; magnetic indices rely on observatories, not variation stations. Examples of currently operated variational arrays include the Canopus array in Canada, which is funded by the Canadian Space Agency; the Maccs array, also in Canada, which is operated by the University of Alberta, Boston University, and Augsburg College; and the Measure array in the Eastern United States, operated by UCLA. There also are arrays in northern Alaska, Europe, Greenland, and Antarctica, and along the 210 east meridian, and elsewhere.

SATELLITE PROGRAMS

Low-Altitude Satellite Missions

There are many ongoing and proposed low-altitude satellite programs supporting space-borne magnetometers operated by NASA and foreign space programs (Purucker, and others, 2002). Some of these programs are low-altitude: Oersted, Champ, and Swarm of the European Space Agency (ESA), and Sac-C of NASA and the Argentine Commission on Space Activities. Since satellites and observatories are situated on opposite sides of the ionosphere, together they provide complementary data for studying this important source region for geomagnetic field variations (Yamashita and Iyemori, 2002; Ritter, and others, 2004). The low-altitude satellite programs are part of the International Decade of Geopotential-Field Research (IAGA Resolution No. 1, 1997).

High-Altitude Satellite Missions

Other satellite programs are high-altitude: GOES and Themis of NASA, Geotail of NASA and the Japanese Institute of Space and Astronautical Science (ISAS), Cluster of ESA, and Double Star of the Chinese Space Agency. These satellites produce data useful for monitoring and modeling the magnetosphere. Oftentimes the analyses are event driven, with concentrated research effort applied to specific magnetic storms (Kokubun, 1997; Huang, and others, 2003), where the ground-based observatories are used either for magnetic index calculation or, more directly, for their detailed magnetographic data. Although satellites provide in-situ data directly from the magnetosphere itself and are therefore vital for studies of magnetic storms, the global distribution of ground-based observatories actually provides better geographic coverage of such events.

DATA CENTERS

Data from most of the world's magnetic observatories, including those of the USGS Geomagnetism Program, are available at the various World Data Centers (WDC), which are also responsible for preserving older photographic magnetograms: those collected prior to the current age of digital magnetometer data. NOAA's National Geophysical Data Center in Boulder, Colorado, is geographically the nearest to the Geomagnetism Program headquarters in Golden, but the Program's closest ongoing operational relationship is with the Copenhagen and Kyoto WDCs. Both Kyoto and Copenhagen have direct involvement with operating magnetic observatories, and both centers send representatives to the annual Intermagnet meetings, while the NGDC is not directly involved with observatory operation. Although users of observatory data can acquire them from the WDCs, it is worth recognizing that the WDCs are not necessarily the authoritative source for the data. In fact, the observatory data are not identical among the various center databases, and no WDC seems to have a complete set of observatory data. Some of these shortcomings are reflective of funding shortfalls of the centers' home institutions. Furthermore, the WDCs are not the source of real-time data. Intermagnet supports a Web site that is an authoritative source for data coming from its participating geomagnetism programs, and although Intermagnet represents the majority of modern observatory programs, its membership is not complete among the wider observatory community.

VII. CUSTOMERS

The Program has an important and influential base of customers who rely on its data service. It is essential that the needs of the user community be well served, but before discussing specific Program goals for enhancing this service, it is worthwhile summarizing the diversity of applications of observatory data. Following is a partial but representative listing of current, recent, and potential future usage of the Program's data, along with some representative references of the corresponding activities and (or) research. The Earth has one magnetic field – connecting all of the Earth's major physical domains, the core, mantle, crust, ocean, atmosphere (ionosphere), and magnetosphere. As a result, a magnetic signal measured at one geographic location and at any particular instance in time is a symptom of physical processes occurring everywhere else in the world. Because of this continuity, it is impossible to divide the subject of geomagnetism into tidy, self-contained categories; the various disciplines within geomagnetism are inextricably interconnected. However, for organization, some categorical divisions are necessary, and this summary is structured along fairly traditional lines.

APPLIED USAGE

Geomagnetic observatory data are used for a variety of practical applications, many of which rely on near-real-time delivery of the Geomagnetism Program's data.

NOAA's Real-Time Space-Weather Diagnostics

NOAA's Space Environment Center (SEC) and the U.S. Air Force Weather Agency (AFWA) use real-time Geomagnetism Program data for evaluation and forecasting of space-weather conditions (Joselyn, 1995; Singer, and others, 2001), a service that is important for both civilian and military activities concerned with hazard mitigation and even national security (Feynman and Gabriel, 2000). As an example, magnetic K and Kp indices (indices are summarized below) formed an important part of SEC and AFWA's response to the potentially deleterious affects caused by rapid field variations during the magnetic storm of October-November 2003 (Balch, and others, 2004). For many of these programs, continuous, real-time data delivery is essential. Other agencies involved with space weather diagnostics and who use USGS Geomagnetism Program data include the Kyoto World Data Center and National Institute of Information and Communications Technology in Japan, the International Service of Geomagnetic Indices in France, GeoForshungsZentrum in Germany, the Geological Survey of Canada, and the British Geological Survey.

U.S. Air Force

The Geomagnetism Program's relationship with the U.S. Air Force deserves some elaboration. Since 1988, the Program has been providing magnetometer data from a specified set of observatories to AFWA in near-real time and ensuring that the data stream is maintained with a specified degree of continuity. This service, for which AFWA compensates the Geomagnetism Program for costs, was formalized in 2004 with the signing of an MOA. Stations specifically cited in the agreement include Boulder, Fredericksburg, Fresno, Newport, and Sitka, along with three Canadian observatories and one British observatory. This service is considered to be “mission critical” to the Air Force, and there are opportunities for an enhancement of the relationship between the USGS and AFWA.

Induced Currents

Rapid variations in the Earth’s magnetic field can induce electric currents in the crust (Lanzerotti and Gregori, 1986; Pirjola, 2002). This can be a nuisance for the power-grid industry where the induced currents can find their way into power lines through ground connections. Since these currents are quasi-steady, they can short-circuit transformers designed for alternating current (Kappenman, and others, 1997; Molinski, and others, 2000). Induced currents are also a problem for the pipeline industries, interfering with electrical surveys of the pipelines and enhancing their corrosion (Boteler, 2000). Work in this subject is dominated by geomagnetism programs of nations at relatively high latitudes, such as Canada and Finland; but hazards associated with induced currents are important for the lower continental United States as well, and support for related research would be worthwhile.

The Great Geomagnetic Storm of March 1989

It is worthwhile to summarize some of the damaging effects of the great magnetic storm of March 1989. As measured by standard planetary-scale magnetic indices (Ap=279 and Kp=9+), this storm was the third largest since 1932, but the real-world effects were certainly the most significant experienced from a magnetic storm. These have been well documented (Allen, 1989) and are summarized here:

- The 21,000 megawatt Hydro-Quebec electric power-system collapsed, leaving 6 million people without power for 9 hours. Estimated economic impact: $300 million. Electric blackouts also affected large parts of Sweden. U.S. systems were affected, but not severely. If similar power failures had occurred in the North-Eastern United States, the economic impact has been estimated at $3 to 6 billion 1989 dollars (Barnes and Van Dyke, 1990).

- Satellite orbits were disturbed, including those of the NOAA polar-orbiting satellite and the USAF DMSP satellite. Seven commercial satellites had considerable problems maintaining operational attitude, requiring manual interventions to make more thruster adjustments in one day than is usually required in a year. A Japanese geostationary communications satellite had severe problems involving a failure of half of the dual redundant command circuitry onboard.

- U.S. Navy MARS (marine high-frequency-radio network) circuits on 10 to 20 megahertz were inoperable. U.S. Coast Guard reported numerous LORAN navigational problems and difficulty using hf-radio communications to alert users of the problems. There were numerous reports in Australia of hf-radio interruption. Geodetic surveys in the United States and geophysical surveys in Australia, Canada, and South Africa were impaired.

- Microchip production facilities went out of production in the North-Eastern United States.

- Magnetic declination swings of greater than 3 degrees were measured in the lower continental United States, thus affecting compass-based navigational systems.

Directional Drilling

Modern oil and gas drilling operations, in addition to drilling down into the ground, often also drill horizontally away from the drill rig. This reduces cost by enabling a single rig to access multiple reservoirs, and it can reduce the environmental impact by minimizing the surface footprint of the operations. In order to drill horizontally, however, it is necessary to know the down-hole orientation of the bit. This is most easily accomplished using a magnetometer loaded in an assembly that follows the drill bit. Measurement of the magnetic field vector and knowledge of the absolute declination for the site enable estimation of drill bit orientation (Thorogood and Knott, 1990; Lowdon and Chia, 2003). Since determination of the absolute declination is a basic product of geomagnetic observatories, and since declination can vary rapidly during magnetic storms, particularly at high latitudes, magnetic orientation for directional drilling represents a down-to-earth application of space weather monitoring to an issue of geological and economic importance.

MODELING AND MAPPING

The subject of modeling and mapping is of both applied and academic interest. In the past, the USGS Geomagnetism Program has been actively involved with modeling and mapping efforts, but because of reduced staffing levels, the Program is no longer directly involved. However, modeling and mapping programs continue to be important user groups of Geomagnetism Program observatory data.

Main Field

Researchers use a combination of satellite and ground-based magnetic observatory data, including those of the USGS Geomagnetism Program, to construct models of the large-scale part of the Earth's magnetic field. Two such models are the International Geomagnetic Reference Field (IGRF) and the World Magnetic Model (WMM) (Mandea, and others, 2000; Sabaka, and others, 2004; McLean, and others, 2005). Satellite and observatory data are important for these efforts: satellites provide global coverage, although only after integration over many orbits, observatories provide temporally continuous coverage, although only at specific geographic sites. These are used in a wide variety of applications, including geographic position finding and orientation and academic studies of the Earth's core, mantle, crust, and nearby space environment.

Aeromagnetic Surveys

Air-borne measurement of crustal magnetic-field anomalies is important for geological mapping. In order to compensate for temporal field variations that are always present, even on magnetically quiet days, air-borne surveys are performed simultaneously with ground-based monitoring. Because of the strict operational standards of the Program's observatories, the network can fulfill a definitive role in establishing baselines needed for such operations (for example, Hegmann, 2001). It has been proposed that a national or continental-scale aeromagnetic survey be performed so that large-scale geological formations can be discovered (Hildenbrand, and others, 2002), and the Geomagnetism Program's observatories would play an important role in such an effort.

Summary of USGS Stations Used in Index Calculations.

Index	Measures	USGS Observatories	Comment
Dst	Ring-current energy	HON, SJG	USGS supplies 2 of 4 sites
AE	Auroral electrojet	BRW, CMO	
K	Local magnetic activity	BOU, FRD, FRN, NEW, SIT	Under contract with USAF
Kp	Global magnetic activity	FRD, SIT	USGS supplies 2 of 11 sites
Kn	Northern magnetic activity	FRD, NEW, TUC	USGS supplies 3 of 13 sites

MAGNETIC INDICES

Like magnetic models and maps, magnetic indices are of such wide-ranging utility that it is difficult to characterize them as being of just operational or academic importance. The calculation of magnetic indices relies on ground-based observatory data. In a sense, they are like Richter-scale measurement of earthquakes: simple scalar measures of what are otherwise extremely complicated time-dependent phenomena (Mayaud, 1980; Rangarajan, 1989). Magnetic indices are generally of two types: range indices and absolute indices. Range indices measure the variation of the magnetic field, usually peak-to-peak, over a certain duration of time, typically 1 to 3 hours. Absolute indices measure the average value of the magnetic field, calculated over a duration of time and usually after a certain baseline has been subtracted. In either case, the accuracy of the indices depends on the quality of the data coming from their corresponding observatories. Institutions making routine calculation of geomagnetic indices include the Kyoto World Data Center in Japan, the International Service of Geomagnetic Indices in France, the GeoForshungsZentrum in Germany, and the U.S. Air Force.

ACADEMIC RESEARCH

Research in geomagnetism spans the entire frequency range of the field's temporal variation. Generally speaking, academics do not require real-time data delivery. This is beginning to change, however, since academic research is often motivated by applied needs. Indeed, academic research not only increases our understanding of the Earth's magnetic field, but it also provides new developments which might some day be used in operational settings. What follows is a brief review of academic research topics for which geomagnetic observatory data are needed. The topics are arranged roughly by "stratigraphy" starting from the Sun and ending with the Earth's core.

The Sun and Climate

The Sun is a dynamic star, emitting a solar wind of charged particles and undergoing intermittent fits of stormy activity, with the likelihood of their occurrence being modulated by an 11-year dynamo cycle. Since the solar wind and the heliomagnetic field drive activity in the magnetosphere, studies of magnetic observatory records, some of which span more than a century, can be used to study the Sun's long-term behavior. In fact, the observation that magnetic activity has been gradually increasing for over a century (Mayaud, 1972; Russell, 1975) is generally attributed to a long-term drift in solar activity (Stamper, and others, 1999). It is well known that changes in solar activity can have a measurable influence on Earth's climate, and, therefore, long-term magnetic observatory records are of possible relevance to studies of global climactic trends (Friis-Christensen and Svensmark, 1997). There have also been recent indications of a link between magnetic activity and anthropogenically induced global warming (Le Mouel, and others, 2005).

Magnetic Storm Current Systems

Many of the studies of magnetic storms focus on the equatorial ring current, caused by the drift of energized charged particles trapped in the near-Earth magnetosphere (McPherron, 1995; Lu, and others, 1998; Daglis and Kozyra, 2002). The energy of the storm-time magnetosphere can be estimated by measuring and modeling the ring current, using low-latitude ground-based magnetometer data (Vassiliadis, and others, 1999; O'Brien and McPherron, 2000). The basic measure of ring-current energy is the Dst index, which relies on four observatories, two of which are USGS Geomagnetism Program observatories. Other studies are concerned with the broader storm-time circuit of magnetospheric-ionospheric electric currents, including field-aligned and auroral-zone electrojet currents (Iyemori, 1990; Cade, and others, 1995; Clauer, and others, 2003). The basic measure of auroral-zone magnetic activity is the AE index, which relies on a high-latitude necklace of observatories, two of which are USGS observatories. The subject of storm-time current systems is integral both to academic studies of the magnetosphere and to real-time space weather diagnostics (described above).

Quiet-Time Ionosphere

As the Earth rotates under the Sun, ionospheric winds are generated through differential heating. These winds flow past the geomagnetic field, thereby generating electric currents which, in turn, generate their own magnetic fields. Through photoionization, solar irradiance also causes an enhancement of the ionospheric electrical conductivity on the day side. As a result, the magnetic field measured at an observatory exhibits a daily variation, the solar-quiet (Sq) variation most easily seen during nonstorm time periods (Campbell, 1989). There is less research being conducted in this field than there is in storm-time current systems. Nonetheless, in order to study the current systems of magnetic storms, it is important to be able to subtract an Sq baseline from storm-time magnetograms. This, in turn, requires that the observatories produce data with minimal instrumental drift.

Oceanic Induction

The motion of a conducting fluid through a magnetic field induces currents. Magnetometer data can, therefore, be used to measure ocean flow since ocean water is electrically conducting. NOAA's Atlantic Oceanographic and Meteorological Laboratory use a combination of voltage data collected from sub-ocean telecommunication cables and USGS Geomagnetism Program data to measure the oceanic fluid transport off the coast of Florida (Larsen, 1992). Induced electric currents are also driven by oceanic tides (Maus and Kuvshinov, 2004), and electric currents induced during magnetic storms can have an affect on observatory data (Olsen and Kuvshinov, 2004).

Crustal and Mantle Conductivity

Since time-dependent variation of the magnetic field can induce currents in the electrically conducting solid Earth, long time-series of absolute-baseline (definitive) data produced by magnetic observatories can be used to estimate crustal and mantle electrical conductivity. This helps to constrain the composition and tectonic structure of the Earth (Egbert and Booker, 1992, Constable, 1993, Weiss and Everett, 1998; Fujii and Schultz, 2002). The study of crustal and mantle conductivity is the primary motivation behind the proposed magnetotelluric component of the National Science Foundation's Earthscope initiative.

The Earth's Core

Absolute-baseline data produced by ground-based observatories, such as those operated by the USGS Geomagnetism Program, are useful for studies of the Earth's core, where fluid motion not only sustains the geodynamo but also causes the magnetic field to exhibit a slow secular variation (Jackson, and others, 2000). Because of core motion, the declination at the Earth's surface changes by about 0.2 degrees per year. Such a drift, when integrated over time, is sufficient to be easily measured, even with a simple compass. Analysis of the large-scale form of the magnetic field and its time dependence can be used to discover fluid motion in the core (Bloxham and Jackson, 1991), to constrain the angular-momentum budget of the Earth's differential rotation (Hide and Dickey, 1991), and to learn about the geodynamo (Roberts, 1992).

ADDITIONAL APPLICATIONS

Following are additional applications of ground-based magnetometer data, for which the USGS Geomagnetism Program's basic one-minute data product is of insufficient temporal resolution to make a substantial contribution. With the development of its one-second acquisition system, the Program will be expanding its data services to customers working in some of these subjects. However, for some needs, subsecond (~100 Hz) acquisition cadence is required, and this will require the installation of induction-coil type magnetometers. Generally speaking, the long-term, continuous collection of high-frequency data, such as that needed for the projects described below, represents an important developing frontier for the ground-based observatory community and for the USGS Geomagnetism Program in particular.

Magnetospheric Waves and Pulsations

The geomagnetic field can sustain waves or pulsations, manifest on magnetograms as quasi-sinusoidal oscillations having frequencies ranging from about 1 mHz to 10 Hz (Samson, 1991; Hughes, 1994). These waves are often associated with magnetic storms and recently have been used for monitoring the integrated plasma density of the magnetosphere (Green, and others, 1993). The Japanese are leading an effort to make operational the routine monitoring of pulsations for purposes of space-weather diagnostics (Nose, 1998). Ideally, this would rely upon one-second data collected at various stations around the globe, including, quite critically, across the continental United States, Hawaii, Guam, and Puerto Rico.

Lightning

The Earth's ionosphere resonates in response to electromagnetic impulses (Sentman, 1995). With an array of induction magnetometers widely distributed across the globe and measuring these so-called Schumann resonances, the location of individual lightning flashes can be found anywhere around the globe (Fullekrug, and others, 2000). Since the ionosphere resonates at about 8 Hz, these locations could, conceivably, be accomplished in near-real time. It also means that data acquisition systems must operate at about 100 Hz or better so that lightning locations could be determined with some useful accuracy. Should the USGS employ such a system, it would be of obvious interest to the meteorological and climatological communities, and collaboration with NOAA would be sensible.

Volcanoes and Earthquakes

It has been well established that large earthquakes and volcanic eruptions produce locally measurable electromagnetic effects, after and possibly during the event (for example, Johnston, 1997). Research on this subject is supported by the USGS Earthquake and Volcano Hazards Programs using arrays of data-acquisition systems located near the region of activity. There is little capacity within the Geomagnetism Program to be actively involved with these efforts since the Program's observatories are simply too wide-spread to provide anything more than data from a single site that might happen to be near a center of activity. On the other hand, on a global scale, the pressure pulse associated with earthquakes and volcanoes can establish gravity waves in the ionosphere that can be detected with magnetometers very far from the source region (Weaver, and others, 1969; Mueller and Johnston 1989), and this is a subject of interest to the USGS.

Nuclear Explosions

As with volcanic eruptions and earthquakes, the pressure pulse associated with atmospheric nuclear explosions sets up gravity waves in the ionosphere and these can be manifest on magnetograms (Burch and Green, 1963). Electromagnetic waves are also produced by nuclear explosions; these propagate around the Earth in the ionospheric wave guide at the speed of light. Magnetometer systems are not currently part of the suite of sensors covered by the Comprehensive Test Ban Treaty (CTBT), but they do have the potential to make a contribution. Should such a program be undertaken, it would be consistent with the seismic CTBT contribution already being made by the USGS.

Summary of Data Requirements of Various User Groups.			
Usage	Real-Time Need	Quality	Resolution needed
Space Weather Diagnostics	Yes	Variational	min and sec
Induced Currents	Yes	Variational	min and sec
Directional Drilling	Nearly real-time	Absolute	min
Main-field Mapping and Modeling	No	Absolute	month and year
Aeromagnetic Mapping and Modeling	Yes, during surveys	Variational	min and sec
Sun and Climate	No	Variational, Absolute	hour, day, month, year
Storm Current Systems	No	Variational, Absolute	min and sec
Ionosphere	No	Absolute	min
Ocean	No	Absolute	min and hour
Crust and Mantle	No	Absolute	sec, min, hour
Core	No	Absolute	month and year
Magnetospheric Pulsations	Yes, for operations	Variational	0.0001-100 Hz
Lightning	Yes, for operations	Variational	0.1-1,000 Hz
Nuclear Explosions	Yes, for operations	Variational	0.1-1,000 Hz

VIII. PRIORITIES AND PROGRESS

In order for the Geomagnetism Program to continue to serve the scientific community, it must adapt to changing needs. For the sake of efficiency and to ensure success, it is important that proposals for change be made in such a way that they represent a continuous and logical extension of the work already being performed by Program staff and that make use of the capacities that already exist within the Program. Therefore, insofar as providing data is the Program’s most important service, then additional developments would be built upon this basic foundation. If the scientific community needs better data, then operational standards should be raised. If the community needs better geographic coverage of magnetic field monitoring, then additional observatories should be opened. If the community needs higher-frequency sampling, then data-acquisition systems should be modified. In each case, however, the establishment of goals, and the planning needed to attain those goals, must be made with an awareness of what is appropriately done by the Program, what needs to be done for the scientific community, and what, realistically, can be done with the financial resources and the personnel skills that exist within the Program or can be obtained.

A similar philosophy applies to research and the development of related products. Given that the Program’s operations are centered on the observatories and their data, proposals for research should focus on the use of those very same observatory data. Such work would enhance the Program’s working relationship with existing customers, and it would help to demonstrate the utility of the data to potential users, thus helping to expand the Program’s customer base. In-house usage of the data would also provide immediate, internal feedback on the suitability of the data for the user community. In response, then, to the staff’s own awareness of the quality of the data, operational issues could be addressed immediately if they were found to be wanting. All of this must be tempered, however, with realistic expectations as to the scope of the proposed research.

Since the research element within the Geomagnetism Program is small, and the diversity of uses for observatory data is so extremely broad, research projects will, by necessity, be relatively specialized. That being said, they should be expected to be of high quality and have the effect of enhancing the profile of the Program.

PRIORITY LEVELS

Following is a set of priority levels, established in response to recommendations made by an external review panel. The three different priority levels are intended to summarize the importance for accomplishing a certain objective within the next 5 years given its role within the Geomagnetism Program's larger mission.

Priority Level A: These objectives are of fundamental importance to the existing primary mission of the Program. The objectives may be vital for an important customer or the community, or they may have been established by some well-defined mandate.

Priority Level B: These objectives are generally consistent with, but not necessarily of fundamental importance to, the Program's existing primary mission.

Priority Level C: Although these objectives might be of practical or scientific importance, they are not part of, nor are they particularly related to, the existing primary mission of the Program.

PROGRESS LEVELS

Following is a set of progress levels, established along the lines of those used for other USGS Program 5-year plans. The three different progress levels are intended to summarize the likelihood that a certain task will be accomplished within the next 5 years, given the difficulty of the task and the availability of funds and staff time.

Progress Level 1: At current level of support, these objectives can be achieved within 5 years, even if they require concerted effort. This progress level indicates that sufficient resources, funding, and worker time, are known to be available.

Progress Level 2: Notable progress is expected to be made on these objectives within 5 years, but progress will be slower than optimal due to constraints on, or uncertainties about, required resources.

Progress Level 3: Little or no progress is expected to be made within 5 years because of insufficient resources or because the objectives do not have short-term guarantees of success.

PROGRAM REVIEW

The entire Program, along with this 5-Year Plan, has been reviewed by an external committee during fiscal year 2005. The Program is regularly represented at annual Committee for Space Weather (CSW) meetings held in collaboration with other related Federal agencies and which functions as part of the interagency National Space Weather Program. The Geomagnetism Program performs an important data-delivery service to the U.S. Air Force Weather Agency. This service is reviewed annually according to terms of a Memorandum of Agreement between the AFWA and the USGS. Within the international scientific community, the Program's operational standards and developments are reviewed, in conjunction with those of other national geomagnetism programs, through Intermagnet. Program magnetometer data are regularly reviewed by external Intermagnet associates for quality and consistency. Workshops and meetings organized by IAGA help ensure that Program operational standards are maintained at a high level, consistent with those of other national geomagnetism programs.

PERFORMANCE MEASURES, GOALS, AND TARGETS

The Geomagnetism Program contributes to the DOI Strategic Goal of Serving Communities, the USGS Hazards Mission Goal to "Provide science ... focusing efforts to predict and monitor hazardous events in near-real time and to conduct risk assessments to mitigate loss." Under the Government Performance Results Act of 1993, the Geomagnetism Program has been tracked and reported under the "Number of formal workshops or training provided to customers" measure by USGS. In 2003; the Geomagnetism Program was reviewed by the White House Office of Management and Budget (OMB), together with the other USGS geologic hazards programs (Earthquake Hazards, Volcano Hazards, Landslide Hazards, and Global Seismographic Network), using the Performance Assessment and Management Tool (PART). The programs were rated by OMB as "Moderately Effective." At the same time, new PART performance measures were developed for these programs, which are currently being tracked and reported on by USGS, including an Efficiency Measure for both Geomagnetism and Global Seismographic Network.

Summary of End Outcome Measures Intermediate or PART Measures/Part Efficiency or Other Outcome.							
Fiscal Year	2005 Plan	2005 Actual	Change from 2005	2006 Enacted	Change from 2005	2007 Request	Change from 2006
Workshops or training sessions	1	2	+1	1	-1	0	-1
Data processing and notification costs (thousand of dollars per gigabyte)	0.99	0.79	+0.63	1.42	+0.63	1.33	-0.09

IX. OPERATIONS AND RELATED DEVELOPMENT

The USGS Geomagnetism Program will acquire, transport, process, manage, and disseminate geomagnetic data collected in the United States and its territories, and it will work cooperatively with related programs in performing such tasks in order to support hazard assessment, risk reduction, scientific research, and public education.

Since magnetometer data are the Program's most fundamental and useful product, the data-acquisition and data-treatment infrastructure must be maintained and enhanced so that the Program's existing customer base is well served and new customers added.

OBSERVATORY NETWORK

South Pole observatory

Install and cooperate on the operation of an absolute magnetic observatory at the South Pole.

Priority 𝔹: An observatory has been operated at the South Pole in the past, and the last absolute measurements were made in 1971. A South Pole observatory would, because of its remote location, be of high profile and is consistent with the existing primary mission of the Geomagnetism

Program. It is reasonable to assume that, should a South Pole observatory be installed, the data it produced would be widely used within the scientific community.

Progress 𝟚: The South Pole currently has a number of variometers, and their data could be used, together with periodic absolute measurements (not made at the moment), to produce definitive, absolute-quality time-series. The highly qualified workers at the site could be easily trained to make the absolute measurements. Collaboration would make accomplishing this objective easier. One current Geomagnetism Program staff member has experience working at the Byrd magnetic observatory, and the South Pole supports a Global Seismographic Network (GSN) station, so it is regularly visited by a Central Region Geologic Hazards Team staff member or contractor. Funding for the project could come from the NSF, possibly as a result of USGS involvement with the International Polar Year (IPY). There have been some discussions on the matter with potential collaborators, but a formal proposal has not yet been submitted.

Additional Alaskan observatories

Install and cooperate on the operation of additional absolute magnetic observatories on the North Slope of Alaska.

Priority 𝔹: This proposal is of obvious political complexity. Insofar as drilling horizontally allows multiple reservoirs to be accessed from a single rig, support for directional drilling programs can be considered to be a practical means of minimizing the negative impact on what is a sensitive natural environment. This project is consistent with the existing primary mission of the Program. It is reasonable to assume that, because of widespread interest in magnetic activity at high latitudes, the data would be widely used within the scientific community.

Progress 𝟚: Geomagnetism Program staff have significant experience working in Alaska: four Program observatories exist in Alaska, and two full-time staff are normally stationed in Fairbanks, thus facilitating work in the region. The Program also has a close working relationship with the Geophysical Institute of the University of Alaska Fairbanks, and some upgrade of their variometer station at Kaktovik would be a logical step toward reaching this objective. If a decision is made to commence with this project, then a Cooperative Research and Development Agreement (CRADA) might be considered, a means by which the USGS and private industry are allowed to enter into a legal working relationship and where funding is appropriately focused. Some funding for this project could also conceivably come from the NSF, possibly as a result of USGS involvement with the IPY, especially if it is found that the research scientific community has particular interest in the observatory and if they have operational needs that differ from the directional drilling industry. This project has been discussed with possible collaborators in the oil-drilling support industry.

Mexican observatories

Assist with the upgrading, expansion, and operation of magnetic observatories in Mexico.

Priority 𝔹: The Mexican geomagnetism program operates one observatory at Teoloyucan, which was recently welcomed into Intermagnet. The program has enthusiastic staff and they have received support from the Belgians, Danes, and from the USGS. Insofar as more observatories are needed on a global scale, then Mexico represents a logical frontier for expansion. Additional observatories in the Yucatan or Baja could make important contributions to studies of the equatorial ring current. Assisting the Mexicans with their program is consistent with the existing primary mission of the USGS Geomagnetism Program.

Progress 3: No specific projects are currently being discussed in detail. Funding opportunities might be found through international agencies, and some contacts might be established through the Pan American Institute of Geography and History (PAIGH), with which Program staff already have been associated.

Midway observatory

Install and operate a new magnetic observatory on the Pacific island of Midway for a minimum of one solar cycle.

Priority B: The Geomagnetism Program operated an observatory on Midway from 2000 to 2002; and one was operated before that from 1964 to 1966. Data from a Midway observatory would find application with scientists engaged in studies of the main field and the equatorial ring current. This project is consistent with the existing primary mission of the Program.

Progress 3: Geomagnetism Program staff found that the Midway observatory was generally difficult to install and operate during the years 2000 to 2002. The island is only inhabited by a few employees of the Fish and Wildlife Service (FWS) and their contractors and partners. As a result, securing a reliable observer for making absolute measurements was and would be a challenge. Flights to and from the island are relatively infrequent, making operations logistically difficult. Rainfall can be heavy, and drainage is a problem since the island is virtually flat; the Program's observatory stopped operating in 2002 after the site was flooded. Working from experience, these problems can be solved with some redesign of a Midway observatory. At present, however, there is no known source for paying for a Midway observatory other than directly with Program funds. But since the Pacific has so few observatories, data from a Midway observatory would be useful, and support might come from the space weather community.

OBSERVATORY INFRASTRUCTURE

Maintenance and renovation

Maintain and renovate existing observatory infrastructure, concentrating on fixes that reduce long-term maintenance needs and costs.

Since many of the Geomagnetism Program's observatories were established decades ago, some of the buildings are in need of repair and replacement. In general, maintenance of the observatory infrastructure is becoming more expensive and labor intensive, but by modernizing operations and making quality repairs, this burden could be reduced in the future.

Barrow

Make substantial renovation of the Barrow observatory infrastructure.

The Barrow observatory is the Geomagnetism Program's most northerly site, recording the active magnetic-field variation characteristic of high latitudes. The observatory is important for measurement of the auroral electrojet, and data are used to calculate the AE index. The site is also important for main-field modeling, because the secular variation of magnetic declination is relatively rapid at high latitudes. Barrow is likely to be useful in the future for directional drilling operations, should the nearby National Petroleum Reserve, Alaska, located west of Prudhoe, be opened more completely to the oil industry for exploration and extraction. The observatory is located on 100 acres, one of the few pieces of Federal Government property on the north shore (a BLM withdrawal).

Priority 𝔸: Conditions at Barrow can be very harsh, with winter temperatures sinking to -50 degrees Celsius and winds reaching 100 km/hour. Therefore, it is not surprising that the buildings have suffered some degradation since their installation; some were installed as long as 55 years ago. All of the buildings need substantial carpentry and electrical repairs, and some should be replaced outright. The buildings are drafty and their interiors need better temperature control. Until fixes are made, fluxgate baselines are drifting more than at most other observatories. This degrades the real-time data and necessitates intensive processing to produce absolute time-series.

Progress 𝟚: There are no known funds available for building replacement; therefore, fairly extensive efforts are underway to re-side building exteriors. Most of the needed funding for repairing the Barrow buildings will come through the Western Region facilities office, although those monies might, in the end, be insufficient to support all the needed work. The difference will have to come from Program funds because meeting this objective is consistent with the existing primary mission of the Geomagnetism Program. Program staff are investigating creative solutions to financing the project, but nothing of certainty has developed.

Winter at the Barrow observatory.

Fredericksburg

Transfer a portion of the Fredericksburg observatory site to NOAA and make substantial renovation of the remaining observatory infrastructure.

Because the Fredericksburg observatory and its predecessor at Cheltenham have been in operation since 1900, the data time-series are of importance for a wide variety of research projects addressing long-term, global-scale phenomena. Fredericksburg data are used extensively by NOAA and the U.S. Air Force for space-weather diagnostics, and they are used for the calculating the K and Kp indices. Fredericksburg is a classic old-style observatory, located on 187 acres of beautiful Virginia countryside. Most of the facilities on the Fredericksburg site date from its establishment in 1956, including several operational buildings, extensive office space, a machine shop, a large coil-calibration facility, and two houses. The site was extensively used by dozens of staff members when operations were more labor-intensive than they are today and when the headquarters of the Geomagnetism Program was located in Fredericksburg. Today, six of the buildings are used by NOAA's National Geodetic Survey (NGS). The ANSS uses one of the buildings for a seismometer, and the remaining buildings are used by the Geomagnetism Program. One full-time Program employee is stationed at Fredericksburg, working as an observer and on maintenance.

Priority A: Since their construction, the Fredericksburg buildings have not been modernized, and in particular, electrical systems are antiquated. Several of the buildings need substantial carpentry repairs, and some should be replaced outright, although all building foundations are in good shape. The building interiors need better temperature control. Until complete fixes are made, fluxgate baselines are drifting more than at most other observatories. This degrades the real-time data and necessitates intensive processing to produce absolute time-series.

Progress 2: Discussions are currently underway to transfer ownership of all buildings not used by the USGS to the NGS. Doing so will reduce the maintenance workload of Program staff. Attention will then be focused on repairing the buildings used for geomagnetic operations. There are no known funds available for building replacement; therefore, fairly extensive efforts are underway to re-side building exteriors. Most of the needed funding for repairing the Fredericksburg buildings will come through the Eastern Region facilities office, although those monies might, in the end, be insufficient to support all the needed work. The difference will have to come from Program funds since meeting this objective is consistent with the existing primary mission of the Geomagnetism Program.

Panoramic view of the Fredericksburg observatory site.

OBSERVATORY IMPROVEMENTS

Improve observatory infrastructure so that data quality and data delivery are enhanced.

As with maintenance and renovation, this is a complicated and multifaceted issue that will be addressed in more detail in a separate document. The summary here is relatively brief, highlighting only the most important issues.

Magnetometer baselines

Priority A: A basic measure of the state of the observatory facilities is the stability of the fluxgate baselines. Since fluxgate magnetometers are temperature sensitive, it is important that the building housing the fluxgates be well insulated and have thermostatically controlled heating. By addressing this problem at a number of observatories, the quality of data produced by the Program will be improved and the labor-intensive data processing required to produce absolute time-series will be reduced.

Progress 1: Program staff are already making progress on this objective. New temperature buildings are being erected at the Fresno observatory, and improved temperature controls have been installed at Barrow and Fredericksburg. Buildings still need to be installed at Del Rio and Stennis. Fortunately, most of this objective concerns the Program’s lower latitude observatories, which present more hospitable working conditions. Funding for this project is being borne directly by the Program since it impacts upon the Program’s existing primary mission.

Internet links

Priority A: In order to operate the Program’s new data-transportation links, each observatory must have Internet links. Once these are installed and once the transportation system is operable at a given observatory, then data can be delivered in real time. Additionally, Internet links allow personnel in Golden and elsewhere to communicate with the observatory’s acquisition system, thereby facilitating remote troubleshooting and the updating of software. All of this will make staff time more efficient.

Progress 1: Program staff are making good progress on this objective, but a few of the observatories, such as Barrow, Del Rio, and Tucson, are going to be more difficult to outfit with Internet links because of their relatively remote locations. Funding for this project is being borne directly by the Program since it impacts upon the Program’s existing primary mission.

Cooperative agreements and sharing of facilities

Explore opportunities for sharing observatory sites with allied geophysical programs.

The Geomagnetism Program’s observatory network is a substantial physical asset; the network is widespread, and each observatory site consists of buildings on a large piece of controlled and relatively secure property having communication links and other basic support. The observatory sites could support more co-located geophysical operations.

Priority A: By cooperating and sharing the observatory sites with other allied geophysical programs, ongoing operations can be further supported and direct costs to the Geomagnetism Program can be reduced. The Program’s existing partnerships have already been summarized herein. The following is a discussion of potential partnerships on specific observatories.

San Juan

Progress 2: The San Juan observatory is situated on 120 acres of property, and Geomagnetism Program staff are currently exploring sharing some of this area with NOAA for the establishment of an elaborate meteorological facility. Spacious and underutilized San Juan office space might be shared with Water Resources Division (WRD) of the USGS and with the newly proposed USGS expansion of Caribbean seismic stations as part of the President’s tsunami initiative.

Sitka

Progress 𝟚: The Sitka observatory is situated on 118 acres of Forest Service (USFS) property, and Geomagnetism Program staff are currently exploring sharing some of this area with NOAA for the establishment of an elaborate meteorological facility.

DATA ACQUISITION

New data-acquisition system

Complete deployment of the new data-acquisition system at all observatories.

Priority 𝔸: The Program's new data-acquisition system (PCDCP) is producing very good one-minute average data. The system is more flexible, allows for Internet links, and also appears to be more robust than the older system (DCP). The new system is being modified for one-second acquisition.

Progress 𝟙: Program staff have made good progress on this objective, and about half of the observatories now support the PCDCP. This objective is well within the Program's existing primary mission, and funding and staff time are being borne directly by the Program. There is no significant obstacle preventing full deployment in the near future.

One-second magnetic data

Complete testing, refinement, and standardized operational deployment of one-second data-acquisition systems at all observatories.

Priority 𝔸: Many new space-weather research and diagnostic programs being developed by governmental and academic agencies rely on real-time, pulsation analyses of high-frequency, ground-base magnetometer data. The 1-second data systems will expand the Program's customer base in this important and rapidly developing field.

Progress 𝟙: Program staff time is the most critical issue affecting progress, but they have already been making a concerted effort on this objective and now have a mastery of the technicalities involved in producing one-second data that meets or even exceeds the standards for time-stamp, filtering, and resolution set by the user community. The Program will benefit by comparing their systems and data with those of other Intermagnet observatory programs and the various variometer programs.

Magnetometer response

Correct for the nonlinear response function of each observatory fluxgate magnetometer so that data fidelity is improved.

Priority 𝔸: Unfortunately, the fluxgate magnetometers used by the Geomagnetism Program have a nonlinear response function; this causes the data to exhibit occasional step offsets. The problem can be, at times, difficult to detect, but it is cause for concern. The Program's variational data do not now meet accepted standards for resolution when the occasional offsets are manifest. Because the offsets can be removed with data processing, the Program's final definitive data do meet accepted standards. The nonlinear response became apparent upon comparison of vector intensity differences between the fluxgate and proton magnetometers operated in parallel at each observatory. It is probable that other geomagnetism programs, those not making such interinstrument comparisons, are afflicted with similar, but undiscovered, problems. Nonetheless, Program staff recognize that the problem must be fixed at USGS observatories.

Progress 𝟙: The majority of the nonlinearity in the fluxgate magnetometer response function can be traced to a digital-to-analog converter. The first priority for resolving the problem is to directly measure some constants associated with the converter. These constants then need to be introduced into software that will adjust the raw data so that the response of the system is made more linear. The only issue affecting progress on this matter is staff time, but this objective should be accomplished within the timeframe of this 5-year plan.

Coil-calibration facility

Complete coil-calibration facility at Boulder so that magnetometer systems can be checked and calibrated prior to deployment.

Priority 𝔹: In order to check the linearity of the Program's fluxgate magnetometers, the coil-calibration facility on the Boulder observatory site needs to be completed. Work on this facility, one of the most important for the Program, represents an awareness of the necessity that the data be of the highest possible quality.

Progress 𝟚: The Program has already benefited substantially from cooperation with the Geophysical Institute of the University of Alaska Fairbanks, where the coils were built. Staff have also been working with a smaller version of the coil system, one developed and installed at College observatory. The nonorthogonality of the coil system needs to be measured and electronic data-acquisition systems need to be installed and tested. The Program will benefit from collaboration with allied programs, including the geomagnetism program of Canada where a similar facility is already in use.

Magnetotelluric data

Outfit the observatories in the contiguous United States for electric-potential measurements.

By measuring the ground electric potential, along with the magnetic field, at a given geographic site, the electrical conductivity of the crust and mantle below that site can be estimated. The longer those measurements are made, the deeper the profile of the estimate. This is an important physical quantity for understanding the tectonic dynamics of the Earth's surface and interior. It is notable that an extended magnetotelluric survey was conducted on the Tucson observatory from 1932 to 1942 when that observatory was still operated by the Carnegie Institution, and similar measurements have been made at a few other observatories for more brief periods of time. However, these measurements are not currently being made at any of the USGS observatories.

Priority 𝔹: The observatory sites are ideally suited for long-term magnetotelluric measurements, and such a project would enhance the usage of Program data, including the magnetic data already being collected, by researchers in what is traditionally a geological discipline.

Progress 𝟚: Outfitting the observatories for making the Earth-current measurements requires the installation of two pair of widely separated electrodes and some modification of the Geomagnetism Program's new data-acquisition system. A larger commitment would be necessary if data are to be collected continuously over a long period of time and if it is required that the data be made available in real time. Some Program staff already have experience in collecting magnetotelluric data. A Program proposal to obtain funds necessary to support these operations has been submitted to Earthscope. A decision is pending.

High-frequency induction-coil data

Outfit a wide-spread subset of the Program's observatories with high-frequency magnetic induction-coil data-acquisition systems.

Priority ℂ: Monitoring for lightning and nuclear explosions, and more generally, conducting research on the ionospheric Shumann resonances, is presently outside of the Program's existing primary mission. Involvement would, however, add significantly to scientific and social relevance of the Program and the USGS. Lightning is an important atmospheric phenomenon, and nuclear explosion monitoring is, of course, a subject of critical importance for national security.

Progress 𝟛: In order to collect the high-frequency data, an entirely new magnetometer system must be used. Its operation will require the development of new software, especially if the data are to be reported continuously, for long periods of time, and in real time. For global-scale studies, the observatories of Guam, San Juan, and College would be suitable sites, with their wide separation allowing for event location through triangulation. Collaboration with outside agencies and institutes could help to facilitate this project. At the moment, no funding is available, but the possibilities are obviously enormous.

DATA TRANSPORTATION

Operational Internet delivery

Make fully operational the Internet transportation of observatory data.

Priority 𝔸: The Geomagnetism Program is now transmitting data from a number of its observatories via the Internet. But most customers, in particular the U.S. Air Force, are receiving real-time data from a stream received in Golden through the older satellite data-transportation links. Since the satellite links will be phased out in the future, and since this will probably occur in stages, with some satellite links brought down before others, a transition must be initiated to make operational the reception and subsequent dissemination of the Internet data streams already in place.

Progress 𝟙: Substantial Program staff effort has been devoted to developing and deploying the Internet data-transportation system. Now, this important capacity needs to be moved to a fully operational stage. There is no significant obstacle to accomplishing this objective in the very near future.

DATA PROCESSING

Software

Complete testing, refinement, and make publicly available in-house-developed, data-processing software.

Priority 𝔸: For several years now, the Geomagnetism Program has been developing specialized software (MagProc) that can be used for cleaning, adjusting, and combining absolute data with variational time-series, so that absolute "definitive" magnetometer time-series can be published. Sharing the software will be welcomed by the wider observatory community, assisting programs that survive with relatively lean funding and staffing support, especially those in developing countries.

Progress 𝟙: Program staff are preparing for the release of the software now, and supporting documents are under preparation. There is no significant obstacle to accomplishing this objective in the very near future.

DATA MANAGEMENT

Oracle database

Complete the development, testing, installation, and full integration of an Oracle database.

Priority 𝔸: The Geomagnetism Program must be able to manage its existing one-minute data and the larger influx of one-second data, and therefore, an Oracle database is being developed. For efficiency, the database needs to be fully integrated with data-transportation, data-processing, and data-dissemination software. Obviously, this objective is well within the Program's existing primary mission, and indeed, it represents an important component in the continuity of Program operations.

Progress 𝟙: Program staff and contractors have already made good progress on the developmental part of this objective, but additional work is needed and operational testing has not yet begun. Specialized training has been undertaken by Program staff, and success depends on their continued and concerted, hands-on effort. Some Program funds are needed to support contractors, but the most important resource needed to meet this objective is staff time.

Old Program data

Complete the assembly and in-house archiving of the Program's old, one-minute, one-hour, monthly, and yearly average data.

Priority 𝔸: Hourly mean data from Program observatories have been produced for more than a century, and one-minute digital have been produced since 1975. Yet, the Program has only a partial compilation of these data, and the World Data Center compilations are incomplete and somewhat inconsistent. Since Program staff have an authoritative understanding of their own data, it is important that users of the data be able to obtain the data, and expert insight on their nature, directly from the Program. This will benefit the scientific community by enhancing understanding of the data themselves, and it will help the Program interface with the data-user community.

Progress 𝟙: Program staff have assembled all available one-minute digital data, but the one-hour, monthly, and yearly data still need attention. There is no significant obstacle to accomplishing this objective in the very near future.

DATA DISSEMINATION

Web-site interface

Complete testing, refinement, and installation of an enhanced data-display and data-retrieval tool for the Program's Web site.

Priority 𝔸: The Internet is now a primary means of disseminating information, and it is vital for the future of the Geomagnetism Program that its Web site tools for data display and data retrieval be upgraded substantially in order to facilitate the usage of Program data, and as a result, improve the service provided by the Program. The Program also needs to have a quick, one-page graphical summary of recent and current magnetic field activity. This should be updated in real time on the Web site.

Progress 𝟙: Program staff and contractors have already made substantial progress in developing the Web-site tools. Some development remains; capacities for one-second data have not yet been initiated, and they still need to be tested in an operational setting. Some Program funds are needed to support contractors, but the most important resource needed to meet this objective is staff time.

DISTRIBUTED OPERATIONS

Make real-time, Internet data deliveries to select users directly and separately from each observatory, independent of any intermediate Golden reception and transmission.

Priority ℂ: Data could be delivered in real time through a distributed observatory system, with data transmitted to users directly from each observatory through the Internet. Should the links to Golden be interrupted, data could still be received because each observatory would be operating independently. The system, as a whole, would be robust since it is unlikely that all, or even several, observatories would ever go off-line simultaneously.

Progress 𝟛: Geomagnetism Program staff have not worked on this objective directly, but in principle, with the ongoing development of Internet-based transportation and delivery systems, there is no substantial obstacle to achieving this objective. The U.S. Air Force might be interested in supporting this effort, but no specific proposal has been made.

X. RESEARCH AND RELATED DEVELOPMENT

The USGS Geomagnetism Program will conduct scientific research and develop related products that will enhance the quality of the Program's data and that can be used for purposes of hazard assessment, risk reduction, scientific research, and public education.

RESEARCH AFFECTING OPERATIONS

Magnetometer filters and data averaging

Determine phase lag, resolution, and accuracy of one-second average data.

Priority 𝔸: In producing one-second average data, multiple subsecond samples are passed through an analog Butterworth filter for purposes of antialiasing. A one-second average datum is then constructed by applying a digital Gaussian filter, centered on the time stamp, to the subsecond samples. The combination of these filters introduces phase lag and affects the resolution and accuracy of the final one-second data. These issues need to be quantitatively analyzed so that Program staff can appropriately adjust their filter parameters and so that the final data product can be more precisely presented to the user community.

Progress 𝟙: The basic starting point here is the construction of a one-second equivalent of the current one-minute filtering system, something that is detailed in the Intermagnet users" manual. However, the combined effects of Butterworth and Gaussian filtering, which is certainly a desirable operational pairing, must be stated more clearly. Obtaining a consensus among one-second-data users as to their specific needs is also required. The issue here is something of a loose end for the entire observatory community, and because of a lack of staff time, progress on this objective has not been as fast as desired. Still, the objective should be easily accomplished within a year or so.

Coil-calibration system

Determine unknown nonorthogonality parameters of the Program's new coil-calibration system, and correct for their effects so that magnetometer nonlinear response can be easily measured.

Priority 𝔸: In order to study the response of the Program's complete fluxgate magnetometer acquisition system, and thereby ensure that the Program's data are of high fidelity, completing the Boulder triaxial calibration facility is a high-priority objective. The primary unresolved issue needing the attention of Program research staff is the determination of the coil's nonorthogonality parameters. Until these are determined, system measurements using each of the three separate coils will be contaminated by an unknown amount of cross-talk. An important issue concerns the ability to determine a unique set of parameters given different inversion methods. Once complete, the facility will be useful to other outside programs and should, therefore, enhance the service provided by the Program.

Progress 𝟚: The primary issue of nonorthogonality has been essentially resolved (for example, Merayo, and others, 2001; Primdahl, and others, 2002), but the theory needs to be put into a form useful for Program staff and the specific problem at hand. The Program will benefit from collaboration with allied geophysical programs, including that of the geomagnetism program of Canada, which already has a similar facility, and possibly also with universities and private industry. Unfortunately, because of lack of staff time, progress on this objective will not be as fast as desired. Funding for this project is being borne directly by the Program since it impacts upon the Program's existing primary mission.

Magnetometer rotation and nonorthogonality

Develop a method for estimating small unknown rotational and nonorthogonality parameters for the Program's operational fluxgate magnetometers in place at each observatory.

Priority 𝔹: In practice, it is impossible to align a fluxgate with the north-south or magnetic meridian, and all multiaxial fluxgates have some degree of nonorthogonality. These issues affect data quality, but they are often conveniently ignored within the observatory community, in part because the issue is so difficult to resolve. It is possible that the absolute data collected at each observatory could be used to determine, or at least constrain, rotational and orthogonality parameters that could then be incorporated into data processing to produce a superior definitive, time-series product. In an abstract sense, this project is related to the Program's development of its coil-calibration facility; the orthogonality parameters of the coil must be determined. Therefore, in some ways this objective must precede that coil-facility objective. Hence the higher priority assigned here.

Progress 𝟚: Some lessons might be drawn from the satellite magnetometer calibration studies (for example, Luhr, and others, 2000; Risbo, and others, 2003), where calibration parameters are often determined after the satellite has been put into orbit using a combination of satellite orientation and fluxgate vector and proton intensity data. As of now, only a reconnaissance study on this issue has been performed, and the theory needs to be put into a form useful for Program staff and the specific problem at hand. An important issue concerns the ability to determine a unique set of parameters. Because of lack of staff time, progress on this objective will not be as fast as desired.

Near-real-time definitive data

Use enhanced data-processing methods to make definitive, or nearly definitive, data available in near-real-time.

Priority ℂ: Many users now need estimates of absolute magnetic data in near-real time; of particular importance is magnetic declination, which is used for navigation and directional drilling, and a refinement of the real-time estimation of the K index would be valuable to space-weather operations. An investigation needs to be made to determine if the current data processing capacities can be made more real time, possibly using dynamic recursive least-squares methods that have already been demonstrated in other contexts (for example, Teunissen, 2001) and possibly also using more sophisticated interpolation functions such as splines.

Progress 𝟛: Only a reconnaissance study has so far been undertaken on this subject, and although there is some cause for optimism, specific results have yet to be obtained. This is a wide-open subject, and much work remains to be done.

ANALYSIS OF OBSERVATORY DATA

Magnetic K-index and delta-B analyses

Perform a statistical analysis of magnetic K indices and minute-to-minute changes in the magnetic field, characterizing those statistics in terms of the temporal and geographic nonstationarity.

As the first part of a multifaceted study, the statistics of magnetic K and Kp indices, characterized in terms of simple mathematical functions, is needed so that gross magnetic activity can be probabilistically predicted. The analysis would need to account for the fact that the statistics of magnetic indices is nonstationary both temporally and geographically. A reconnaissance search through the literature finds relatively few studies of the occurrence statistics of K and Kp indices; the modern abundance of data needs to be more fully exploited. The second part of the study would concentrate on the more complicated vectorial observatory data themselves, characterizing the statistics of minute-to-minute differences (delta-B) in the magnetic field (for example, Viljanen, and others, 2001; Weigel and Baker, 2003). Finally, the two studies need to be brought together, with an analysis of the relationship between the range indices and the spectral content of delta-B. This particular objective is actually a logical first step in what has sometimes been described as a “magnetic hazard-map” analysis. Once field activity is characterized by statistical functions, the parameters of these functions can be adjusted to geographically interpolate between observatory positions, thereby yielding a continuous function that can be displayed on a map and used for more general, global-scale depiction of field activity.

Priority 𝔸: This type of study is not necessarily real time, but it would help to put real-time activity into a meaningful context. It is expected that this analysis will be of interest to the U.S. Air Force, NOAA, and the electric power-grid industry.

Progress 𝟙: Since the arrival of a USGS Mendenhall postdoctoral fellow, good progress has been made on this objective. Concentration has been on the Kp index, and the analysis of its recurrence statistics modeled as a Poisson process; preliminary inspection of the delta-B data indicates that they occur in statistics according to an exponential distribution. An abstract has been given at a space-weather conference and another has been submitted. Work will continue with the near-term goal of writing a definitive paper on the subject, something that, because of its fundamental nature, is bound to be highly cited.

Magnetic ring-current and Dst analyses

Perform an analysis of Dst and the spatial structure and temporal evolution of the equatorial ring current, utilizing data from numerous midlatitude magnetic observatories.

The traditional measure of magnetic-storm energy is the Dst index, which measures the equatorial ring current and which is constructed from data from four midlatitude observatories, including the USGS observatories of Honolulu and San Juan. Today, there are about 30 observatories suitable for analysis of the equatorial ring current, making it possible to study in detail the structure and evolution of the current system. Of interest are the current's magnitude and symmetry and how these quantities change over the duration of a magnetic storm. Some work on this subject has already been conducted (for example, Clauer and McPherron, 1974), but further analysis is needed, depicting results in ways that are easily understood and exploiting the abundance of modern data.

Priority 𝔹: This type of study could eventually become a real-time operationally diagnostic product. The U.S. Air Force has recently shown an increased interest in Dst, what with no domestic organization making its routine calculation. It is expected that the analysis proposed here will be of interest to the USAF, NOAA, and academic scientists, and would, more generally, help the Geomagnetism Program interface with an important subset of the observatory-data-user community.

Progress 𝟚: An equatorial ring-current map has already been constructed for two storms that occurred in October and November of 2003. This map is spatially and temporally dependent, constructed by fitting a truncated Fourier series to the distribution of horizontal intensities from various midlatitude observatories at different moments in time over the duration of each storm. Results were presented at a recent space-weather conference, and a publication on the subject is now in preparation.

XI. OUTREACH

In order to enhance its service to the scientific community, the USGS Geomagnetism Program will communicate and work with users of observatory data.

Priority 𝔸: Since the range of applications of observatory data is very broad and since the needs of the various groups using observatory data are different, it is important that Geomagnetism Program staff communicate and work regularly and directly with the outside user community. This objective is also related to similar needs on the part of almost all observatory programs and, indeed, even Intermagnet. Meeting this objective will enhance the usage of observatory data and improve the profile of all geomagnetism programs, including that of the USGS.

Progress 𝟙: There are few obstacles to attaining this objective. The Geomagnetism Program could, itself, host a users' meeting in Golden. The venue is obviously attractive, and speakers and other participants could be invited to attend using their own external funds. A meeting of this type could include a tour of the Boulder observatory, thus providing feedback to Program staff. The meeting could also be coordinated with the annual Intermagnet meetings and possibly also with the Space Weather Week conference put on by the Space Environment Center of NOAA.

APPENDIX A: PROGRAM PUBLICATIONS 2000 TO 2005

2005

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APPENDIX B: PROGRAM ABSTRACTS 2000 TO 2005

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