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INTERIOR



UNITED STATES
GEOLOGICAL
SURVEY

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United States Geological Survey

GEOMAGNETISM PROGRAM



Branch of
Global Seismology and Geomagnetism

INTRODUCTION

Off the coast of Oregon, at sunset, four sailors in a small ketch are caught in a terrifying gale. Having lost all sense of direction in the darkness, they must now rely upon their magnetic compass. With the help of a nautical chart, they determine a course toward the nearest harbor. The chart tells them that the magnetic declination in that region is 20 degrees east--in other words, their compass will point 20 degrees east of true north. After several tense hours of sailing by compass, all the while correcting their heading for the amount of declination, they are relieved to enter the mouth of the harbor. The vital declination information shown on the chart was provided by the National Geomagnetic Information Center.

In Virginia, a surveyor is asked by a judge to help settle a dispute between two farmers over the location of their common boundary. The existing title descriptions are based on a survey made in 1871. As was usual back then, the survey was tied to the Earth's magnetic field. Since then, however, the field has changed. A new survey will require a reliable estimate of the amount of change. The surveyor, keenly aware that even a small error would cause many acres to wrongly change hands, calls the National Geomagnetic Information Center for the authoritative information.

In Maine and Minnesota, cities and towns are suddenly plunged into darkness, electrical trains and machinery grind to a halt, and hospitals activate emergency power generators. Meanwhile, thousands of miles above the Equator, a meteorological satellite behaves erratically and, elsewhere in space, vital navigation satellites are incapacitated by orbital changes and electronic malfunctions. Radio communication signals between America and Europe fade and disappear. In the frozen northlands of Canada and Russia, early warning radars are blinded by intense auroras; the same Northern Lights that are seen by startled ranchers in Texas. The Earth is enveloped in a magnetic storm! Up-to-date information on the storm is made available to the news media by the National Geomagnetic Information Center.

Events like these happen all the time. If you are surprised, this pamphlet is for you. It will increase your awareness of the importance of geomagnetic information in our daily lives and the role of the U.S. Geological Survey's National Geomagnetic Information Center (NGIC) in providing geomagnetic data.

The National Geomagnetic Information Center, located in Golden, Colorado, is one of the nation's primary sources of information on the Earth's magnetic field. The Center operates magnetic observatories, processes and distributes magnetic data, conducts magnetic repeat surveys, issues magnetic models and charts, is currently developing a real-time network called INTERMAGNET, and conducts basic research. These six major activities are

described in the following pages. The next section of this pamphlet comprises a brief review of the basics of geomagnetism, which will be useful if you need more background before reading about our program. Should you wish to learn more about geomagnetism, we have included a short list of suggested readings at the very end.

BASIC GEOMAGNETISM

The Earth, like many other planets of the solar system, has a magnetic field that originates inside the Earth's surface and extends far out into space. The shape of the Earth's field resembles that of a small bar magnet, or *magnetic dipole* --in fact, a fairly good model of the geomagnetic field would be a bar magnet (dipole) located near the Earth's center and tilted about 11 degrees with respect to the axis of rotation. The theoretical line around the Earth along which the field is horizontal is called the *magnetic equator*, and the two places where the field is vertical are called the *magnetic poles* (north and south). Magnetic field strength or intensity is measured in units of nanotesla, abbreviated nT. The strength of the field on the Earth's surface ranges from about 24,000 nT in South America to nearly 62,000 nT in the polar regions. Far away from the Earth, on the sunward side, the magnetic field extends out to about 40,000 miles (approximately 10 Earth radii), but goes more than 100 times as far on the nighttime side (well beyond the moon's orbit). This is because the sun is constantly emitting a stream of charged particles and

radiation, called the *solar wind* that strikes the field and forces it into an enclosure shaped much like that of a comet. The enclosed region is called the *magnetosphere*. Figure 1 shows a cross-section of how the magnetic field would look from outer space in the noon-midnight meridian plane.

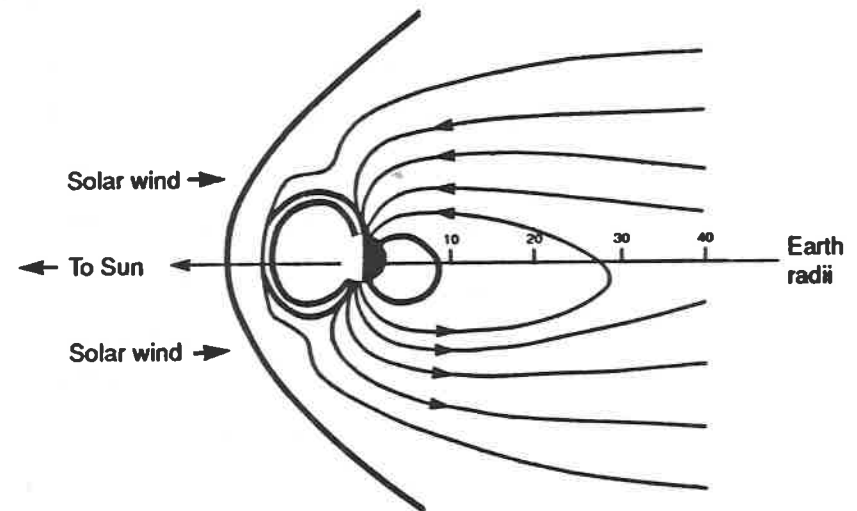


Figure 1 - Cross-section of the Earth's magnetic field along the noon-midnight meridian.

The geomagnetic field is a composite of fields from several distinct sources. The *main field* is believed to be generated by electric currents flowing in the Earth's core, which begins about 3000 km below the surface (about halfway to the center of the Earth). The *crustal field*, which

can exceed 1000nT but averages only about 200 nT, is caused by magnetic rock in the crust. Contributions to the magnetic field from sources external to the Earth's surface are produced by electric currents flowing in the upper atmosphere and beyond. Still other fields result from electric currents induced in the Earth by variations in the external field.

Continual measurements of the geomagnetic field at one place, such as at a *magnetic observatory*, show that the field is subject to *time variations* with periods ranging from fractions of a second to hundreds of thousands of years. Most of the rapid variations, with periods of a day or less, result from changing currents in the magnetosphere and *ionosphere*. There is a prominent daily or *diurnal variation* that results from the Earth rotating under large currents in the ionosphere, about 100km above the surface.

In contrast to the crustal field, which is relatively stable, and to the external field, which is mostly transient, the main field undergoes long-term change, called *secular variation*. Over extremely long periods of time, measured in tens or hundreds of thousands of years, the main field can undergo *polarity reversal* --- the north magnetic pole becoming the south magnetic pole, and vice versa. The secular variation presently exceeds 100nT per year in some places. Although the secular variation in a particular place can be nearly constant for many years, it can also change

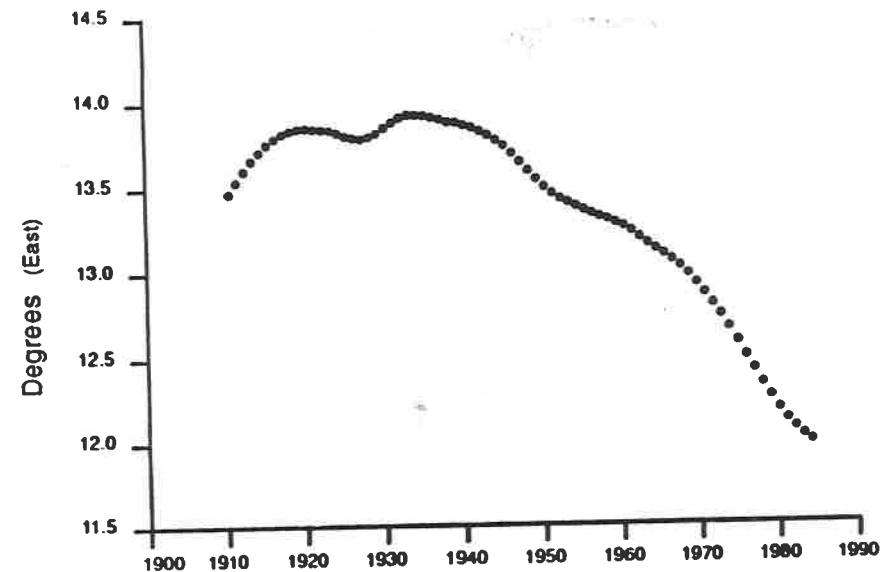


Figure 2. - Magnetic declination at Tucson Magnetic Observatory from 1910 to 1986.

rapidly. This is illustrated by *figure 2*; which shows the *magnetic declination* at the Tucson (Arizona) Magnetic Observatory since 1910.

Declination, also called compass variation, is one of the *geomagnetic elements* (see *figure 3*). It is the horizontal angle between true north and the direction in which a compass points. Other elements include *inclination* (also called dip), which is the vertical angle between the horizontal plane and the field direction; and the *horizontal*, *vertical*, and *total intensities*.

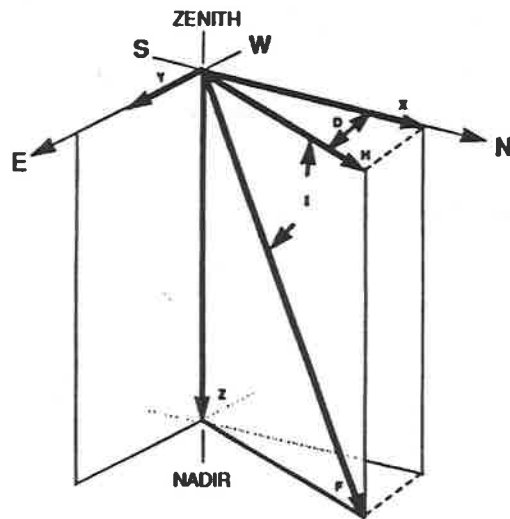


Figure 3. - The magnetic elements, seen from the northeast.

D	Declination	Y	East component
I	Inclination (or dip)	Z	Vertical intensity
H	Horizontal intensity	F	Total intensity
X	North component		

Our present knowledge of the Earth's magnetic field would be impossible without measurements, most of which come from magnetic observatories and surveys. After several centuries of sporadic measurements, mainly declination measurements taken by mariners, extensive surveying on land and sea began in the last century. Since World War II, land and sea surveys have mostly given way to aerial and satellite surveys.

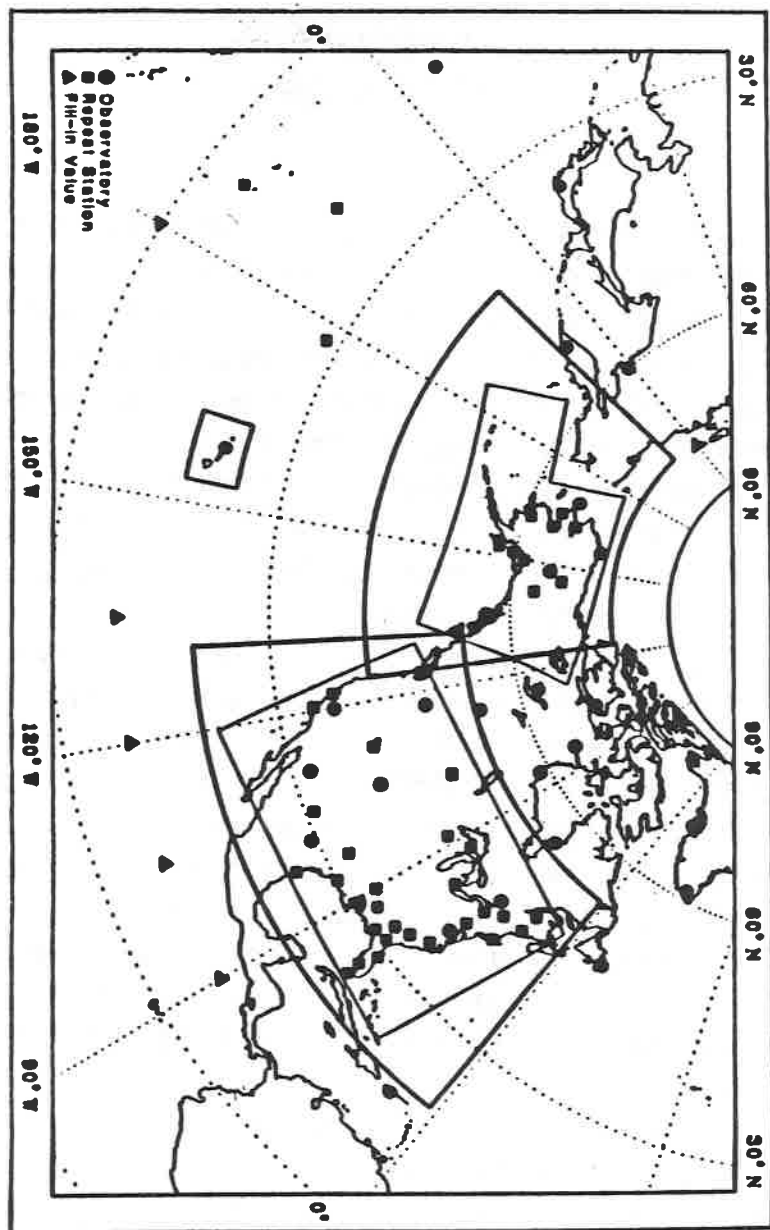
MAGNETIC OBSERVATORIES

A magnetic observatory is a laboratory where the Earth's magnetic field is monitored and recorded continually, and precise calibration measurements are made on a frequent basis. The first ones were established in the early 1800's, and today there are about 200 observatories in operation around the world. The National Geomagnetic Information Center operates 13 magnetic observatories: seven in the contiguous States; three in Alaska; and one each in Hawaii, Puerto Rico, and Guam. Their locations are shown on the map in figure 4.

Each observatory is equipped with fluxgate and proton magnetometers to measure the strength and direction of the field. Many samples are taken and averaged into one-minute values and stored in system memory and on magnetic tape using an on-site computer. The stations are queried at regular intervals to acquire data and to check for problems and equipment malfunctions. Periodic absolute measurements of the magnetic field components are made with standardized instruments to provide calibration files for the conversion of variation data values into magnetic field values.

Plans are being made to install eight new observatories in the equatorial zone to collect data for a more complete distribution of coverage in this magnetically important region; and to support geomagnetic field mapping satellites.

Figure 4 - Map showing locations of magnetic observatories and repeat stations



DATA PROCESSING AND PRODUCTS

Data retrieved by the Center undergoes a long series of arduous and time-intensive processing steps. Over two million data values are processed per month. Each of these values undergoes more than a dozen processing steps designed to retrieve, plot, clean, edit, perform quality checks, and store the data. With the addition of the planned equatorial stations and the INTERMAGNET network, the number of data points processed could easily quadruple.

Once the data has been processed, it is stored on magnetic tape and made available for worldwide distribution. Each day of digital data, for all observatories, is plotted to produce magnetograms like those in *figure 5*. *Figure 5a* shows the magnetically quiet day of January 19, 1989 and *Figure 5b* shows the magnetic storm of March 13, 1989 for the Fredericksburg Geomagnetic Observatory. Additionally, tables of hourly, monthly, and annual mean values for the elements are derived. K-index tables, which measure the range of magnetic activity during 3-hour intervals for each day are also compiled.

Many people from government, private industry, and the academic community request these data from the Center. The British Antarctic Survey; the U.S. Air Force; NASA; the Naval Research Laboratory; the Universities of California, Minnesota, Texas; and numerous oil and gas

exploration companies; represent some of the organizations that utilize NGIC data. The range of requirements and applications for geomagnetic data is broad and growing.

REPEAT SURVEYS

Recognizing the complex and irregular nature of the Earth's magnetic field, in 1899 the U.S. Coast and Geodetic Survey (now a part of the USGS) embarked upon a program to conduct a nationwide magnetic survey by establishing a set of magnetic stations about 30-40 miles apart. The objective was to have at least one station in each county so that county surveyors would have the data necessary for testing their compasses. Of the nearly 9000 stations, a group of about 100 was designated as repeat magnetic stations which were permanently marked by a bronze or aluminum disk set in concrete. Due to population growth and expansion of our towns and cities, the National Geomagnetic Information Center now considers only 25-30 repeat stations to be adequate for measuring the magnetic field free of artificial disturbance.

These repeat stations are reoccupied about every 2 to 5 years, and are sometimes used by surveyors and engineers for calibrating instruments. During an occupation, which usually lasts several days, many sets of measurements are taken. The measurements are later reduced, or corrected for transient variations. The results are used to help estimate secular variation of the magnetic field and provide values at key locations for the production of magnetic models and charts.

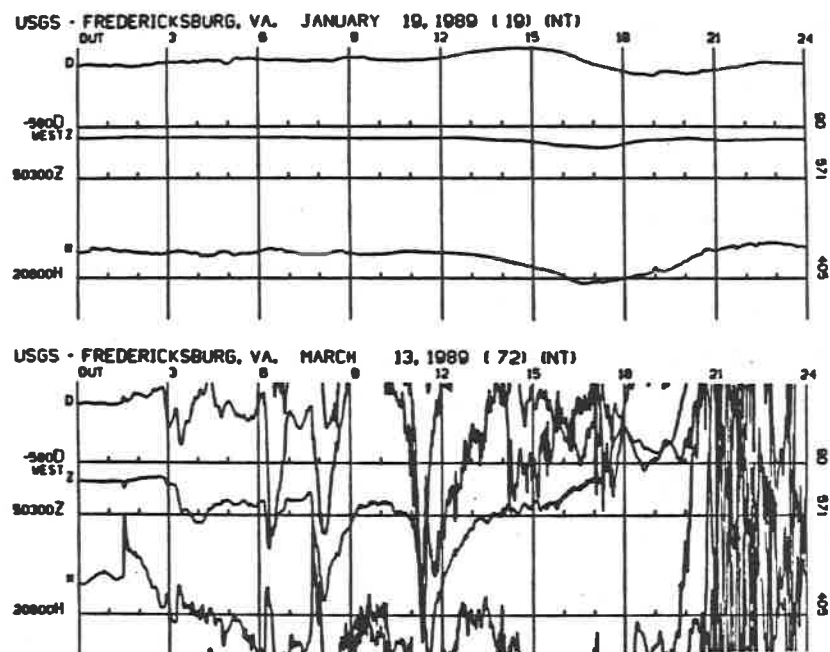


Figure 5 - Fig. 5a (top) shows a plot of the 3 elements for a quiet day at the Fredericksburg observatory; Fig. 5b (bottom) is a plot for the magnetic storm of March 13.

MODELS AND CHARTS

Magnetic models and charts are a principal means of conveying information about the geomagnetic field. They tell us the strength and direction of the field at any place, and the rate at which the field is changing. Surveyors and scientists in the private sector and in government agencies use them directly; navigators, pilots, and others use them indirectly when they use the magnetic information shown on nautical charts, aeronautical charts, and topographic maps.

Models are mathematical descriptions of the field that are normally used with computers. They provide specific information more quickly and with fewer errors than values that are hand-scaled from charts. Because models are continuous functions they represent the field everywhere in their region of applicability and provide values for any location. They thus serve to interpolate on the original field measurements, each of which tell us the value of the field at only one place and one time. Models are derived from measurements using the method of spherical harmonic analysis developed by the mathematician Karl F. Gauss over 150 years ago. The measurements come from land, marine, aerial, and satellite surveys, and from magnetic observatories and repeat stations. The National Geomagnetic Information Center cooperates with NASA and

the Navy in the design and planning of magnetic surveys by satellite, such as the MAGSAT survey, helping to ensure that resulting data will be useful for modeling and charting.

Charts are graphical representations of the field, and are based on models. A simplified small-scale version of a chart of magnetic declination for the United States is shown in figure 6. Charts are handy for scaling occasional values, and aid in the visualization of the field. The National Geomagnetic Information Center produces models and charts for the region of the United States and for the world. Modeling and charting is an ongoing project because the Earth's magnetic field is continually changing, and the changes are unpredictable. Currently our magnetic models and charts are revised every five years.

The International Geomagnetic Reference Field (IGRF), is a standard set of field models that has been tested and approved by specialists from around the world. The National Geomagnetic Information Center helps ensure the continued reliability and effectiveness of the IGRF by playing a leading role in its periodic revisions.

The NGIC operates a computer-based online system, called *GEOMAG*, that provides model values of the geomagnetic elements, such as declination and total field intensity, directly to the user's terminal or microcomputer via telephone line.

REAL-TIME ACTIVITY INDICES: The global, near-real time nature of the INTERMAGNET network provides the

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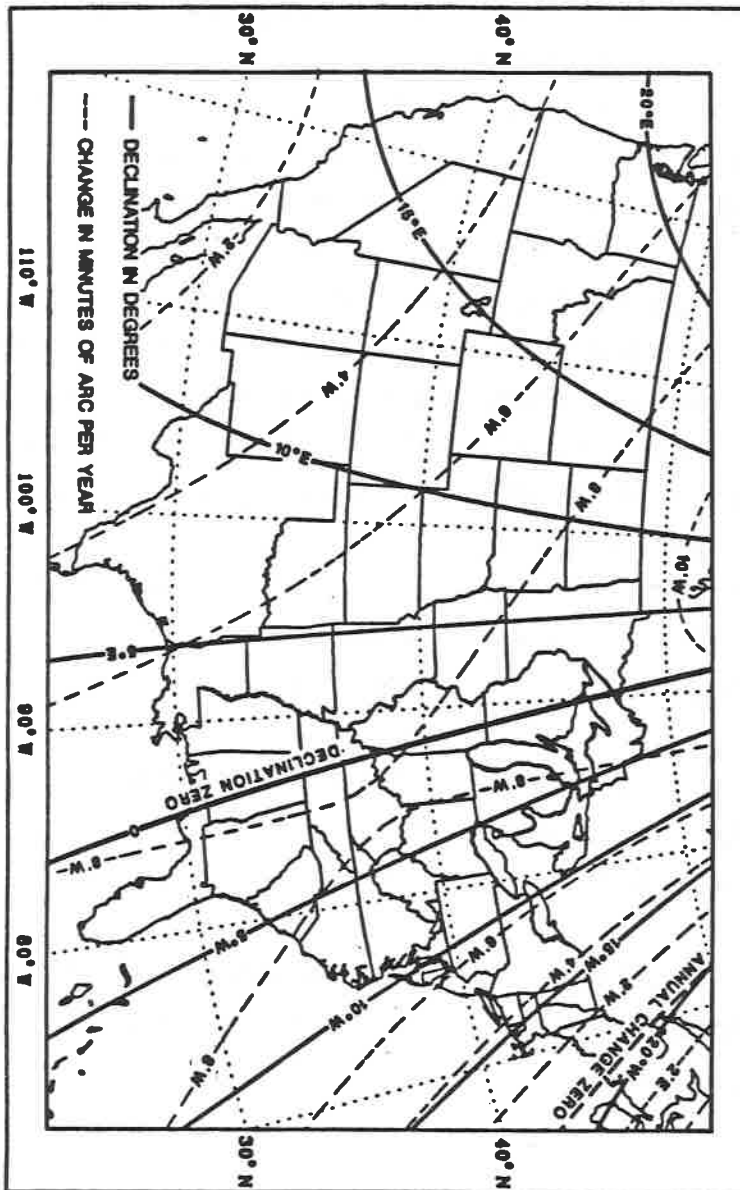
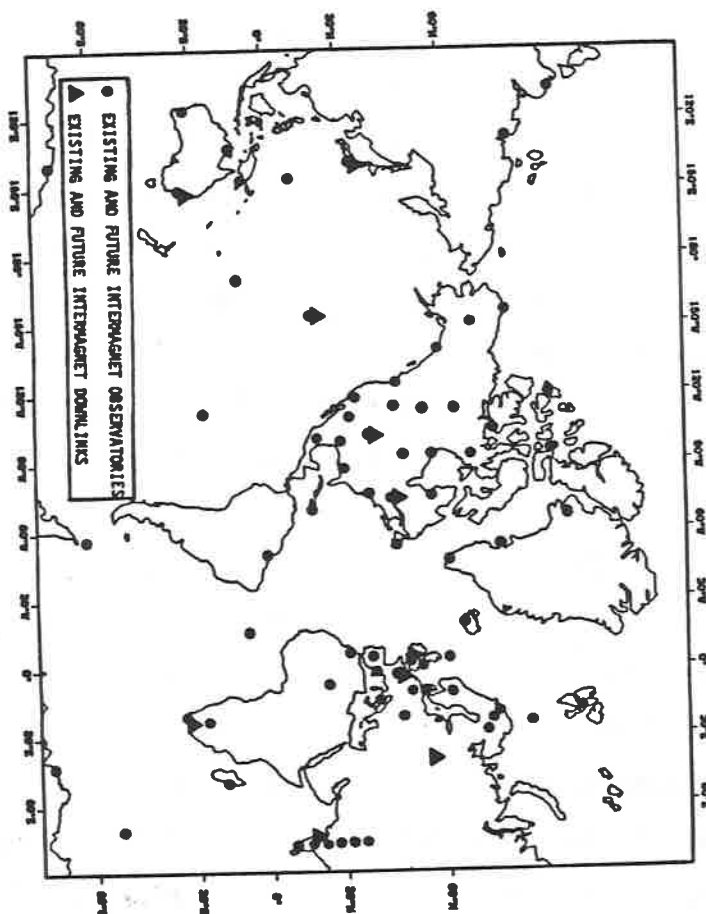


Figure 6 - Magnetic Declination in the United States - 1985

Figure 7 - Distribution of proposed INTERMAGNET observatories and downlink stations



means for monitoring, modeling, and predicting magnetospheric and terrestrial effects of geomagnetic disturbances. These effects can be reported every 12 minutes by means of activity indices. These include real-time 1-hour and 3-hour versions of the classical K-index. With real-time data from INTERMAGNET, other indices could be generated including: the Kp-index, which measures planetary variations in geomagnetic activity; the AE-index, which measures the activity level in and near the auroral zones and indicates the magnitude of auroral electrojet currents in the ionosphere; and the Dst-index, which indicates the average magnetic storm variations in the ring current around the Earth.

The effects of a magnetic storm are numerous and include: the auroral lights, massive power outages, and interruption in communication systems. Some of the known effects due to geomagnetic storms are given in Table 1. These storms can last for a few hours or several days and can produce dissipations of energy at roughly the rate the U.S. consumes electrical energy (10^5 - 10^6 megawatts). The magnetic storm of February, 1986, produced a depression in the field at the equatorial and temperate latitudes that lasted several months; and the storm of March, 1989, caused a 9-hour blackout in the Hydro-Quebec power system in Montreal, Canada.

TABLE 1

POSSIBLE EFFECTS OF A MAGNETIC STORM

- Auroral lights (aurora borealis & aurora australis)
- Radiation degradation and failure of integrated circuits in satellites.
- Radiation danger to astronauts
- Radiation exposure hazard to occupants of high altitude aircraft.
- Satellite drag increase -- orbital errors, shortened lifetimes, early re-entry.
- Faults (glitches) and failures in satellite control systems from high electric fields.
- Fadeouts and blackouts of long distance radio communications
- Interference in ground-to-satellite communications.
- Position errors in VLF navigation systems.
- Degradation of accuracy in Global Positioning System (GPS).
- Induced voltage interference on long line telephone links.
- Power Distribution system outages ("blackout" and "brownouts").
- Degradation of geophysical surveys.
- Blinding of over-the-horizon and other radars.

RESEARCH

The National Geomagnetic Information Center conducts research on a wide variety of topics. Variations of the geomagnetic field enable scientists to study processes that span distances from the Earth's core to deep in outer space, and time intervals from seconds to millions of years. Such studies include: research on electromagnetic dynamo models of the Earth's molten core in an attempt to explain the origin of planetary magnetic fields; field polarity reversals so important to paleomagnetic, archeomagnetic, and paleoclimatological research; conductivity studies of the Earth's crust and mantle; mathematical modeling that attempts to predict changes in the field; magnetic monitoring and measuring equipment including data acquisition systems and methods; and even research on relationships that exist between solar-induced geomagnetic disturbances and long-term global weather patterns. Such research is vital to the continued growth in our understanding of the Earth and its surroundings.

CONSULTING / ADVISORY SERVICES

The National Geomagnetic Information Center provides advice, consultation, and information to people in other governmental agencies, the academic community, and the private sector. Some of these services include the calibration of magnetic instruments, recommendations on the installation and operation of magnetic equipment and data acquisition systems, and advice on methods for identifying and eliminating magnetic influences on satellite spacecraft. Such services play an important role in providing technical support to the scientific community.

LIST OF SUGGESTED READINGS - BOOKS

Geomagnetism

Sydney Chapman and Julius Bartels
Clarendon Press, 1940 (1st ed.),
1962 (2nd ed.), 2 volumes

Introduction to Geomagnetism

W.D. Parkinson
Elsevier, 1983

The Earth's Magnetic Field

Ronald T. Merrill and Michael W. McElhinny
Academic Press, 1983

Introduction to Geomagnetic Phenomena

edited by S. Matsushita and W.H. Campbell
Academic Press, 1967, 2 volumes

Geomagnetism

edited by J.A. Jacobs
Academic Press, 1987, 3 volumes

Notes on geomagnetic observatory and survey practices

K.A. Wienert
Van Buggenhoudt Press, 1970

LIST OF SUGGESTED READINGS - ARTICLES

- "The Evolution of the Earth's Magnetic Field", Jeremy Bloxam and David Gubbins
Scientific American, December, 1989 pp 68-75
- "The Dynamic Aurora", Syun-Ichi Akasofu
Scientific American, May, 1989 pp 90-97
- "The Earth's Magnetotail", Edward W. Hones, Jr.
Scientific American, March, 1986 pp 40-47
- "The Source of the Earth's Magnetic Field", Charles R. Carrigan and David Gubbins
Scientific American, February, 1979 pp 118-130
- "Magnetic Pointers to Stormy Weather", John Gribbin
New Scientist, 25 December 1986/1 January 1987
pp 70-72
- "Nature's Incredible Night Show", Lowell Ponte
Reader's Digest, December, 1989 pp 86-91

THE NATIONAL GEOMAGNETIC INFORMATION CENTER
WAS ESTABLISHED IN THE FALL OF 1989 TO MEET THE
GROWING NEEDS OF THE SCIENTIFIC COMMUNITY
FOR NATIONAL AND INTERNATIONAL GEOMAGNETIC
INFORMATION.

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