INTERMAGNET: WORLDWIDE NEAR-REAL-TIME GEOMAGNETIC OBSERVATORY DATA

David Kerridge

British Geological Survey, Murchison House, West Mains Road, Edinburgh, EH9 3LA, UK, djk@bgs.ac.uk

ABSTRACT

A European Space Weather Programme will rely on the availability of near-real-time data to monitor and predict the Earth's response to changes in solar activity and conditions in the near-Earth space environment. Some relevant datasets are derived from ground-based geomagnetic field measurements and, through the INTERMAGNET programme, magnetic observatories are encouraged to send one-minute data in near real time to data collection centres designated Geomagnetic Information Nodes (GINs). Many observatories send data to a GIN within one hour, some within minutes. In 2001 there were 80 INTERMAGNET observatories worldwide, and six GINs, two located in Europe. GINs also act as data supply centres, with data delivery by electronic mail or by direct download from web pages hosted at GINs (http://www.intermagnet.org). The number and distribution of INTERMAGNET observatories, and the capability to deliver data, means that the programme is well-positioned to play a significant role in providing space weather services.

1. INTRODUCTION

The origins of INTERMAGNET can be traced to discussions on the possibility of rapidly exchanging data between magnetic observatories, which took place at the Workshop on Magnetic Observatory Instruments in Ottawa, Canada in August 1986. In 1987 the British Geological Survey (BGS) and the United States Geological Survey (USGS) agreed to a pilot scheme to exchange geomagnetic observatory data in near real time, communicating via the US GOES-East satellite (Geostationary Operational Environmental Satellite). The motivation for this trial was the demand for near-real-time data from the US Space Environment Center (SEC) acting principally on behalf of the US Air Force, which was concerned with the effects of space weather on its operations.

The initial trial, in which data were exchanged between Hartland Observatory (UK) and Boulder Observatory (US), was successful in demonstrating the feasibility of rapid geomagnetic data exchange, and the Geological Survey of Canada (GSC) and the Institut de Physique du Globe de Paris (IPGP) agreed to join BGS and the USGS in promoting the modernisation of geomagnetic observatory operations worldwide by establishing a programme which was christened INTERMAGNET.

The programme's purpose is stated as follows [1]:

> "The INTERMAGNET objective is to establish a global network of co-operating digital magnetic observatories adopting modern standard specifications for measuring and recording equipment in order to facilitate data exchange and the production of geomagnetic data products in close to real time."

The initiative to establish INTERMAGNET was supported by the International Association of Geomagnetism and Aeronomy (IAGA) and close contact is maintained with the IAGA bodies with interests in magnetic observatory practice, data, data derivatives, and applications.

Many magnetic observatories have operated for decades, some for more than 150 years. In the 1980s many observatories were still operating in "classical" mode, with analogue recording requiring labour-intensive processing and, consequently, long turn-round times for data processing. Developments in technology at around that time gave the opportunity to change to digital operation, and the evident demand for prompt access to data amounted to a requirement to do so, to make observatory operations relevant for users of near-real-time data and data products.

Magnetic observatories are characterised by the production, at stable sites, of long-term, continuous records of data of quality suitable for studies of the secular variations of the main (core) geomagnetic field. High quality is achieved by making regular absolute measurements to determine baselines for the continuous recordings. For INTERMAGNET to succeed it was necessary to convince the international observatory community that adopting modern technologies and data-processing practice would not compromise the data quality required for secular variation studies. This has now been clearly demonstrated, and participation in INTERMAGNET has grown steadily, to the point where (in 2001) about half of the world's observatories are members.

To provide an interface between individual observatories and data users, INTERMAGNET has established data collection centres, designated Geomagnetic Information Nodes (GINs). There are

GINs in North America (USGS, Golden and GSC, Ottawa), Europe (BGS, Edinburgh and IPGP, Paris) and Japan (Kyoto and Hiraiso). (The Kyoto GIN is run by the World Data Center for Geomagnetism at Kyoto University. The GIN in Hiraiso is operated by the Hiraiso Solar Terrestrial Research Center, Communications Research Laboratory.)

Since 1991, INTERMAGNET has published, annually, definitive one-minute data from all participating observatories on CD-ROM. This serves those in the scientific community concerned more with data quality than rapid access to data. This includes scientists developing models such as the International Geomagnetic Reference Field (IGRF) and researchers investigating the workings of the Earth's core. (All institutions participating in INTERMAGNET are provided with copies of the annual CD-ROMs. This has direct scientific value to the institutions, and has the added benefit of creating a distributed archive of the complete INTERMAGNET observatory datasets.)

In this paper, the management and activities of INTERMAGNET are discussed, and the operational methods and standards, from data collection to delivery are described. Examples are given of magnetic observatory data, and data products, relevant to users with interests in the effects on their activities resulting from changes in the state of the ionosphere and magnetosphere in response to changes in space weather.

2. INTERMAGNET MANAGEMENT

At the first formal meeting of INTERMAGNET, the representatives of the "founding institutions", USGS, BGS, GSC and IPGP, each responsible for magnetic observatory operations in their respective countries, agreed to establish a two-tier management structure consisting of an Executive Council and an Operations Committee.

The Executive Council is responsible for INTERMAGNET policy and liaison with national and international scientific and governmental agencies. The Operations Committee advises the Executive Council on technical matters and establishes standards for INTERMAGNET magnetic observatory operations.

Members of the committees work actively to persuade national institutions responsible for magnetic observatory operations, to join INTERMAGNET and add their observatories to the network. Through the Operations Committee, assistance is given to observatory operators to, where necessary, enable them to adjust their modes of operation to meet INTERMAGNET requirements. Such assistance has been effective in accelerating the rate of participation by observatories in less developed regions of the world where observatory coverage is sparse and, consequently, their inclusion in the INTERMAGNET network is particularly significant. More generally, many observatories in all parts of the world have made improvements to their procedures as a result of advice provided by INTERMAGNET members, resulting in the production of higher quality data.

3. INTERMAGNET OPERATIONS

The operations of INTERMAGNET are illustrated in Fig. 1. It is recommended that observatories run both a three-component vector magnetometer, with samples taken at least every 10 seconds, ideally every second, and an independent scalar magnetometer. The resolution of the magnetometers should be 0.1 nT. The sampled data are filtered to produce one-minute values, which are transmitted to a GIN within 72 hours of collection. In practice, many observatories are able to transmit data within minutes.

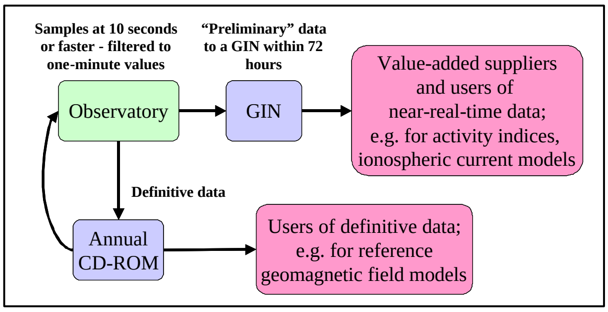

Fig. 1. Components of INTERMAGNET Operations

When INTERMAGNET started, the majority of the data were transmitted via geostationary meteorological and environmental satellites. This is still necessary for observatories in some remote areas of the world, but Internet communications are now widespread and reliable, and many observatories now transfer data to GINs by file transfer over the public Internet. Also, in the early days, data delivery from GINs to users was by electronic mail request and response. Recent work on the INTERMAGNET web pages has been carried out to enable flexible and interactive selection of data for display and download. The GINs operate mirror web sites to ensure a timely response from the web pages for users in different regions of the world at all times of the day. For users with a requirement for sets of data to be delivered regularly, "standing order" arrangements can be made with one of the GINs for automated delivery.

The INTERMAGNET operations and functions are underpinned by detailed work carried out by sub-committees of the Operations Committee. The following list summarises the current sub-committee structure and functions.

- **INTERMAGNET Applications and Standards**

Considers applications for INTERMAGNET membership against standards for instrumentation, data quality, and acquisition, processing and transmission of data, which the sub-committee has developed.

- **Geomagnetic Information Nodes (GINs) and the World Wide Web**

Defines GIN operational standards and develops the content of the INTERMAGNET web pages, including access to data (http://www.intermagnet.org).

- **Data Formats**

Defines data formats to be used in all aspects of INTERMAGNET operations.

- **CD-ROM**

Compiles and applies quality control procedures to the definitive one-minute datasets submitted for publication on CD-ROM. Data accession and display software is supplied together with the CD-ROM.

- **Technical Manual**

The work of all the sub-committees is brought together in the INTERMAGNET Technical Manual. This contains all the information needed by prospective members to compare their operations against the INTERMAGNET standards. The manual, which also sets out conditions on INTERMAGNET membership and the organisation's principles, can be downloaded from the INTERMAGNET web pages.

4. INTERMAGNET DATA AND SPACE WEATHER APPLICATIONS

Magnetic activity indices are the most frequently used parameterisations of the degree of disturbance of the geomagnetic field. They are computed using records from specific networks of magnetic observatories. At an early stage, INTERMAGNET strategy, recognising the importance of indices, was to recruit observatories in the various index networks. INTERMAGNET policy is not to compute indices, but to improve the timeliness of the supply of data to the organisations with official responsibility for their production. These are organised under the auspices of the International Service for Geomagnetic Indices (ISGI), a component of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS).

4.1 Commonly-Used Magnetic Activity Indices

Values of the ***aa* index**, based on data from Hartland (UK) and Canberra (Australia), are available at 3-hour UT intervals from 1868. Both observatories are INTERMAGNET members.

The ***Kp* index** (and equivalent ***ap* index**), probably the most widely used geomagnetic activity index, is a generalised mid-latitude index computed at 3-hour UT intervals, available from 1932. All 13 contributing observatories are INTERMAGNET members.

The ***Km* index** (and equivalent ***am* index**) is an "improved *Kp*" mid-latitude geomagnetic activity index computed at 3-hour UT intervals, available from 1959. The improvements over *Kp* come from the greater number and better distribution of the contributing observatories. Of the 21 observatories in the *Km/am* index network 18 are INTERMAGNET members.

The ***Dst* index** is a measure of the equatorial current system in the magnetosphere usually referred to as the ring current. The index has been computed at one-hour resolution since 1957. All four of the contributing observatories are INTERMAGNET members.

The ***AE* index** is a measure of the intensity of the auroral electrojet current system, computed at one-minute resolution, and available from 1978. Of the eleven observatories contributing data for computation of the index seven are INTERMAGNET members.

It is notable that all but one of the observatories providing data for these indices that are *not* INTERMAGNET observatories are in the Former Soviet Union (FSU).

(More information on the various indices can be found at the ISGI web site, and via links from the ISGI site to the web sites of affiliated organisations.)
(http://www.cetp.ipsl.fr/~isgi/homepag1.htm.)

The ease of access to digital data and modern computing facilities opens up the possibility of devising new measures of geomagnetic activity with a more transparent physical interpretation than some of the older indices. However, the value of the long homogeneous series of the traditional indices should not be underestimated. For example, the *aa* index series has been used to demonstrate long-term variability in solar-terrestrial interactions, with possible implications for climate change.

Both geomagnetic indices and data from individual observatories are used in monitoring the instantaneous state of the geomagnetic field and as inputs to models of processes, which may have a predictive element. For example, solar and magnetic activity indices are used in atmospheric density models used in computing drag on low-Earth-orbit satellites. Such models can be used as a planning tool using predicted values of the appropriate indices [2].

4.2 <u>Examples of Applications of Near Real-Time Data</u>

The geomagnetic field is used as a directional reference in well-bore surveys carried out in the oil industry using magnetic sensors. The accuracy of directional drilling relying on the geomagnetic field reference depends on how well the geomagnetic field (all three components) is specified at the drilling location. In this application, the geomagnetic field is used as a navigational tool, but the risk to operations at magnetically disturbed times is increased unless the short-term magnetic field variations are taken into account, or the error model used in analysing survey data is adjusted to use appropriate parameters. More details of this application are given in [3], [4] and [5].

At magnetically disturbed times, the time-varying magnetic fields created by ionospheric electric currents induce electric fields in the solid Earth leading to so-called Geomagnetically Induced Currents (GIC). The GIC pose a hazard to electrical power distribution systems, particularly to transformers. The value of near-real-time monitoring data and activity forecasts to power transmission system operators is discussed in [6].

5. CONCLUSIONS

INTERMAGNET has, in over little more than 10 years, grown into a worldwide federation of institutions running magnetic observatories, and become the *de facto* professional body representing magnetic observatory operators. By promoting modernisation of observatory practice INTERMAGNET has helped to improve data quality as well as availability. It has also been influential in the establishment of several new magnetic observatories. Approximately half the world's observatories are now INTERMAGNET members, and the number continues to rise year by year.

Overall, the INTERMAGNET initiative can be judged to have been a success, but there are problems. Of particular concern is the state of observatories in the FSU. These observatories cover a substantial area of the globe and it seems that many are ceasing to function. INTERMAGNET has had very limited success in its efforts to bring observatories from the FSU into the programme, despite considerable efforts. Also, there remains a bias in the distribution of participating observatories towards the developed parts of the northern hemisphere. Nevertheless, the INTERMAGNET observatory network does now provide reasonable global coverage.

INTERMAGNET has created the capability to supply ground-based geomagnetic variation data quickly and efficiently and is ready to work with users of the data to tailor services to suit particular applications. Users include individual research scientists, providers of "added-value" products such as the ISGI magnetic activity indices and forecasts issued by, for example, the Regional Warning Centers of the International Space Environment Service. It is anticipated that a number of new customers will be found within the community interested in the establishment of a co-ordinated European Space Weather Programme.

6. ACKNOWLEDGEMENTS

The contributions of members of the INTERMAGNET Executive Council and Operations Committee, and of the participating national institutions and observatories, and funding support via the International Council for Science (ICSU) are all gratefully acknowledged. I pay tribute to Bill Green of the USGS, the initial prime mover in INTERMAGNET, who was a member of the Executive Council from its establishment until he passed away in December 2001.

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