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An International Network of Magnetic Observatories

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Since its formation in the late 1980s, the International Real-Time Magnetic Observatory Network (INTERMAGNET), a voluntary consortium of geophysical institutes from around the world, has promoted the operation of magnetic observatories according to modern standards [e.g., *Rasson,* 2007]. INTERMAGNET institutes have cooperatively developed infrastructure for data exchange and management as well as methods for data processing and checking. INTERMAGNET institutes have also helped to expand global geomagnetic monitoring capacity, most notably by assisting magnetic observatory institutes in economically developing countries by working directly with local geophysicists.

Today the INTERMAGNET consortium encompasses 57 institutes from 40 countries supporting 120 observatories (see Figures 1a and 1b). INTERMAGNET data record a wide variety of time series signals related to a host of different physical processes in the Earth's interior and in the Earth's surrounding space environment [e.g., *Love,* 2008]. Observatory data have always had a diverse user community, and to meet evolving demand, INTERMAGNET has recently coordinated the introduction of several new data services.

Standard Data Types

INTERMAGNET has traditionally focused on observatory production of 1-minute average magnetic vector data of two types. "Preliminary" data are unprocessed records of the time-dependent minute-to-minute change of the geomagnetic vector, acquired by a fluxgate magnetometer and made available to users through the INTERMAGNET website, by requirement, within 72 hours of acquisition.

"Definitive" data are produced through processing, combining fluxgate data with auxiliary measurements of absolute field direction and intensity to correct for fluxgate orientation and baseline drift [e.g., *Jankowski and Sucksdorff,* 1996]. INTERMAGNET coordinates the checking of this calibration process. Organized and certified definitive data have been produced annually since 1991. They are available from the INTERMAGNET website, on DVDs, and through the World Data System.

Standard Derived Products

Because observatories are a reliable source for geomagnetic time series having good long-term continuity and accuracy, INTERMAGNET data are used for two important and very different derived products. First, the International Geomagnetic Reference Field (IGRF) is a spherical harmonic expansion model of the main field, which is mostly generated by the geodynamo in the Earth's core. Widely used in scientific research and for orientation, navigation, and near-surface magnetic surveys, IGRF is constructed using a combination of data from low-orbiting satellites, ground observatories (including INTERMAGNET observatories), and surveys [e.g., *Matzka et al.,* 2010]. Because the geomagnetic field exhibits secular variation, the IGRF is updated every 5 years [e.g., *Finlay et al.,* 2010]. Figure 1b shows a map of 2010 IGRF declination (compass deviation from geographic north).

Second, magnetic indices are summary measures of magnetic disturbance and magnetic storm intensity [e.g., *Mayaud,* 1980]. For example, the storm time magnetic disturbance index, *Dst,* measures the strength of the magnetospheric equatorial ring current; *Dst* is the standard measure of overall global magnetic storm intensity, and it is often used in numerical simulations of the active magnetosphere. The auroral electrojet index, *AE,* measures the strength of electric currents in the high-latitude auroral oval. The older *K* and *Kp* indices measure the range of midlatitude magnetic field variation, and they are often used for space weather hazard assessment.

Meeting Evolving Demands

In support of the upcoming European Space Agency Swarm magnetic satellite mission [*Friis-Christensen et al.,* 2006], scheduled to be launched in November 2013, and in response to interest within the scientific community for the prompt updating of main field models, several INTERMAGNET institutes now produce lightly processed "quasi-definitive" data reported within a few months of first acquisition [*Peltier and Chulliat,* 2010]. Data of this type will be used during the Swarm mission to calculate and validate spherical harmonic models of the core, lithospheric, ionospheric, and magnetospheric fields. They will also be used for data-assimilated forecasting of main field evolution [*Fournier et al.,* 2010], taking into account rapid secular variation and acceleration.

Magnetic observatories contribute important real-time data to national and regional projects for integrated space weather monitoring and hazard mitigation [e.g., *Kerridge,* 2001; *Love and Finn,* 2011]. Large magnetic storms can cause loss of radio communications, reduce the accuracy of global positioning systems, damage satellite electronics and affect their operation, increase pipeline corrosion, and induce voltage surges in electric power grids, causing blackouts. Figure 1c shows INTERMAGNET data recording the Halloween storm of October 2003. As of July 2013, data from about 40 INTERMAGNET observatories are available in near–real time for noncommercial use, often with a delay of less than 10 minutes.

During a magnetic storm, the solar wind's interaction with the Earth's magnetosphere often causes abrupt rearrangement of field lines in the magnetotail, generating transient waves and pulsations in the geomagnetic field that can be detected at the Earth's surface. To support the study and monitoring of this phenomenon, several INTERMAGNET institutes now produce high-quality 1-second resolution data in addition to the traditional 1-minute data. This important new service augments the geographic coverage already provided by 1-second data collected by, for example, university magnetometer networks [e.g., *Yumoto et al.,* 2012], and it has led to the development of new diagnostic indices for magnetic waves and pulsations [e.g., *Nosé et al.,* 2012].

Several INTERMAGNET institutes now apply simple real-time calibrations to produce "adjusted" preliminary data that are expressed in geographic coordinates but that have not yet been subjected to detailed scrutiny. These are used by the oil and gas industry for directional

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drilling, a method by which multiple reservoirs can be accessed from a single platform by drilling down and then out horizontally. Directional drilling reduces development costs, and it minimizes impact to the surface environment, but it requires a method for absolute downhole orientation of the drill bit. One way of accomplishing this orientation is with a magnetometer in the drill string instrument package and simultaneous monitoring of the geomagnetic field on the surface at an observatory [e.g., *Reay et al.,* 2005]. At high latitudes, such as in the North Sea or northern Alaska, the geomagnetic field can be very active, and therefore, accurate real-time observatory data can be of critical importance for accurate directional drilling.

Looking Forward

In the future, improved global monitoring of the Earth's magnetic field could be accomplished in several ways: spatially, by expanding the geographic distribution of the observatory network, and temporally, by expanding acquisition sampling to higher frequencies. Alternatively, magnetic observatories might also augment their operations by, for example, collecting electric field data that are useful for magnetotelluric studies of the Earth's interior electrical conductivity. Such data are also increasingly of interest for analysis of geomagnetically induced currents that are potentially hazardous to electric power grids. In this era of limited funding for science, progress on these and other geophysical frontiers will continue to benefit from international collaboration [e.g., *Onsager,* 2012].

For more information and to download data, please visit http://www.intermagnet.org.

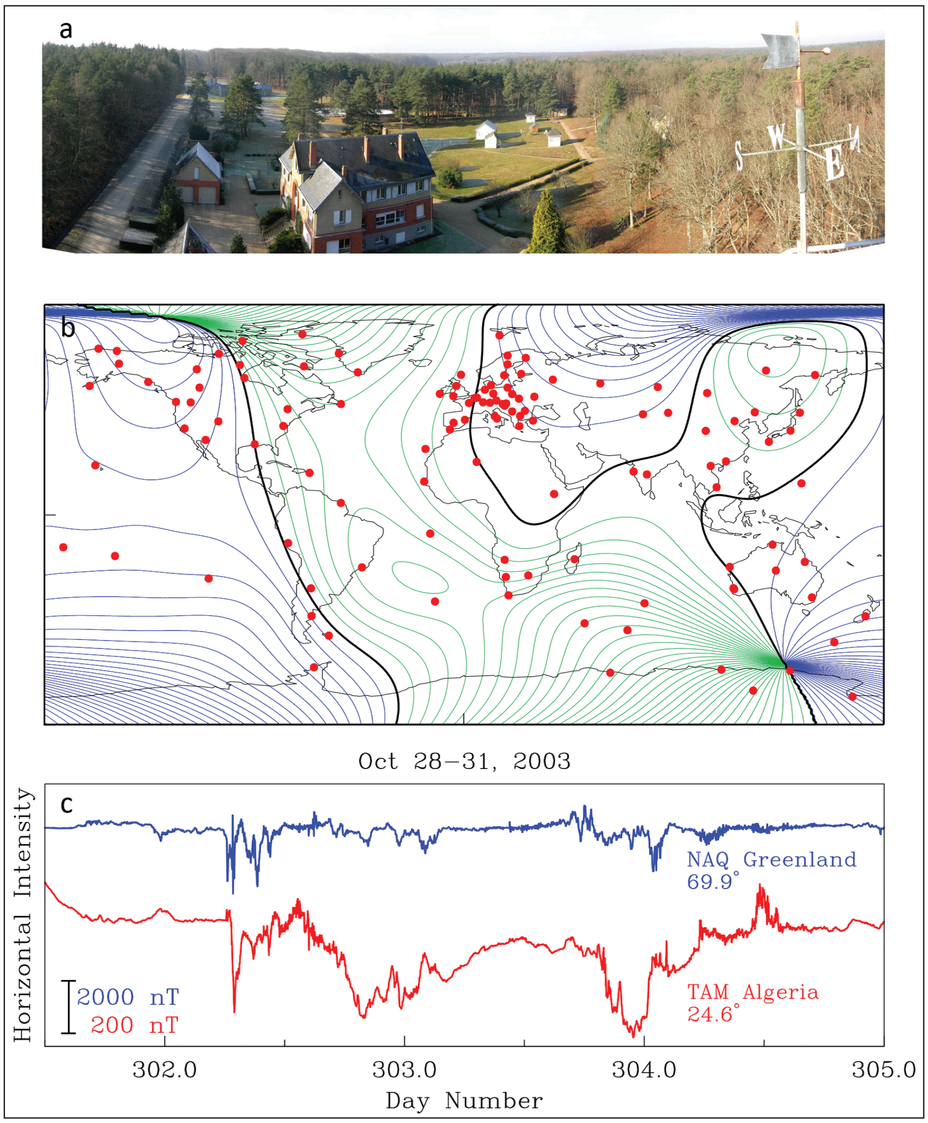

Fig. 1. (a) Panoramic view of the Chambon-la-Forêt observatory, outside of Paris, France. (b) Map showing the locations (red) of the International Real-Time Magnetic Observatory Network (INTERMAGNET) observatories as of February 2013, together with 2010 International Geomagnetic Reference Field (IGRF) magnetic declination. Contour levels are 5°: east, blue; west, green; zero, black. (c) Examples of observatory magnetograms recording the October 2003 Halloween storm that are now available in near–real time; horizontal intensity is shown for Narsarsuaq (NAQ), Greenland, and Tamanrasset (TAM), Algeria. Occasional partial "substorm" collapses of the magnetospheric ring current and diversion along field lines into and out of the ionosphere are seen as intermittent anticorrelations in magnetic time series acquired at low and high latitudes.

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