Geomagnetic Field Monitoring at Barrow, Alaska

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Temporal variations in the Earth's magnetic field occur over an astonishingly wide spectrum, with periods ranging over 20 orders of magnitude: sub-milliseconds to tens of millions of years [*Parkinson*, 1983; *Courtillot and LeMouel,* 1988]. These variations have a variety of causes and effects, some of which are understood and others of which remain rather more mysterious. Magnetic field variations with periods less than a few decades can be monitored and studied with magnetic observatories, such as that operated by the U.S. Geological Survey (USGS) in Barrow, Alaska.

The most rapid geomagnetic field variations are of external origin, coming from the ionosphere and magnetosphere. The magnetic field is particularly time dependent during so-called "magnetic storms," which, at the surface of the Earth, are prominent manifestations of the variable conditions in the near-Earth space environment, or "space-weather." The most energetic magnetic storms occur during peaks in solar activity and when the interplanetary magnetic field (IMF) becomes intimately connected with that of the Earth (Figure 1) [*Russell*, 1991; *Gonzales et al,*. 1994; *Cowley,* 1995; *Burch*, 2001].

Data from ground-based magnetic observatories play an important role in the diagnosis of space weather conditions, which influence the performance and reliability of technological systems that are critical to modern civilization [*Dooling*, 1995; *Scott*, 1997; *Nordwall*, 1999]. During stormy conditions both high- and low-frequency radio technological systems that are critical to modern civilization communication can be difficult if not impossible, Global Positioning Systems (GPSs) can be degraded, satellite electronics can be damaged, satellite drag can be enhanced, and astronaut and high-altitude pilots can be subjected to enhanced levels of radiation [*Maynard*, 1995; *Shea and Smart*, 1998; *Feynman and Gabriel*, 2000].

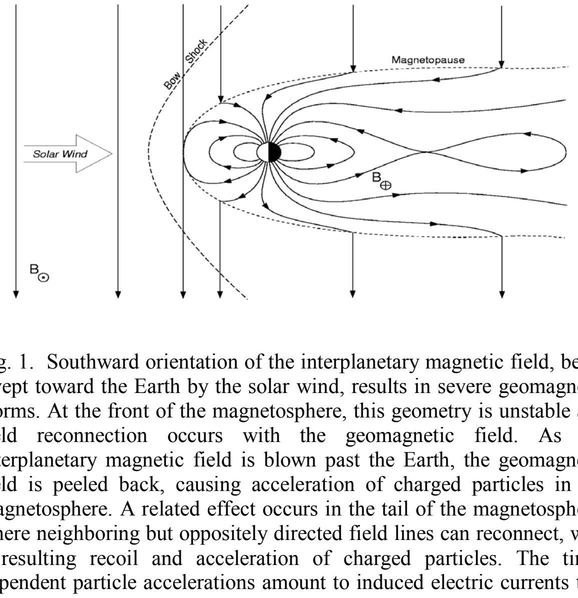

Fig. 1. Southward orientation of the interplanetary magnetic field, being swept toward the Earth by the solar wind, results in severe geomagnetic storms. At the front of the magnetosphere, this geometry is unstable and field reconnection occurs with the geomagnetic field. As the interplanetary magnetic field is blown past the Earth, the geomagnetic field is peeled back, causing acceleration of charged particles in the magnetosphere. A related effect occurs in the tail of the magnetosphere, where neighboring but oppositely directed field lines can reconnect, with a resulting recoil and acceleration of charged particles. The time-dependent particle accelerations amount to induced electric currents that sustain their own magnetic fields and contribute to the magnetic variations detectable at the Earth's surface.

Toward the other end of the temporal scale, geomagnetic variations with periods longer than a few decades, including the occasional reversal of the magnetic field, are of internal origin, caused by fluid motion in the Earth's liquid iron outer core [*Busse*, 1983; *Bloxham and Gubbins*, 1989; *Lov*e, 1999]. It is well known that the compass does not usually point toward true north. In fact, the deviation from north, or declination, differs depending on the observer's geographic location. Furthermore, over historical times, declination and the entire magnetic vector change noticeably with time. These complexities, while scientifically interesting, have long been a nuisance for navigators [*Jackson et al.*, 1997] and helped to motivate some of the original research in geomagnetism.

THE GEOMAGNETIC OBSERVATORY

The Barrow Geomagnetic Observatory is the northernmost of 14 USGS digital magnetic observatories. Established in 1949 by what was then the U.S. Coast and Geodetic Survey, responsibility for observatory operation was passed on to NOAA in 1970 and then ultimately to the USGS in 1973. Its location puts it near the boundary of the auroral zone and polar cap, two distinctly different regions of the Earth's magnetic field. As such it is an important site in the global network of geomagnetic observatories, which, in combination, allows for global monitoring of geomagnetic field variations. Ground-based stations, such as the Barrow Geomagnetic Observatory, serve as controls for internal and external field modeling, as reference stations for satellite measurements made within or above the ionosphere, and as absolute calibration locations for field surveys.

Over its lifetime Barrow Observatory (Figure 2) has been extensively upgraded, with new buildings, magnetometers, and data transmission equipment installed to meet modern demands for precision and timeliness [*Townshend*, 2001]. Building insulation and heaters provide a thermally stable environment for the magnetometers even though the outside temperature can reach –50ºC. All buildings and exterior structures must be capable of handling wind speeds in excess of 113 km (70 mi) per hour.

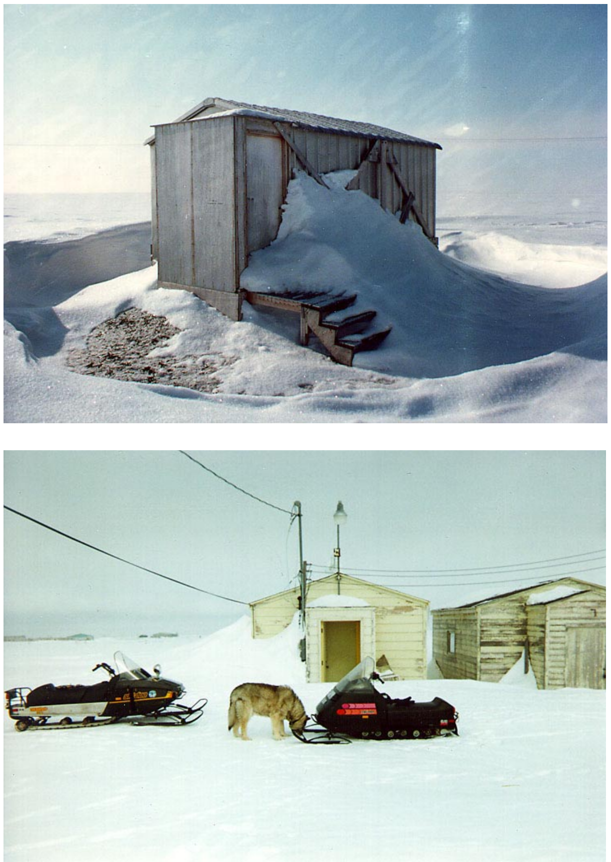

Fig. 2. Top: The variation building that houses the fluxgate magnetometer. Bottom: The main building that contains data collection electronics.

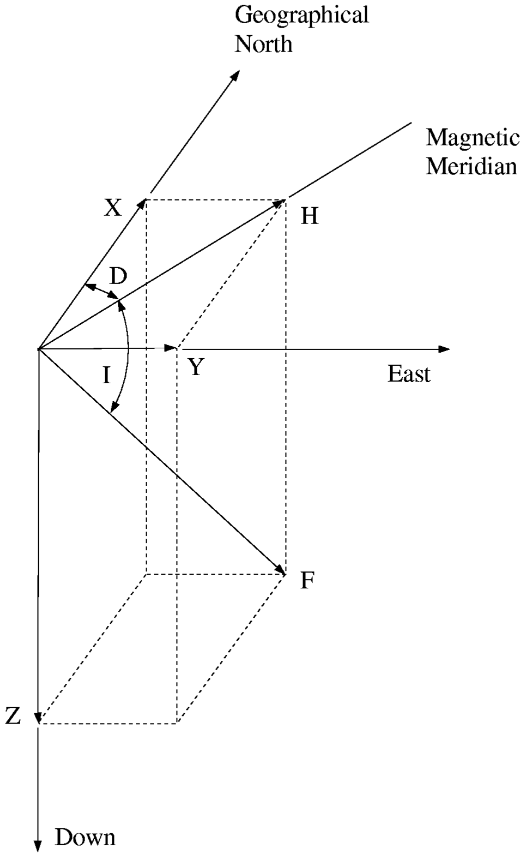

Fig. 3. The magnetic field components. The Cartesian components (X, Y, Z) define north, east, down; the spherical components (F, I, D) define intensity, inclination, declination; H is the horizontal component of intensity.

Magnetic measurements at Barrow are made consistent with standards set by Intermagnet, an international consortium that oversees the operation of about 80 magnetic observatories throughout the world. Being a vector, the Earth's magnetic field has both direction and intensity; field components are defined in Figure 3. To measure the various parts of the magnetic vector, the observatory is equipped with a tri-axial fluxgate magnetometer and a total field proton magnetometer, both of which are controlled by a digital data acquisition system. The fluxgate, shown in Figure 4, continuously records variations in the Earth's magnetic field, specifically, the horizontal field (H), the deviation from geographic north, or declination (D), and the vertical field component (Z). To account for a slow drift in calibration, the intensity (F) is measured absolutely by the proton magnetometer, and direction is measured absolutely by hand with a declination-inclination magnetometer, consisting of a single-axis fluxgate magnetometer mounted to a theodolite (Figure 5).

Piers within the site buildings (Figure 6) provide stable platforms to make the vectorial magnetic measurements, but the active permafrost layer makes pier construction difficult. At most observatories large non-magnetic concrete piers are set straight into the ground. However, at Barrow a pier can shift because concrete acts as a heat conductor, warming the permafrost, and thereby causing a seasonal freezing and thawing. To avoid this, a hole is

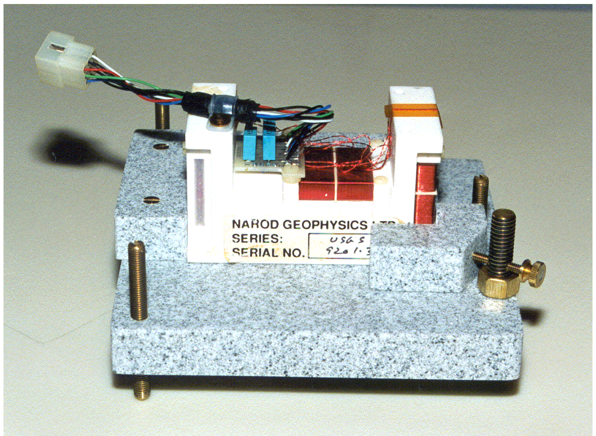

Fig. 4. A tri-axial fluxgate sensor of the type used to measure magnetic field variations at Barrow.

Fig. 5. A declination-inclination magnetometer of the type used to measure the absolute magnetic field direction.

drilled to a depth below the active permafrost layer, and a long wooden post is then frozen into place during the wintertime. The post is packed around with insulating Styrofoam. The top part of the post is encased in a concrete jacket, which uses Styrofoam pellets and vermiculite as the aggregate. This concrete is a thermal insulator but retains enough strength to achieve stability. The surface around the pier is covered with rigid foam insulation to insulate the ground from the building.

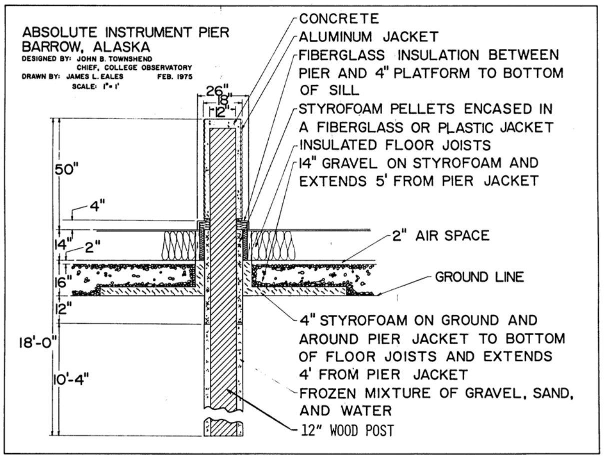

Fig. 6. The design of the absolute pier used at Barrow.

MAGNETIC DATA: EXAMPLES AND USES

Data from Barrow are transmitted via a combination of satellite and ground links to the USGS Geomagnetism Group, which is part of the Central Region Geologic Hazards Team headquartered in Golden, Colorado. Near-real-time data from Barrow, together with similar data from the group's other observatories, are forwarded by the USGS to the NOAA Space Environment Center (SEC) and to the U.S. Air Force for use to forecast space-weather phenomena. Final processed data from Barrow, and the other 13 USGS observatories, are sent to NOAA to be archived, and they are also distributed on Intermagnet CDs.

During magnetic storms, data recorded at Barrow display a high level of activity compared with data from observatories at lower latitudes. As an example, data recorded during the so-called "great" magnetic storm of March 1989 are shown in Figure 7. This storm induced currents in power grids, thereby causing system-wide power blackouts in Quebec, power equipment problems in the northeastern United States, radio communication blackouts, and increased satellite drag that actually altered the orbits of a number of satellites [*Joselyn*, 1989]. The sharp, sudden onset of magnetic field variation in the beginning of March 13 is the result of a large mass ejected 2 days earlier from the surface of the Sun (Figure 7).

The higher level of activity seen at Barrow is caused by magnetic fields sustained by the auroral electrojet (AE). As illustrated in Figure 1, with an enhancement of the solar wind caused by ejection of charged particles from the Sun's surface and a coupling of the solar and geomagnetic fields, energy stored in the magnetosphere is released as an electric current. This current flows into the ionosphere near the geomagnetic poles and drives the auroral electrojet, a symptom of which are the bright auroras seen during magnetic storms. Barrow is one of 12 high-latitude magnetic observatories that provide magnetic data to compute the AE index, a simple measure of the auroral electrojet intensity [*Parkinson*, 1983; *McPherron*, 1995]. Near-real-time and historical values of AE can be obtained from the World Data Center at Kyushu University, Japan.

Long-term averages of the magnetic data can be used to study the dynamic processes operating in the Earth's liquid iron outer core, which is the site of the dynamo that sustains the main part of the geomagnetic field. With annual means of magnetic data it is possible to observe the slow drift in the field that results from fluid motion in the core. Figure 8 shows the change in the declination, inclination, and intensity at Barrow since the observatory was opened in 1949. Ultimately, the data from Barrow and other observatories are used to generate maps and models of the Earth's magnetic field, such as the International Geomagnetic Reference Field [*Macmillan and Quinn*, 2000].

CONCLUSION

The USGS Geomagnetism Group is working to upgrade the facilities at Barrow so that measurements are made with better precision and finer temporal resolution. Data transmission capabilities are being upgraded so that the data can be distributed in real time with improved reliability. All

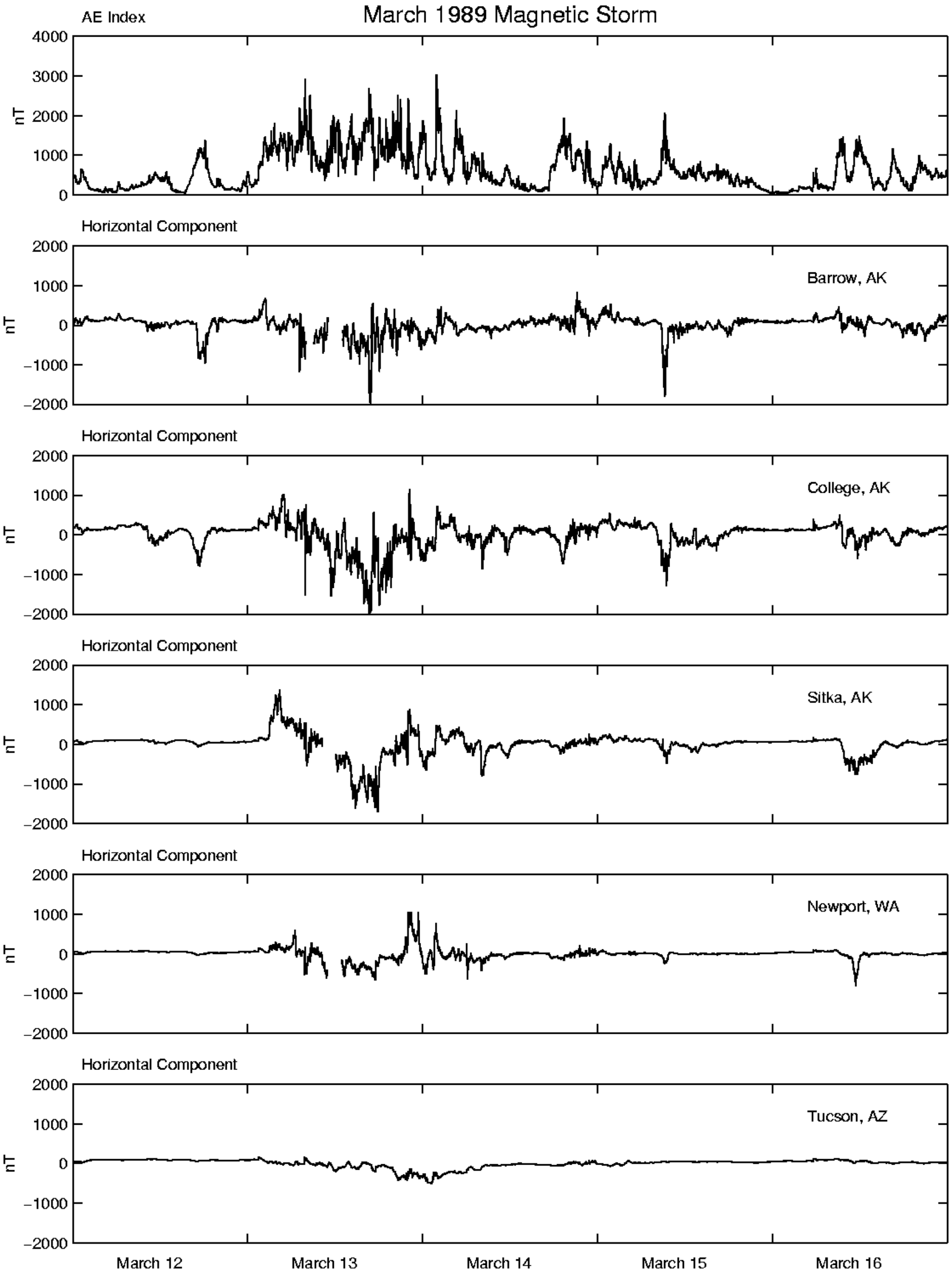

Fig. 7. Measurements made during the "great storm" of March 1989. The top panel is the AE index, which measures auroral electrojet current; below are the horizontal magnetic fields as measured at five different USGS magnetic observatories.

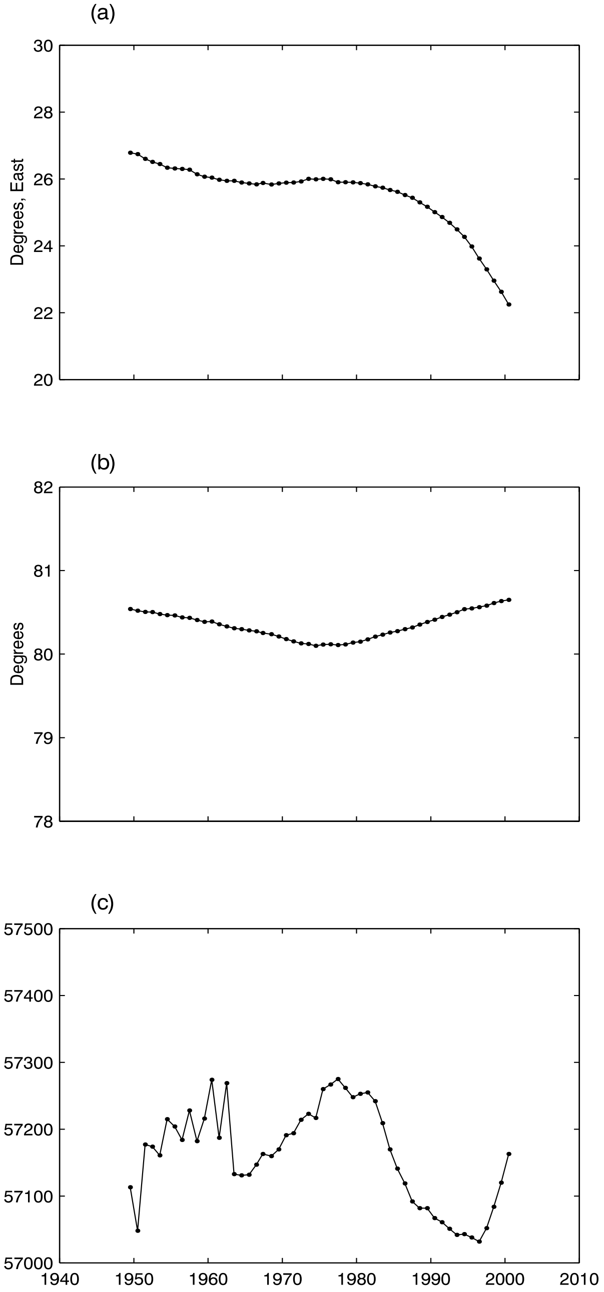

Fig. 8. Field components at Barrow from 1949 to present: (a) declination angle, (b) inclination angle, and (c) intensity as measured in nanoTeslas (nT). Reduction in the scatter seen in the field intensity after 1962 reflects an instrument upgrade.

these efforts will enhance the scientific and societal relevance of the USGS Barrow Geomagnetic Observatory.

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