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Survey of Annual Fluctuations in Total Geomagnetic Intensity Observations

by

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Abstract

Annual fluctuations in total magnetic intensity are observed at the continuous total geomagnetic intensity station (79F) at the Memambetsu branch. To identify the causes of this fluctuation, we measured outdoor air temperature and underground temperatures (at depths of 0.1, 0.5, and 1 m) near 79F in order to clarify their relationship with the fluctuations in total geomagnetic intensity. The results of this survey revealed that the annual fluctuations have a high correlation with the underground temperatures near the ground surface. We also conducted a magnetic survey in an area of the Memambetsu branch including 79F, and we found that the magnetic gradient near 79F was considerably greater in the east-west direction (10 nT/m) than that in the north-south direction. We therefore concluded that the annual fluctuations at 79F are caused by local variations in the magnetic field around the station that result from temperature changes.

1. Introduction

The Memambetsu Geomagnetic Observatory (hereafter called "Memambetsu") is equipped with three proton magnetometers (MO-PE-79F [79F], MO-PE-79H [79H], and MO-P75TF [TF]; Fig. 1). Of these three, 79F is designated the continuous observation point for total magnetic intensity. Observations and surveys in the past have confirmed annual fluctuations in the total magnetic intensities at different observation points at the Memambetsu site (Hasegawa et al., 2005). Differences in the total magnetic intensity measured by the three proton magnetometers are plotted in Fig. 2. The differences from 79F (TF-79F, 79H-79F) indicate a large annual fluctuation; it is estimated that there is an annual fluctuation of about 1 nT between the winter and the summer. To investigate the cause, we measured the fluctuations in external air temperature, underground temperatures (at depths of 0.1, 0.5, and 1 m), and the total magnetic intensity in the area around 79F, and also conducted a geomagnetic survey in the 150×150 m area on the south side of the premises which included 79F. The ambient and underground temperatures were measured by temperature data logger (Ondotori TR-52; T&D Co., Ltd., Nagano, Japan).

2. Comparison of total magnetic intensity and temperatures

Past surveys confirmed that the annual fluctuations at 79F showed a pattern similar to the temperature changes in the central semi-subterranean room (2 m below the ground). On the hypothesis

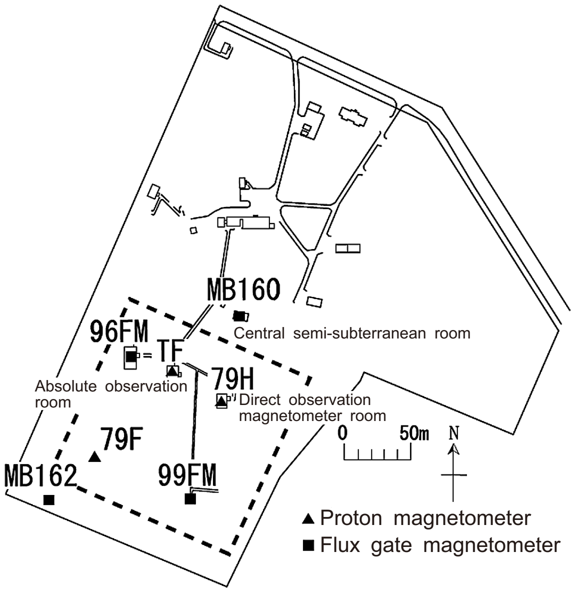

Fig. 1 Location of proton magnetometers and flux gate magnetometers at the Memambetsu Observatory
The square marked by the dotted line indicates the range of magnetic field observation

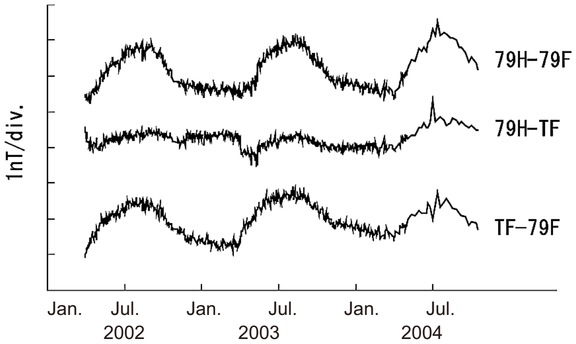

Fig. 2 Differences in total magnetic intensity
(Period: Jan. 2002 - Sept. 2004)

that one cause of these annual fluctuations was magnetic variations due to changing soil temperatures, we installed thermometers 5 m south of 79F in order to measure the ambient and underground temperatures (at depths of 0.1, 0.5, and 1 m) over the period from June to July 2004.

Fig. 3 shows time-series plots of the differences in total magnetic intensity and temperatures during the period from January to December 2004 (from August to December 2004 for the temperatures). The ambient temperatures and the temperatures at a depth of 0.1 m show short-period fluctuations. For ambient temperatures, diurnal differences of around 15°C and seasonal differences between summer and winter of around 30° are seen. At the depth of 0.1 m, the short-period fluc-

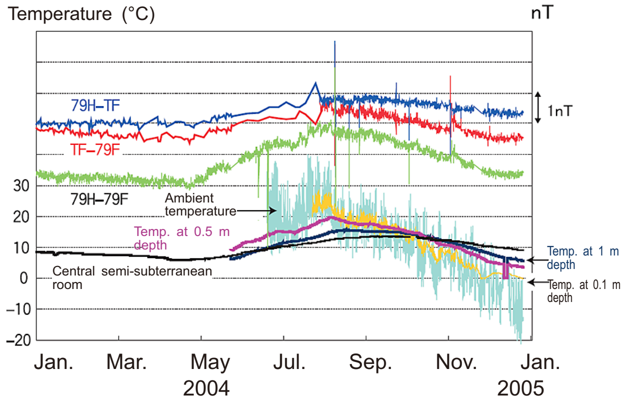

Fig. 3 Time-series plots of differences in total magnetic intensity, ambient temperature, and underground temperatures (at depths of 0.1, 0.5, and 1 m)
(Period: Jan. 2004 - Dec. 2004)

tuations ranged by as much as 5°C during summertime when there was strong solar radiation. The range became narrower over the period from fall to winter, stabilizing at near 0°C in early December onward due to snow accumulation. The temperature range between summer and winter was about 25°C. No short-period fluctuations were observed at depths of 1 and 0.5 m, and a phase lag was evident relative to the ambient temperatures. The temperature range was around 20° in summer and around 10°C in winter. Values of the difference in total magnetic intensity between TF and 79F varied by about 0.2 nT/day and 1.0 nT/year.

Fig. 4 and 5 are scattergrams of ΔF (TF-79F; 79H-79F) plotted against ambient temperature and underground temperatures (at depths of 0.1, 0.5, and 1 m) for the period from August to December 2004. Correlation between ambient temperature and ΔF deteriorates at the time of a low temperature (coinciding with the snow season). The underground temperatures and ΔF show a stronger correlation at depths of 0.1 and 0.5 m than at 1.0 m. At depths of 0.5 and 1 m the slope of the correlation of temperature with ΔF changes at around 18°C and 15°C, respectively, but at a depth of 0.1 m the correlation remains strong throughout the period from summer to winter. These results suggest that the annual fluctuations at 79F is affected by variations in the underground temperatures at relatively shallow depths of 0.1 to 0.5 m.

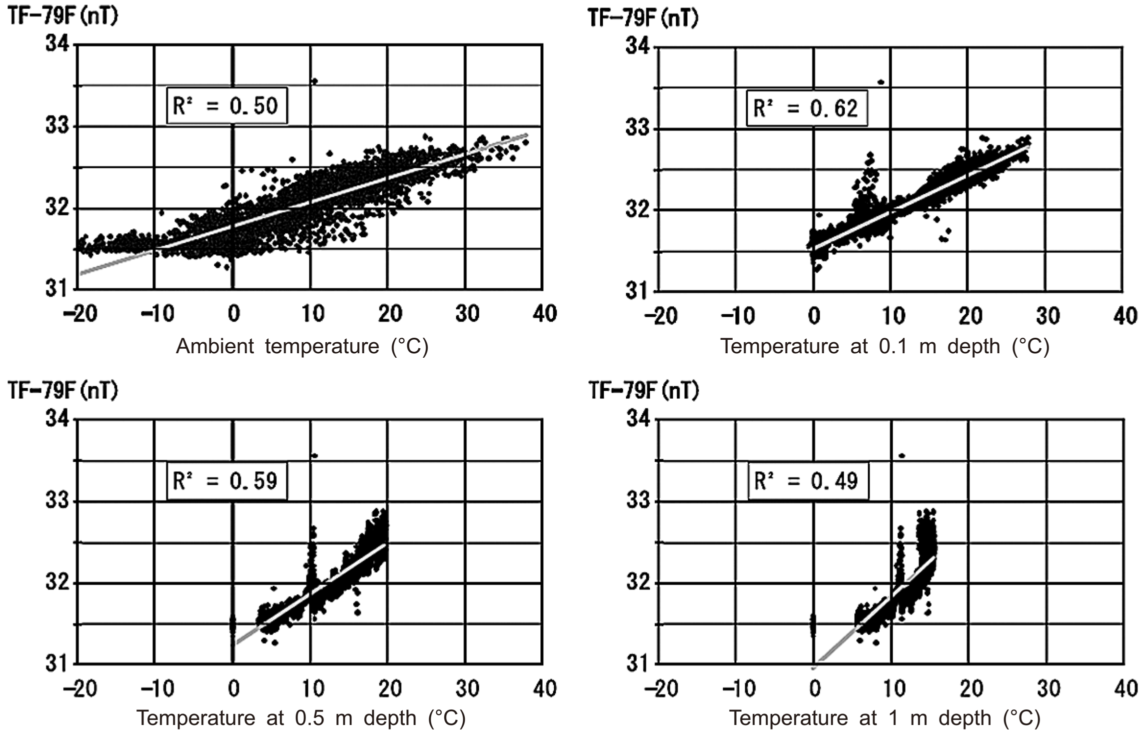

Fig. 4 TF-79F plotted against ambient temperature and underground temperatures (at depths of 0.1, 0.5, and 1 m)
R^2: Square of correlation coefficient; White line: Linear first-order approximation

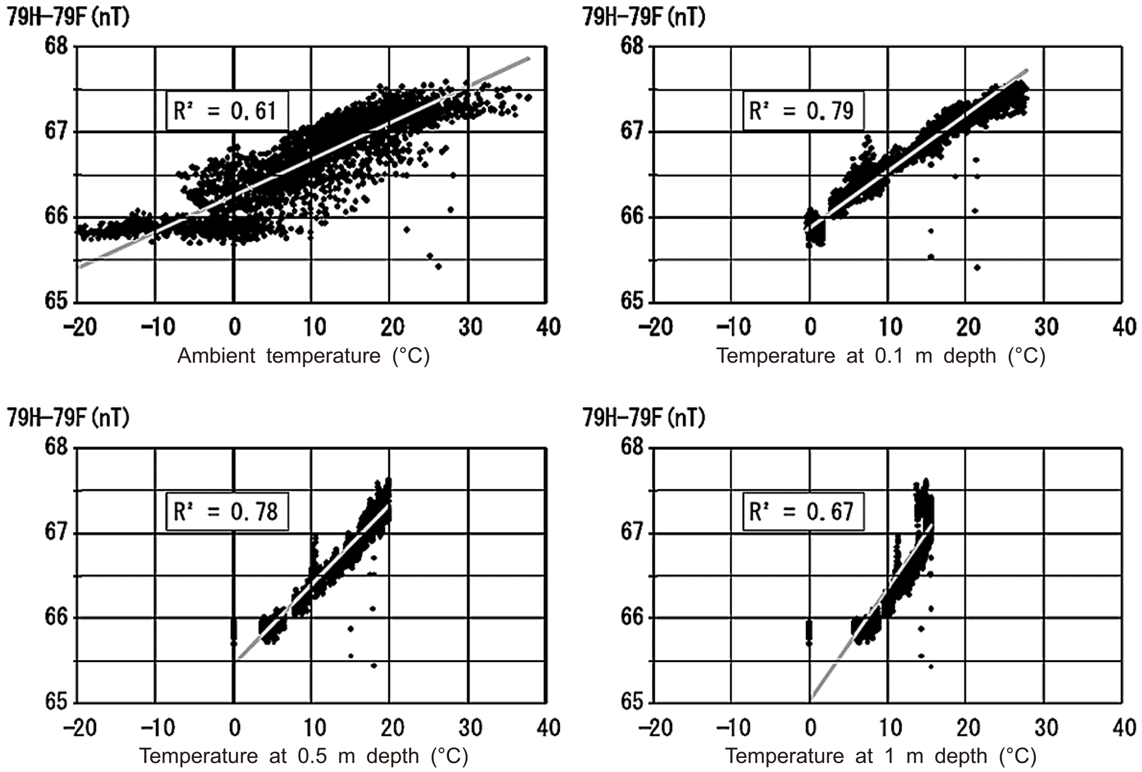

Fig. 5 79H-79F plotted against ambient temperature and underground temperatures (at depths of 0.1, 0.5, and 1 m)
R^2: Square of correlation coefficient; White line: Linear first-order approximation

3. Results of the magnetic field survey

Fig. 6, 7, and 8 present the results of the magnetic field survey on the south side of the Memambetsu premises in August 2004. Measurements were taken at a total of 165 points by sensors installed at 2 and 3 m above the ground in a 150×150 m area sectioned into a 12.5-m mesh. A G856 proton magnetometer was used in

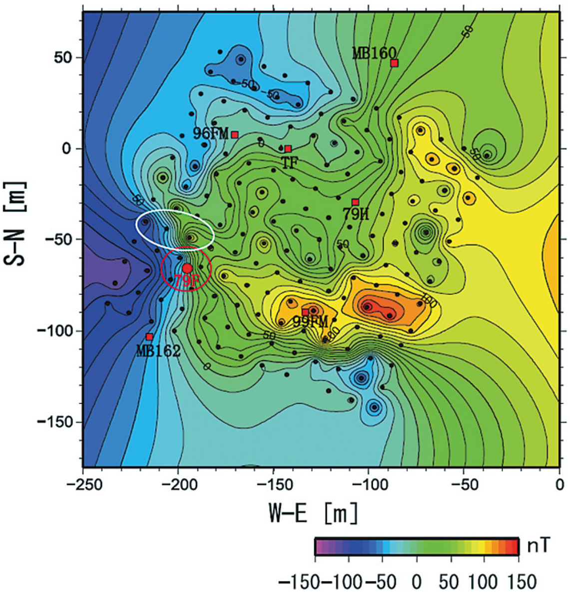

Fig. 6 Horizontal magnetic field gradient (sensor at 2 m above ground)
Measurements taken in the square area marked in Fig. 1 (165 points in the 150×150 m area sectioned into a 12.5-m mesh). Bold contour: 50 nT; Thin contours: 10 nT
Contour map represents the difference between total magnetic intensity at each point and that at TF at the same time.
96FM, 99FM, MB162, and MB160 are flux gate magnetometers used at Memambetsu Observatory.

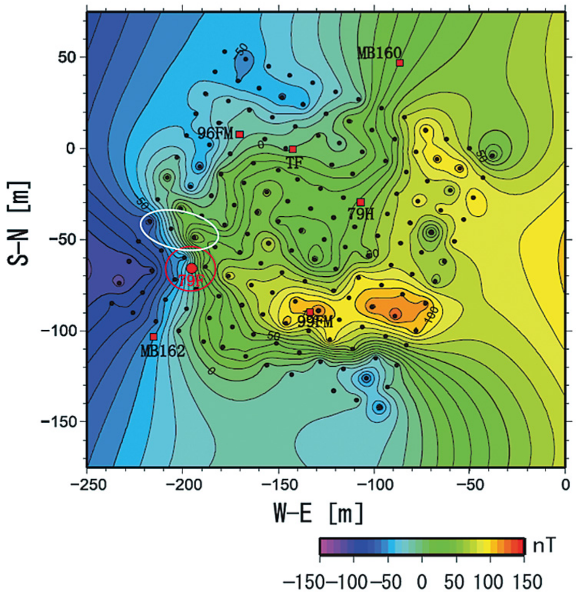

Fig. 7 Horizontal magnetic field gradient (sensor at 3m above ground)
Measurements taken in the square area marked in Fig. 1 (165 points in the 150×150 m area sectioned into a 12.5-m mesh). Bold contours: 50 nT; Thin contours: 10nT
Contour map represents the difference between total magnetic intensity at each point and that at TF at the same time.
96FM, 99FM, MB162, and MB160 are flux gate magnetometers used at Memambetsu Observatory.

the observation. In the area surrounding 79F (identified by the red circle in Fig. 6, 7, and 8), the gradient of the magnetic field in the east-west direction was extremely steep (about 10 nT/m) compared with that in the north-south direction. In Fig. 8, which compared the results of the magnetic field measurements taken at 2 and 3 m above the ground, a dipole-type of anomaly is apparent north of 79F (identified by a white oval). These findings suggest the non-uniform presence of a ferromagnetic layer, such as an iron sand layer, beneath the area surrounding 79F.

4. Summary

A comparison of observations by three proton magnetometers installed at the premises showed annual fluctuations of about 1 nT only at 79F. Comparing ΔF (TF-79F; 79H-79F) with the ambient temperature and underground temperatures (at depths of 0.1, 0.5, and 1 m) measured around 79F revealed a strong correlation between ΔF and temperatures at the depths of 0.1 and 0.5 m. The magnetic field survey carried out around 79F on a 12.5-m mesh found that the gradient of the magnetic field in the east-west direction was about 10 nT/m and much steeper than that in the north-south direction, which suggested the non-uniform distribution in the earth of layers with different magnetic characteristics. According to Hashimoto et al. (2003), even with a variation in normal temperature of only about 5°C, magnetization of rocks may vary by as much as 10%. They reported that the annual variations in the differences in total geomagnetic intensity in the Long Valley Caldera region were most likely caused by changes in magnetization due to variations of temperatures occurring under the ground to a depth of several meters. The total geomagnetic intensity at Memambetsu is about 49,600 nT, with an annual temperature range of about 25°C at a depth of 0.1 m and 15°C at 0.5 m. Because of the non-uniform distribution of layers of different magnetic charac-

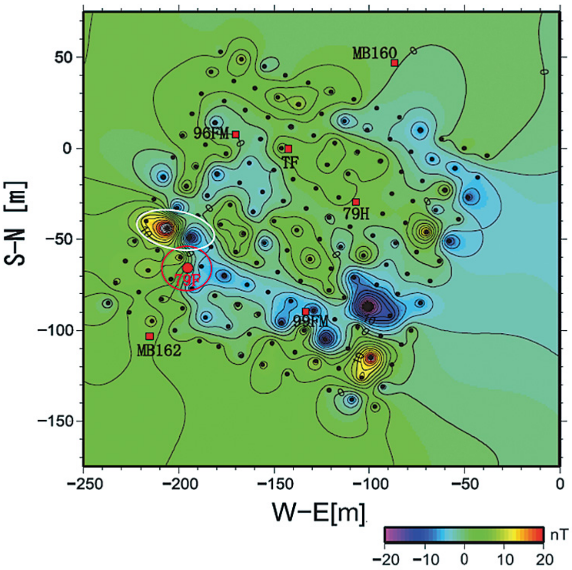

Fig. 8 Vertical magnetic field gradient (difference between sensors at 3 and 2 m above ground) Measurements taken in the square area marked in Fig. 1 (165 points in the 150×150 m area sectioned into a 12.5-m mesh). Bold contours: 10 nT; Thin contours: 2 nT
Contour map represents the difference between total magnetic intensity at each point in Fig. 6 and that at the corresponding point Fig. 7.
96FM, 99FM, MB162, and MB160 are flux gate magnetometers used at Memambetsu Observatory.

teristics in the ground beneath the sensor and the strong thermal characteristics of that magnetization, the annual fluctuations of about 1 nT at 79F were likely to have been caused by localized variations in the magnetic field around 79F, which in turn were due to variations in shallow underground temperatures. A similar phenomenon was reported by Utada et al. (2000) with respect to annual variations in the total geomagnetic intensity in a volcanic area. The results of our survey indicate the presence of such a phenomenon at the Memambetsu premises.

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