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Accuracy Evaluation of a Regional Geomagnetic Field Model around Japan – Affectivity of Sites Deployed by DPRI –

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Synopsis

Accuracy of the regional geomagnetic field model based on geomagnetic observatories in Japan has been examined under some assumptions on the spatial distribution of the Earth's geomagnetic main field variation. The geomagnetic field model is used as a reference to distinguish small tectonomagnetic signals which are as small as 1 nT from the main field variation, so that the model should be more accurate than 1 nT. This criterion is satisfied in east Japan, whereas it is not satisfied in the vast part of west Japan. It is clarified that the model has the least accuracy at the place of the TOT site among all stations deployed by Disaster Prevention Research Institute (DPRI). This means that the TOT site has a great importance to determine more accurate reference field models.

Keywords: geomagnetism, tectonomagnetic phenomena, regional reference field model, accuracy evaluation

1. Introduction

Some parts of the geomagnetic field changes are originated from the magnetization of the Earth's crust. They changes in association with stress and temperature changes within the crust via mechanisms of the piezomagnetic and the thermo-magnetic effects. Changes in the geomagnetic field changes generated by such mechanisms are often referred as tectonomagnetic phenomena. Tectonomagnetic phenomena can give us information which is independent from geodetic or seismological data, so that magnetic records can be probes to monitor the physical properties within the Earth's crust. For this reason, geomagnetic observations are intensively carried out in some countries, including Japan.

However, the detection of tectonomagnetic phenomena is a difficult prpblem because they are generally far smaller than the variation of the main field, which is originated from the Earth's inner core or the external current system. One of the commonly used ways to extract tectonomagnetic phenomena is to take the simple difference between the data at a field station and the data observed simultaneously at a reference station (Stacey and Westcott, 1965; Rikitake, 1966). Since the main field variation is approximately uniform in a small area, the difference between two stations is expected to contain only tectonomagnetic phenomena. Nevertheless, this method fails to the precise extraction when the main field variation is not the same between two stations.

Regional geomagnetic reference field models, which are expressions of the main field as functions of location and time, are used for the extraction, recently. Once a reliable model is obtained, tectonomagnetic phenomena can be easily obtained only by subtracting the predicted values of the model from the observed data.

In order to construct precise models, it is desirable to use data from geomagnetic stations as many as possible. In Japan, there are several tens of geomagnetic stations. Although they had been installed to detect tectonomagnetic phenomena in originally, their roles have been shifted to providing basic data for the construction of regional reference field models. Disaster Prevention Research Institute (DPRI) has deployed five geomagnetic stations in Hokuriku, Chubu, Kinki, and Chugoku-district. However, four of them are not running in present because of difficulties in observation.

In the present report, we evaluate the accuracies of the regional geomagnetic field which can be constructed by the present arrays of geomagnetic observations. By using the result, we will suggest the station which is the most important to construct a precise regional field model.

2. Formulation

Any components or the total force intensities of the geomagnetic field at any location (x,y) in a region can be expressed as a infinite series expansion by using a certain set of basis functions, u_k (k=1,2,…):

$$f(x,y) = \sum_{k=1}^{\infty} a_k\, u_k(x,y) \qquad (1)$$

where a_k is the expansion coefficient. By contrast, values of a reference field models at the same region are represented by a series expansion of finite terms:

$$f^*(x,y) = \sum_{k=1}^{\mathrm{BK}} a_k^*\, u_k(x,y) \qquad (2)$$

where variables or functions with an asterisk represent estimation of values, and K is the truncation degree.

Since (2) is truncated by a certain degree, K, and a_k* contains estimation errors, the actual field, f, and its estimation, f*, are generally not the same. The difference between them, δf, defined by

$$\delta f(x,y) \equiv f^*(x,y) - f(x,y) \qquad (3)$$

gives the evaluation of the errors of the estimation. This depends on the distribution of the sites and errors in each datum, d_m (m=1...M), where M represents the number of the observation stations. Each datum is composed by the actual field values and observation errors, e_m,

$$d_m = f(x_m,y_m) + e_m \qquad (4)$$

where (x_m,y_m) is the location of m-th station, and e_m is an observation error.

The actual value of the model error, δf, cannot be determined because it depends on a_k and e_m, both of which are unknown and cannot be determined by a finite number of data. However, we can calculate statistical quantities when we regard a_k and e_m as probability variables. Yamazaki (2008) has derived an expression to give the variance of δf based on the concept of the stochastic inversion (e.g., Gubbins, 1983):

$$\begin{aligned} &\mathrm{V}[\delta f(x,y|x_1,y_1,\cdots,x_M,y_M)^2] \\ &= \sum_m p_k(x,y|x_1,y_1,\cdots,x_M,y_M)^2\, \mathrm{V}[a_m] \\ &\quad + \sum_m q_m(x,y|x_1,y_1,\cdots,x_M,y_M)^2\, \mathrm{V}[e_k] \end{aligned} \qquad (5)$$

where p_k and q_m are functionals of the location of all stations and the set of basis functions, V represents the expected value. The concrete forms of p_k and q_m are given in the paper by Yamazaki (2008).

3. Accuracy of the regional model

In the present study, we evaluate the accuracy of the regional field model based on the data from 15 geomagnetic stations in Japan, which have been operated by the Japan Meteorological Agency (JMA), Geographcal Survey Institute (GSI), and Earthquake Research Institute of The University of Tokyo (ERI). Six of them are geomagnetic observatories which are free from artificial noises, and other stations are continuous stations which have been deployed by GSI since 1996. The basis system of functions adopted in the present model is as follows:

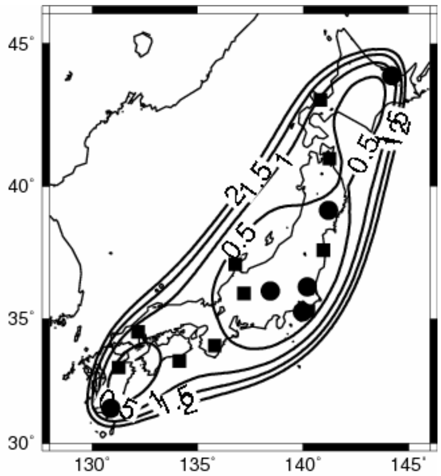

Fig. 1 Accuracy of the regional geomagnetic field model based on data from JMA, GSI, and ERI. Solid circles and squares indicate location of geomagnetic observatories and continuous field stations, respectively. Contour intervals are 0.5 nT.

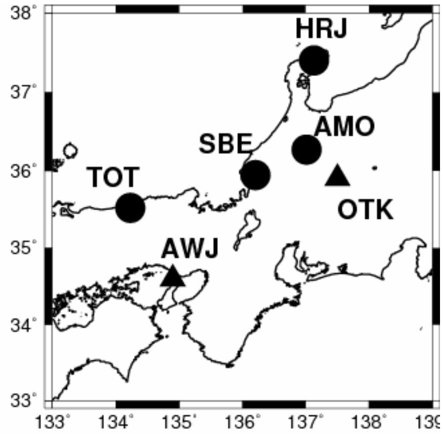

Fig. 2 Location of sites for geomagnetic field observation deployed by DPRI. Stations to provide data for the reference field model is plotted by triangles, while those to detect tectonomagnetic signals are plotted by circles.

$$u_1(x,y)=\mathrm{P}_0(x)\mathrm{P}_0(y)$$
$$u_2(x,y)=\mathrm{P}_1(x)\mathrm{P}_0(y),\ u_3(x,y)=\mathrm{P}_0(x)\mathrm{P}_1(y)$$
$$\cdots \qquad (6)$$

where P_k and variables x, y represent the Legendre Polynomial of order k and regularized latitude and longitude defined by:

$$x = (\text{latitude} - 37) / 10,$$
$$y = (\text{longitude} - 137) / 10, \qquad (7)$$

respectively. This set of functions is the same as that used in the modeling by Fujiwara et al. (2001), so that the estimation given by the present study can be applicable to evaluate the accuracy of the model by them.

In order to evaluate the variance of the model errors by using eq. (4), we must assume certain values of a priori variance of model parameters and observation errors. Taking the observation environment at each site into account, we assume variances of errors at observatories and at continuous stations are 1% and 5% of the observed absolute values, respectively. On the other hand, variances of model parameters are assumed to obey the following decay law:

$$\mathrm{V}[a_1] = A$$
$$\mathrm{V}[a_2] = \mathrm{V}[a_3] = A\exp(-b)$$
$$\mathrm{V}[a_4] = \mathrm{V}[a_5] = \mathrm{V}[a_6] = A\exp(-2b)$$
$$\cdots \qquad (8)$$

where A and b are positive constants. The constant, b, which controls the exponential decay is determined based on coefficients of the International Geomagnetic Reference Field (IGRF) model. A is determined in such a way that $\mathrm{V}[a_2]$ and $\mathrm{V}[a_3]$ are the same as the square of the spatial gradient of the secular change rates around Japan. With the above considerations, A and b are set to 20 and 0.77, respectively.

4. Discussion

In central and west Japan, DPRI have installed five sites at Tottori (TOT), Sabae (SBE), Nishi-Amou (AMO), Houryuu (HRJ), Aawaji (AWJ), and Ontake (OTK). Location of sites is shown in Fig. 1. Some of the highlight results obtained through the observation at these sites are described in the earlier reports (Doi et al., 1986; Goto et al., 1994; Sakanaka et al., 1996, 1998, 1999; Sumitomo and Yabe, 1974, 1978; Yabe et al., 2001; Yamazaki et al., 2007). Among them, sites at

AWJ and OTK are installed to detect tectonomagnetic phenomena, while the other sites are intended to be used as references for the construction of the regional geomagnetic field model.

In order to extract tectonomagnetic phenomena from the data, the site should be placed in an area where the regional geomagnetic field model has enough precision to describe the main field variation. Otherwise, we cannot distinguish whether the detected signals is actually a tectonic origins or not. As can be seen in Fig. 2, the present regional field model is more accurate that 0.5 nT at the location of OTK station, but is less accurate than 0.5 nT at AWJ. It means that tectonomagnetic signals at the OTK site can be well detected by the processing with the present regional field model, but those at the AWJ site cannot.

By contrast to those aiming at detecting tectonomagnetic signals, sites for the reference data acquisition should be placed in the region where the accuracy of the present model is insufficient. The accuracy of the model at the TOT station is worse than 0.5 nT, which is the minimum accuracy required for the model, while that at other stations, HRJ, AMO, and SBE is better than 0.5 nT. Therefore, it can be conclude that the TOT station is the most important point among these stations.

5. Summary and conclusion

We have evaluated the accuracy of the regional geomagnetic reference field model in Japan based on the data from GSI, JMA, and ERI. It is revealed that the present model has enough accuracy in east Japan, which includes the place of the OTK station installed by DPRI. Therefore, we can expect that tectonomagnetic phenomena at the OTK station can be detected by using the present reference model if the phenomena really exist. By contrast, it is also clarified that the present model is not enough accurate in most parts of west Japan. In particular, the precision is the worst in an area including the Tottori observatory of DPRI. This means that the data from the TOT geomagnetic station is the most important among those installed by DPRI.

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Figures in this manuscript are drawn by using the Generic Mapping Tools (Wessel and Smith, 1998).

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地殻活動地磁気現象検出のための地域地磁気モデルの精度
― 北陸・近畿・中国地方における観測点の効果 ―

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要 旨

地球主磁場の空間分布についていくつかの仮定にもとづき，観測所データをもとに構成可能な日本周辺の地域地磁気モデルの決定精度を評価した。地域地磁気モデルは，地磁気変化のなかから地殻活動起源のわずかな変化を抽出するための基準として用いられるものであり，1 nT よりも高い精度が求められる。評価の結果，西日本におけるモデルの精度が不十分であることが示された。防災研究所が展開する地磁気観測点のなかでは，鳥取観測点の位置におけるモデル決定精度がもっとも低く，同観測点における地磁気観測が日本周辺の地域地磁気モデルの精度向上のために最重要であることが結論される。

キーワード:地磁気，地殻活動地磁気現象，地磁気モデル，精度評価