あらせ衛星/MGF センサにおける人工衛星起因の直流成分磁場ノイズ

(2) Tsyganenko-Sitnov 04 モデルを用いた評価

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DC component of spacecraft-origin magnetic field noise at the Arase/MGF sensor: (2) Evaluation with Tsyganenko-Sitnov 04 model

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ABSTRACT

The evaluation of the spacecraft-origin magnetic field noise ($B_{\_DCnoise}$) at the position of the sensor of Magnetic Field Experiments (MGF) onboard the Arase satellite has been performed. We examined the difference between the observation of the magnetic field with MGF and the Tsyganenko-Sitnov 04 (TS04) model field in DSI coordinates (ΔB_{DSI}) during the quiet time intervals. $\Delta B_{z,\,DSI}$ was ~0.7 nT on average, which indicates that the $B_{\_DCnoise}$ in the spin-axis direction is quite small. We conclude that the MGF data are well-calibrated and no large $B_{\_DCnoise}$ is included in the measured magnetic field. Although the difference between the MGF observations and the TS04 model in the X_{DSI} and Y_{DSI} directions was a few nT, it may be attributed to the TS04 model field, not an observational error of MGF.

Keywords: Arase, Magnetic field experiments (MGF), Spacecraft-origin noise, Tsyganenko-Sitnov 04 model

1. Introduction

The Exploration of energization and Radiation in Geospace “Arase” (ERG) satellite was launched on 20 December 2016 to investigate the generation mechanism of the radiation belt and the dynamics of the geomagnetic storms in the Earth’s inner magnetosphere (Miyoshi et al., 2018). It has an elliptical orbit with an inclination of ~31° with an apogee of ~6 R_E and a perigee altitude of ~460 km. Its spin period is ~8 s and the spin axis is approximately pointing to the Sun.

The Magnetic Field Experiment (MGF) instrument (Matsuoka et al., 2018) onboard Arase measures the three vectors of magnetic field by a triaxial fluxgate magnetometer with a sampling rate of 256 vectors/s. MGF has two dynamic ranges, ±60,000 nT and ±8,000 nT, which are switched depending on the background magnetic field, and are used for measurement at L < ~2 and L > ~2, respectively. Since the magnetic field controls the motion of the charged particles in space, quite accurate measurements of the background magnetic field is expected for MGF.

In general, magnetic field instruments include measurement errors caused by many factors, such as the sensor offset, the sensor sensitivity, the estimation of the sensor alignment, and the effects from the satellite body. To evaluate the sensor offset and the sensitivity, many experiments had been done before the satellite launch at the Japan Aerospace Exploration Agency (JAXA) Tsukuba Space Center (Teramoto et al., 2017). In addition, the errors of the sensor alignment are accurately calibrated when the data processing is performed. Although the MGF sensor is attached on the tip of the extendable MAST ~5 meters away from the satellite body to avoid the spacecraft-origin magnetic field noise ($B_{\_DCnoise}$), there may be non-zero $B_{\_DCnoise}$. Therefore, we estimate the $B_{\_DCnoise}$ in this report on the assumption that the ground calibration and the data processing calibration have been precisely performed, and we do not consider the sensor offset variations with the

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temperature in this report.

The X-axis and Y-axis in Spinning Satellite Geometry Axis (SGA) coordinates rotate synchronized with the satellite spin, which enables us to estimate the $B_{\_DCnoise}$ in the X_{SGA} and Y_{SGA} components from the observational data. The $B_{\_DCnoise}$ can be removed by fitting a sinusoidal wave. However, we cannot estimate the $B_{\_DCnoise}$ in the Z_{SGA} component (i.e., spin-axis direction) from the observational data. To evaluate it, we compare the observational data to the Tsyganenko-Sitnov 04 (TS04) magnetic field model (Tsyganenko and Sitnov, 2005), which intends to express the strongly disturbed geomagnetic field on storm time and is often used to model the magnetic field in the inner magnetosphere. However, it should be noted that the difference between them may be generated by two factors, errors in the TS04 model and MGF. They will be discussed in Section 4.

2. Methods

We use the 8-s averaged magnetic field data on the geomagnetically quiet time during 23 March 2017 to 30 April 2018, excluding the period from 1 August to 3 November because of the malfunction of the dynamic range switching. In this time period, Arase covered almost all MLT ranges. The quiet time is determined by the 3-hour Kp index to be 0 or 0+. In addition, we impose the condition that the magnetic field does not significantly vary during one spin. This condition is implemented by a criterion that the dynamic range of the instrument is ±8,000 nT and the variation of the two successive spin-averaged magnetic field (δB) divided by the background magnetic field (Bt) is smaller than 0.006 ($\delta B/Bt < 0.006$). We compare the magnetic field data obtained by MGF to the TS04 model field in the selected time intervals in Despun Sun sector Inertia (DSI) coordinates, in which satellite spin is canceled and the Z-axis is almost along the spin axis. The discrepancy between the Z_{SGA} and Z_{DSI} coordinates is smaller than 1°. Input parameters for the TS04 model are solar wind dynamic pressure, Dst index, and IMF-Y, -Z values. In the present study, we use the SYM-H index instead of the Dst index, and interpolate their 1-min data to 8-s sampling of MGF.

3. Results

3.1. $\Delta B_{z,DSI}$

Figure 1a shows the histogram of the difference value between the magnetic field observed by MGF and TS04 model in the Z_{DSI} component (i.e., $\Delta B_{z, DSI}$) with a bin size of 0.1 nT. The mean value of $\Delta B_{z, DSI}$ is 0.66 ± 0.007 nT and the median value is 0.78 nT, which mean that the observational value is slightly larger than the TS04 model, but is quite closer to 0 nT. Figure 1b illustrates the distribution of the $\Delta B_{z, DSI}$ projected onto the R-MLT plane in Solar Magnetic (SM) coordinates with each mesh of 0.5 hr MLT by 0.5 R_E. White meshes show regions where no data satisfy the selection criteria. $\Delta B_{z, DSI}$ is generally be larger than 0 nT on the dayside, while it tends to be smaller than 0 nT on the nightside.

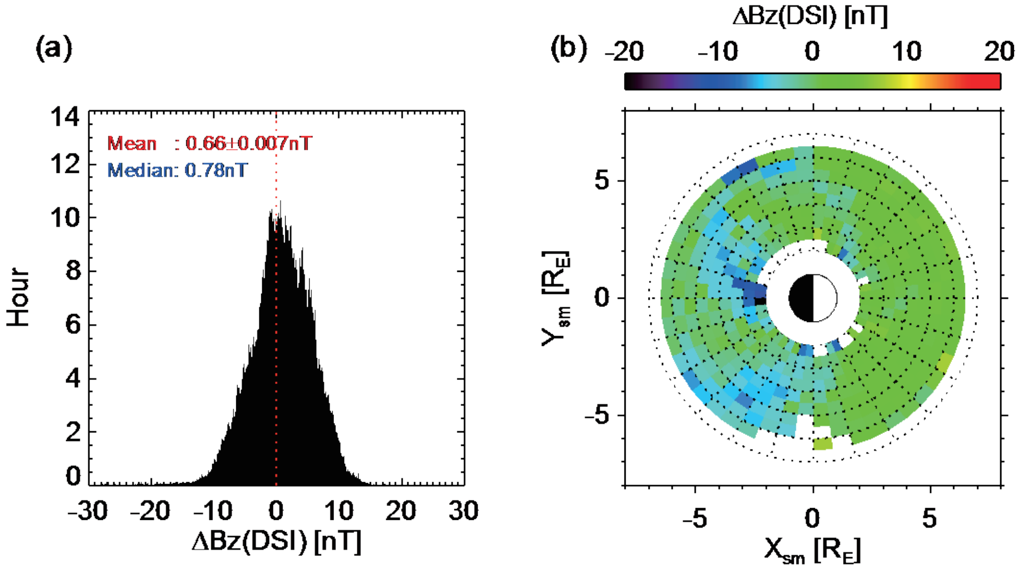

Fig. 1 (a) Histogram of the $\Delta B_{z,\,DSI}$ with a 0.1 nT bin. (b) Distribution of the $\Delta B_{z,\,DSI}$ projected onto the R-MLT plane in SM coordinates. Each mesh size is 0.5 hr MLT by 0.5 R_E.

3.2. $\Delta B_{x,\,DSI}$ and $\Delta B_{y,\,DSI}$

Figure 2 shows the histogram and distribution of $\Delta B_{x,\,DSI}$ in the same format as Figure 1. The mean value of $\Delta B_{x,\,DSI}$ is 2.36 ± 0.012 nT and the median value is 2.22 nT. $\Delta B_{x,\,DSI}$ is larger than $\Delta B_{z,\,DSI}$. The day-night asymmetry is not seen in Figure 2b.

Figure 3 gives the histogram and distribution of $\Delta B_{y,\,DSI}$. The mean value of $\Delta B_{y,\,DSI}$ is 4.81 ± 0.011 nT and the median value is 5.21 nT, which are much larger than those of $\Delta B_{z,\,DSI}$ and $\Delta B_{x,\,DSI}$. Also, the variance of the $\Delta B_{y,\,DSI}$ histogram is larger than those of $\Delta B_{z,\,DSI}$ and $\Delta B_{x,\,DSI}$. Figure 3b shows that $\Delta B_{y,\,DSI}$ is larger on the dayside than that on the nightside, and values are larger than 0 nT on both dayside and nightside. We find a specific orbit at dusk to midnight, where $\Delta B_{y,\,DSI}$ is quite smaller than the surrounding area.

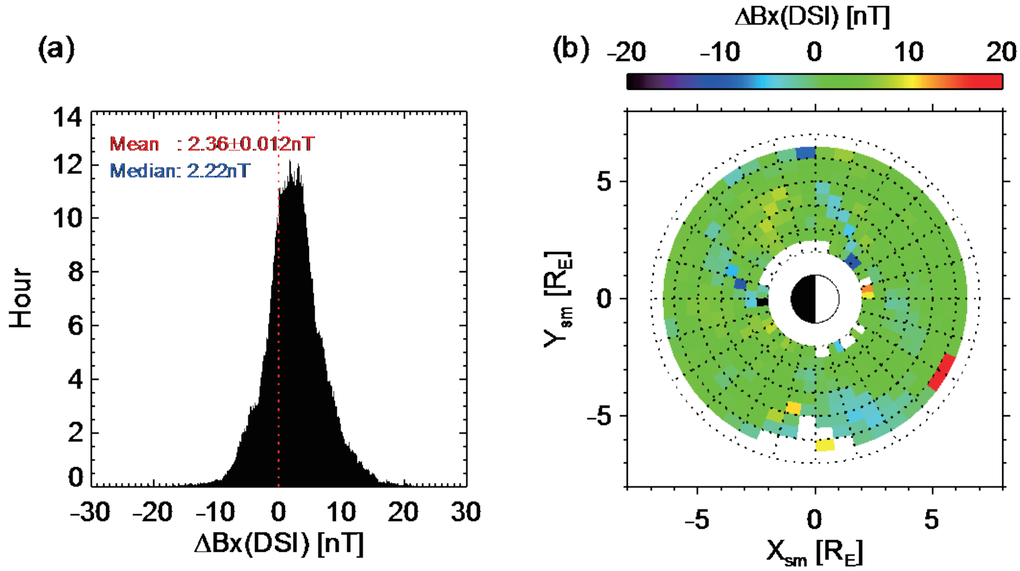

Fig. 2 Same as Figure 1 except for the $\Delta B_{x,\,DSI}$ component.

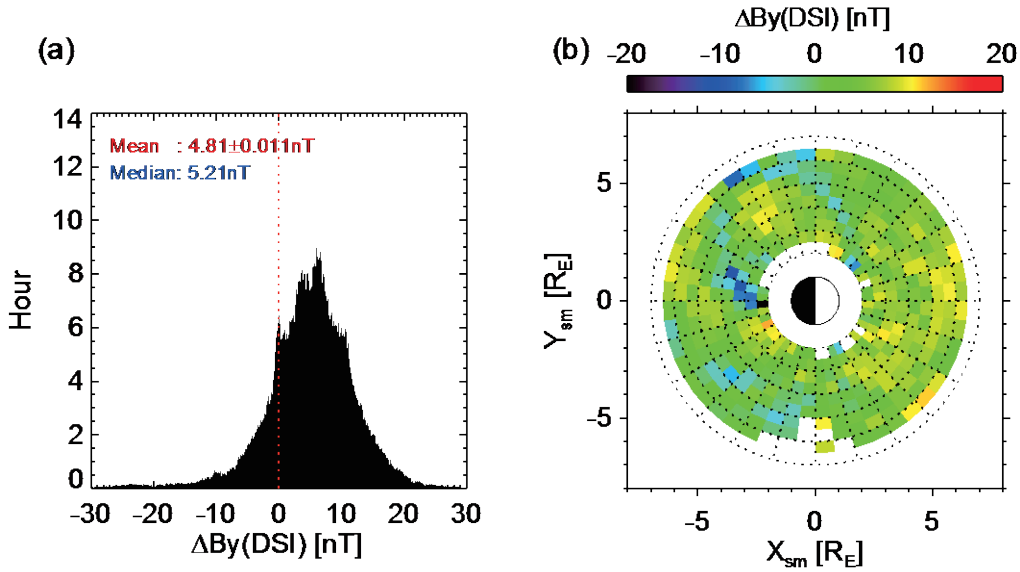

Fig. 3 Same as Figure 1 except for the $\Delta B_{y,\,DSI}$ component.

4. Discussion

4.1. $\Delta B_{z,\,DSI}$

The goal of this work is to estimate the $B_{\_DCnoise}$ in the Z_{DSI} direction (i.e., spin-axis direction). In the previous section, we obtained the histogram of $\Delta B_{z,\,DSI}$ in Figure 1a, and the result shows the $\Delta B_{z,\,DSI}$ to be quite small on average (0.66 nT). We conclude that the $B_{\_DCnoise}$ in the spin-axis direction is very small, and the magnetic field data obtained by MGF are well-calibrated and contribute to the accurate measurements by Arase.

4.2. $\Delta B_{x,\,DSI}$ and $\Delta B_{y,\,DSI}$

The $\Delta B_{x,\,DSI}$ and $\Delta B_{y,\,DSI}$ were supposed to be small because the $B_{\_DCnoise}$ in the X_{DSI} and Y_{DSI} components can be removed by subtracting the sine-fitted data, if the TS04 model expresses the actual magnetic field correctly. However, the results showed large $\Delta B_{x,\,DSI}$ and $\Delta B_{y,\,DSI}$ (2.4 and 4.8 nT, respectively) as shown in Figures 2a and 3a. Although Z_{DSI} nearly directs to the Sun, the direction of X_{DSI} and Y_{DSI} axes varies according to the satellite positions. Yamamoto et al. (2019) investigated the direction of the X_{DSI} and Y_{DSI} axes, and found that these axes point roughly to −Y direction and +Z direction in SM coordinates, respectively. This indicates that the difference between the observational value and the TS04 model is the largest in the direction of the main field.

The possible causes of this large difference between the observational data and the TS04 model are considered to be due to an error in the measurement or the model. In this case, the $\Delta B_{x,\,DSI}$ and $\Delta B_{y,\,DSI}$ were large in spite of the expectation that they are small, and the difference in the component along the background geomagnetic field is larger than that in other components. Also, the day-night asymmetry of $\Delta B_{y,\,DSI}$ in Figure 3b may be due to the difficulty of the TS04 model to express accurately the compressed magnetic field and the elongated tail field. Thus, we suggest that the error is originated from the TS04 model.

We suppose two possible reasons for this error. The first one is that the TS04 model itself may overestimate the global current systems in the magnetosphere from the beginning, which influence on the magnetic field along the main field. The second reason may be the gradual decrease of the geomagnetic field of the Earth (i.e., magnetic moment). The TS04 model was created more than ten years ago. In recent year, the geomagnetic field becomes smaller. Although the model parameterization might have been correct when the model was created, the estimation of the external magnetic fields such as the magnetospheric current systems may not be appropriate for the present circumstances.

5. Conclusions

Our purpose of this report is to evaluate the spacecraft-origin magnetic field noise ($B_{\_DCnoise}$) at the sensor location onboard Arase. We compared the observational magnetic field of MGF to TS04 model field in the DSI coordinates during the quiet time intervals. $\Delta B_{z,\,DSI}$ was ~0.7 nT on average, which indicates that the $B_{\_DCnoise}$ in the spin-axis direction is quite small. We conclude that the MGF data are well-calibrated and provide accurate measurements of magnetic field. We also surveyed $\Delta B_{x,\,DSI}$ and $\Delta B_{y,\,DSI}$, and found that the difference is the largest in the direction of the ambient field. We attribute it to the TS04 model field, not an observational error of MGF.

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