Observation of the Earth's Magnetic field from KOMPSAT-1

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Abstract
The Earth's total magnetic field was extracted from on board TAM (Three Axis Magnetometer) observations of KOMPSAT-1 satellite between June 19th and 21st, 2000. In the pre-processing, the TAM's telemetry data were transformed from ECI (Earth Centered Inertial frame) to ECEF (Earth Centered Earth Fixed frame) and then to spherical coordination, and self-induced magnetic field by satellite bus itself were removed by using an on-orbit magnetometer data correction method. The 2-D wavenumber correlation filtering and quadrant-swapping method were applied to the pre-processed data in order to eliminate dynamic components and track-line noise, respectively. Then, the spherical harmonic coefficients are calculated from KOMPSAT-1 data. To test the validity of the TAM's geomagnetic field, Danish/NASA/French Ørsted satellite's magnetic model and IGRF2000 model were used for statistical comparison. The correlation coefficient between Ørsted and TAM is 0.97 and IGRF and TAM is 0.96. It was found that the data from on board magnetometer observations for attitude control of Earth-observing satellites can be used to determinate the Earth's total magnetic field and that they can be efficiently used to upgrade the global geomagnetic field coefficients, such as IGRF by providing new information at various altitudes with better temporal and spatial coverage.

Introduction

Geomagnetic field is one of the most important invisible forces by which the earth protects itself from radioactive rays and solar wind. It also influences electric wave that deeply connects our live because the reflection of electrowave is effected by the variation of geomagnetic field and ion particle of Van-Allen zone. In addition, Geomagnetic field should be observed continuously due to its changes over time [1].

Global scale magnetic field measurements have been performed with rocket-and satellite borne. The first attempt to observe geomagnetic field was performed by 3-axis magnetometer that mounted on Sputnik-3. Sun-synchronous orbit satellite with high precision magnetometer is OGO-2, -4, -6(POGO, Polar Orbiting Geophysical Observatories). Magsat, the first satellite for observing magnetic field, was launched in November 1979. Twenty years after the Magsat mission, the Ørsted satellite was launched in 1999 in a near polar orbit and it investigated accurate map of the Earth's magnetic field caused by internal sources and current system in the ionosphere and magnetosphere [2].
A magnetometer mounted on satellite was used for monitoring the near-earth space environment, momentum management, and attitude determination and control [3]. In this study, data from the three-axis magnetometer mounted for attitude control was used for continuous observation of the Earth's main field between 19-21, June, 2000. Then, the spherical harmonic coefficients was calculated, and compared with Ørsted, and IGRF2000 (International Geomagnetic Reference Field: IGRF)[4].

Data Processing

1) Coordinate Transform
In case of KOMPSAT_1 data, original Body coordinate x,y,z direction data were transformed to ECI(Earth centered inertial frame, ECI), ECEF(Earth centered Earth fixed frame) and spherical coordinate(Latitude, Longitude).
2) Pre-processing
To remove induced field of satellite body, errors from temperature change, and the effect of solar wind, pre-processing method was applied. In body coordinate, magnetic field values are corrected by 970nT in x-direction, -150nT in y-direction, 900nT in z direction [3].

3) 2-D Wavenumber Correlation Analysis

Transformation of data set X & Y into the frequency domain using Fourier transformation and analysis of CCk (Correlation Coefficient) between data set X & Y for each wave number k.

Uncorrelated features between data sets can be separated by the application of correlation filters in the frequency domain of the data sets [5].

$$\overline{X}(k) = |\overline{X}(k)| \exp(-j\theta_{\overline{X}(k)}), \overline{Y}(k) = |\overline{Y}(k)| \exp(-j\theta_{\overline{Y}(k)})$$

$$CC(k) = \cos(\Delta\theta_k) = \frac{\overline{X}(k) \cdot \overline{Y}(k)}{|\overline{X}(k)||\overline{Y}(k)|}$$

4) Quadrant Swapping

In satellite data, same area is observed in ascending and descending direction and trackline noise is amplified. Therefore, gridding ascending and descending direction separately, combine the area that has no trackline effect in fourier domain.

5) Calculating Spherical Harmonic Coefficients

The potential fuction V is generally written in the form of a spherical harmonic series,

$$V = a \sum_{n=1}^{N} \sum_{m=0}^{n} \left(\frac{a}{r}\right)^{n+1} [g_n^m \cos m\phi + h_n^m \sin m\phi] P_n^m(\cos\theta)$$

and magnetic field B is $B = -\nabla V$.

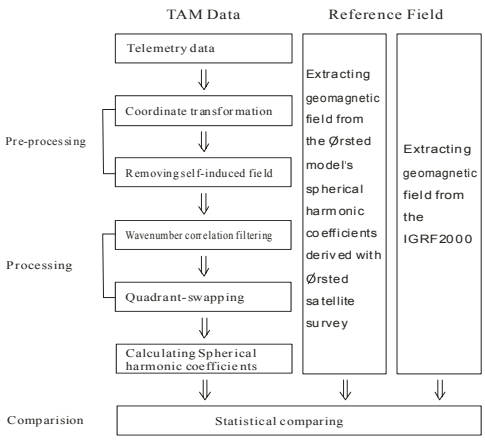

Fig. 1. Flowchart of data processing

Results

To verify KOMPSAT-1 data processed by this study, they were compared with Ørsted and IGRF2000. Ørsted has almost same observation periods and altitude with KOMPSAT-1, so Ørsted is most suitable for comparison.

Fig. 2 is the total magnetic values before any correction process from KOMPSAT-1. The distribution of total magnetic field shows good coherence between KOMPSAT-1 that processed by this study, Ørsted, and IGRF2000 (Fig. 3). When adding the line of 36,000 nT value, the similarity between data is identified well. The correlation coefficient between data is 0.97 and 0.96, and it shows the three data is well correlated. The maximum and minimum value of KOMPSAT-1 is 18,219 ~ 49,351 nT, those of Ørsted is 19,265 ~ 53,463nT, and those of IGRF is 18,215 ~ 50,096 nT.

Table 1 is the spherical harmonic coefficients G_n^m, H_n^m from KOMPSAT-1, Ørsted, and IGRF2000 with n=10. It also shows relatively good coherence. Table 2 is the Statistical comparison of the Earth's magnetic field values from Ørsted model. IGRF2000 and the result of this study

Table 1 Spherical Harmonic Coefficients

		KOMPSAT-1		Ørsted		IGRF 2000	
n	m	gnm	hnm	gnm	hnm	gnm	hnm
1	0	−29314	0	−29617	0	−29615	0
1	1	−1799	5184	−1729	5186	−1728	5186
2	0	−2757	0	−2268	0	−2267	0
2	1	3055	−2341	3069	−2482	3072	−2478
2	2	1641	−395	1671	−458	1672	−458
3	0	1224	0	1340	0	1341	0
3	1	−2236	−258	−2288	−228	−2290	−227
3	2	1206	327	1252	293	1253	296
3	3	767	−412	714	−491	715	−492
4	0	1150	0	932	0	935	0
4	1	756	262	787	273	787	272
4	2	255	−236	250	−232	251	−232
4	3	−363	118	−403	120	−405	119
4	4	107	−264	111	−304	110	−304
5	0	−283	0	−217	0	−217	0
5	1	338	34	352	43	351	44
5	2	197	157	222	171	222	172
5	3	−77	−113	−131	−133	−131	−134
5	4	−176	−29	−168	−39	−169	−40
5	5	−7	67	−13	106	−12	107
6	0	492	0	71	0	72	0
6	1	87	−39	67	−17	68	−17
6	2	84	65	74	64	74	64
6	3	−144	65	−161	65	−161	65
6	4	−31	−49	−6	−61	−5	−61
6	5	34	−12	17	1	17	1
6	6	−67	47	−90	44	−91	44
7	0	60	0	79	0	79	0
7	1	−41	−63	−74	−65	−74	−65
7	2	24	0	0	−25	0	−24
7	3	13	35	33	6	33	6
7	4	−28	0	9	24	9	24
7	5	31	−3	7	15	7	15
7	6	10	−11	7	−25	8	−25
7	7	10	6	−1	−6	−2	−6
8	0	50	0	24	0	25	0
8	1	3	22	6	12	6	12
8	2	−2	−8	−9	−21	−9	−22
8	3	−11	20	−8	9	−8	8
8	4	−21	−46	−17	−21	−17	−21
8	5	17	−9	9	15	9	15
8	6	−1	46	7	9	7	9
8	7	−8	−5	−8	−15	−8	−16
8	8	−28	−11	−7	−2	−7	−3
9	0	−28	0	5	0	5	0
9	1	12	−26	10	−20	9	−20
9	2	−13	28	3	13	3	13
9	3	−17	11	2	13	−8	12
9	4	7	−17	6	−6	6	−6
9	5	21	−11	−9	−8	−9	−8
9	6	−16	21	−2	8	−2	9
9	7	3	−4	9	4	9	4
9	8	2	−20	−4	−8	−4	−8
9	9	0	−3	−8	5	−8	5
10	0	−6	0	−3	0	−2	0
10	1	−14	−2	−6	2	−6	1
10	2	1	−7	2	0	2	0
10	3	−14	0	−3	4	−3	4
10	4	−9	−13	0	5	0	5
10	5	24	−9	4	−6	4	−6
10	6	−8	15	1	−1	1	−1
10	7	−1	−6	2	−3	2	−3
10	8	16	12	4	0	4	0
10	9	−20	5	0	−2	0	−2
10	10	−42	−25	−1	−8	−1	−8

Conclusion

In this study, KOMPSAT-1 data were processed by Coordinate Transform, Pre-processing, 2-D Wavenumber Correlation Analysis, and Quadrant Swapping. Then, the global geomagnetic field and Spherical Harmonic Coefficeints were obtained and compared with Ørsted, and GRF2000. With the process of this study, induce field of satellite body, trackline noise, field from outside the earth were removed efficiently, and the total magnetic field and spherical harmonic coefficients between KOMPSAT-1, Ørsted, and IGRF2000 showed good coherence with each other.

Table. 2. Statistical comparison of the Earth's magnetic field values from Ørsted model, IGRF2000 and the result of this study.

		Min	Max	Mean	Std.
(a)	KOMPSAT-1 TAM	18,219	49,351	35,450	8,585
(b)	Ørsted model	19,265	53,463	36,622	9,004
(c)	IGRF2000	18,215	50,096	34,338	8,437
(d)	Point-by-point differenced field(KOMPSAT-Ørsted)	-6,499	4,283	-1,172	2,165
(e)	Point-by-point differenced field(KOMPSAT-IGRF)	-3,213	5,960	1,111	2,287

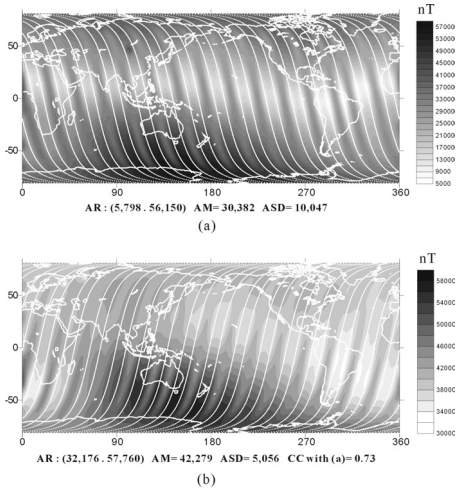

Fig. 2. The total magnetic values before any correction process from KOMPSAT-1 for June 19th - 21st, 2000. White lines indicate that data acquired points on satellite's tracks. (a) is for ascending, (b) is for descending mode.

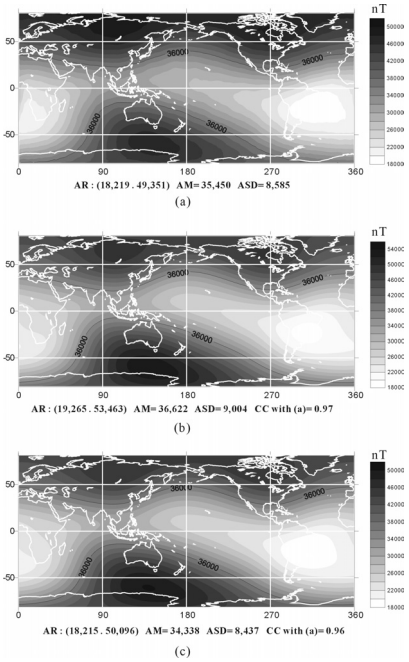

Fig. 3. The total magnetic values (a) KOMPSAT-1 after processing, (b) Ørsted, (c) IGRF2000 total field magnetic fields.

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Reference

[1] Hwang, J. S, S.H, Lee, K. D. Kim, J. W. Kim, Extraction of Geomagnetic Field from KOMPSAT-1 Three-Axis Magnetometer Data, Proceedings of ISRS, 242, 2002.

[2] Olsen, N., R. Holme, G. Hulot, T. Sabaka, T. Neubert, Ørsted initial field model, geophyscal Research Letters, v. 25, No.2, 3607-3610, 2000.

[3] Seon-Ho Lee, Rhee S. W, Shin I, On-orbit magnetic filed correction of magnetometer and geometry-based attitude determination for small satellite, IEEE 2002 Aerospace conference, 139

[4] Olsen, N., R., J., S., Terencce, T.,Lars Determination of IGRF2000 model. Earth Planets Space, 52, 1175-1182, 2000.

[5] Kim, J. W., J.-H. Kim, R. R. B. von Frese, D. R. Roman, K. C. Jezek, Spectral attenuation of track-line noise, Geophys. Res. Lett., v.25, No.2, 187-190, 1998.