NTIS $3.00

X-645-72-445

PREPRINT

NASA TM X- 66133

QUIET-TIME MAGNETOSPHERIC FIELD DEPRESSION AT 2.3 TO 3.6 R_E

MASAHISA SUGIURA

NOVEMBER 1972

GSFC

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

Quiet-Time Magnetospheric Field Depression at 2.3 to 3.6 R_E

by

Masahisa Sugiura

Laboratory for Space Physics
Goddard Space Flight Center, Greenbelt, Maryland 20771

November 1972

A statistical analysis of the Rb magnetometer results from OGO 5 has shown that the magnitude of the equatorial field depression in the magnetosphere increases with decreasing radial distance to at least 3 or 4 R_E (Sugiura et al., 1971; Sugiura, 1972a, 1972b). However, because of inadequate coverage of data near the dipole equator at these close distances, it was not possible to draw the innermost contours of ΔB (defined as the difference between the observed scalar field and a theoretical reference field) with certainty, especially on the dawn-dusk meridian plane (Sugiura et al., 1971). Furthermore, these contours contained considerable irregularities due to temporal variations. The purpose of this communication is to present OGO 5 GSFC fluxgate magnetometer data to establish the existence of large field depressions under conditions of varying degree of disturbance at distances ranging from 2.3 to 3.6 R_E at all local times. The results also provide the average ΔB at these distances when Dst, as being derived at present, is zero.

For this study, fluxgate data obtained near perigee during the period of approximately one year from January 21, 1969 to February 23, 1970 were used. The geocentric perigee distance during this period increased from 1.9 to 3.5 R_E. The orbit in the near earth region on July 9, 1969 is shown in Figure 1 to describe typical orbit characteristics; the projection onto the geographic equatorial plane is shown on the right-hand side of Figure 1, and the trajectory on the dipole meridian plane rotating together with the satellite is given on the left-hand side to show the dipole latitude change of the satellite position. As seen in Figure 1 the satellite changes its dipole latitude very rapidly near perigee (0423 UT) from south to north, crossing the dipole equator about 25 minutes after the perigee pass; at the same time the local time of the satellite increases rapidly. Therefore the interpretation of ΔB along the orbit near perigee can be complex if there are variations in ΔB with radial distance, local time, dipole latitude, and U.T. However, it has been found that the ΔB behavior near perigee is relatively regular except when rapidly changing disturbance fields are superimposed on the regular variations.

During the selected one year period there were 88 orbits on which fluxgate data were complete enough to locate a minimum in ΔB near perigee. Values of ΔB used here are based on the reference field derived by Cain et al., (1967) which is the same reference field as the one used for OGO 5 in our 1971 paper. The position of the minimum in ΔB, referred to as ΔB_{min} below, was found to be near, but not necessarily at, the dipole equator. Of the 88 orbits 84 (i.e. 95%) had their ΔB_{min} between dipole latitudes 15^{o}N and 16^{o}S; on 38 orbits (i.e. 43%) ΔB_{min} was within 6^{o} of the dipole equator. There was a period of approximately two months, July to August 1969, when the ΔB curve tended to have double minimums, one on each side of the dipole equator, or occasionally to have a broad, flat minimum. In these cases also, ΔB at its lowest point was selected as ΔB_{min} for each orbit. These double minimums occurred between 10 and 14 hours local time and at geocentric distances roughly from 2.5 to 3 R_E. Their systematic occurrence suggests that their existence is quite real. It is likely that they occur because equal ΔB surfaces in this region are indented toward the earth near the dipole equator (at least during those two months).

The ΔB_{min} values defined in the above manner are plotted in Figure 2 against corresponding hourly Dst values. Figure 2 shows that ΔB_{min} is statistically well correlated to Dst, the correlation coefficient being 0.87. By least squares fitting the relation between the two variables is expressed by

$$\Delta B_{min} = -45 + 0.83 \text{ Dst} \tag{1}$$

in units of gamma (nanotesla in SI units). Although the radial distances at which ΔB_{min} was obtained ranged from 1.9 to 3.6 R_E, there was only one data point at 1.9 R_E (and at local time 0.3 hours) and all other points were at $R \geq 2.3$ R_E. Therefore, the above relation may be considered as applying effectively to ΔB_{min} at geocentric distances 2.3 to 3.6 R_E. Equation 1 shows that statistically ΔB_{min} near the dipole equator at these distances is -45γ when Dst is zero. The data used in the analysis cover all local hours, and hence the above result is for the average over local time.

Now, an obvious, and important, question that arises is whether or not there is any local time variation in ΔB_{min}. This is a difficult question to answer with the present set of data, because both the local time and the radial distance of the point at which ΔB_{min} occurs varied gradually over the one year period. Hence the dependence of ΔB_{min} on these two parameters cannot be separated in principle. Table 1 gives the average difference between the observed ΔB_{min} and the ΔB_{min} calculated from equation 1 for three-hourly local time intervals; the average radial distance, $\overline{R}$, for each local time group is given in the third column. There is an indication that the deviations tend to be more negative than

Table 1. Average deviations of the observed ΔB_{min} from the ΔB_{min} calculated from equation 1, for different local time groups; $\overline{R}$ is the average radial distance for each group

Local Time	$\overline{\Delta B_{min}^{obs} - \Delta B_{min}^{cal}}$	$\overline{R}$
hours	gamma	R_E
0 - 3	3	3.2
3 - 6	6	3.2
6 - 9	12	2.9
9 - 12	-3	2.7
12 - 15	5	2.7
15 - 18	-2	2.7
18 - 21	-8	2.6
21 - 24	-11	2.8

positive in late afternoon to midnight, and that they tend to be more positive than negative from midnight to 9 hours LT. However, the average deviations in Table 1 must be looked at cautiously because of the small sample statistics. For instance, -8γ for the 18 to 21 hour interval was influenced greatly by one data point taken during a storm; this point is the isolated point in Figure 2 near the lower left corner. When this data point (deviation = -61γ) is omitted, the average for this interval becomes -3γ. Even with this average value, the above tendency is still recognizable. The standard deviation of ΔB_{min} for the whole data set used in the least squares fit was 12γ. Therefore, it is not possible to establish the local time variation from the present data set with statistical certainty. The problem has to be studied with a more extensive set of data selected for this specific purpose. It is pointed out here that the absence of a pronounced local time change is not in conflict with the well-known asymmetric development of the storm time ring current (Akasofu and Chapman, 1964; Cummings, 1966; Cahill, 1966). The present discussions pertain to the average configuration of the magnetospheric field, which is still not completely known.

The present study poses an important question of how the field behaves between the regions we are concerned with here (i.e. 2.3 to 3.6 R_E) and the earth's surface. The field depression from the ring current, whether it is a toroidal ring or an extended sheet, decreases in magnitude on the inner (i.e. earthward) side of the current region (e.g. Akasofu and Chapman, 1961; Hoffman and Bracken, 1965). This is due to the eastward current at the inner boundary of the ring current; the $\underline{j} \times \underline{B}$ force from this eastward current balances the particle pressure gradient, supporting the particle belt at the inner edge. Does the magnetic field increase earthward from the level of $\Delta B = -45\gamma$ at 2 or 3 R_E to a substantially higher level, if not to such an extent as to make ΔB zero at the earth's surface? The spherical harmonic analyses of the ground-based magnetic field observations so far made do not have sufficient accuracies to deduce reliable values for the ΔB at the ground. To obtain from ground-based magnetic observations an accurate set of spherical harmonic coefficients representing the earth's internal field the data must be taken when the fields from external sources are identical. Obviously, it is impossible, in practice, to meet such a condition. To a first approximation a set of data corresponding to the same value of Dst may be used. Even such an only approximately uniform data set would be difficult to obtain at present. Thus no substantial progress is likely to be made on this problem from analyses of ground-based observations. The most promising approach appears to be accurate vector field measurements by low-altitude, polar orbiting satellites. An analysis of the Rb magnetometer results from the POGO satellites specifically designed to answer the question raised above would seem highly desirable.

The present author has shown that the population of trapped protons having energy of several hundred kev are the most likely major source for the current causing the inflation of the inner magnetosphere and that the protons with lower energies (200 ev to 50 kev) observed by Frank (e.g. his 1971 paper) are significant secondary contributors to the diamagnetic effect during magnetically quiet conditions (Sugiura, 1972b). It was shown that energetically, the total energy of protons with energy > 100 kev is sufficient to produce a field decrease of about -37γ at the center of the earth. Frank (1967) estimated the corresponding field decrease, also for quiet conditions, produced by the protons with energies 200 ev to 50 kev to be -12γ. These estimates are based on the Dessler, Parker, Sckopke relation $\Delta B(0)/B_0 = -2\epsilon/3\epsilon_m$, where $\Delta B(0)$ is ΔB at the earth's center, B_0 is the equatorial field intensity at the earth's surface and ϵ and ϵ_m are the total energy of the particles and the dipole field energy integrated over all space outside the earth, respectively (Sckopke, 1966). Thus there is no fundamental difficulty in accounting for a field decrease by 45γ at the equator on the earth's surface. If the field depression there is less than at 2 or 3 R_E as is expected from the existing ring current models, this must mean that the above particle energies are overestimated. On the other hand it would be very hard to explain an absence of field depressions at the earth's surface. There is a question of the induction in the earth, but this effect can either increase or decrease ΔB, and on the average, it is unlikely to alter ΔB on the ground drastically. In any case, reliable determination of ΔB at the earth's surface appears to be an urgent problem.

Acknowledgement

I wish to thank Dr. B. G. Ledley for valuable discussions on the present study.

REFERENCES

Akasofu, S.-I., and S. Chapman, The ring current, geomagnetic disturbance, and the Van Allen radiation belts, J. Geophys. Res., 66, 1321, 1961.

Akasofu, S.-I., and S. Chapman, On the asymmetric development of magnetic storm fields in low and middle latitudes, Planetary Space Sci., 12, 607, 1964.

Cahill, L. J., Jr., Inflation of the inner magnetosphere during a magnetic storm, J. Geophys. Res., 71, 4505, 1966.

Cain, J. C., S. J. Hendricks, R. A. Langel, and W. V. Hudson, A proposed model for the International Geomagnetic Reference Field, 1965, J. Geomagn. Geoelec., 19, 335, 1967.

Cummings, W. D., Asymmetric ring currents and the low-latitude disturbance daily variation, J. Geophys. Res., 71, 4495, 1966.

Frank, L. A., On the extraterrestrial ring current during geomagnetic storms, J. Geophys. Res., 72, 3753, 1967.

Frank, L. A., Relationship of the plasma sheet, ring current, trapping boundary, and plasmapause near the magnetic equator and local midnight, J. Geophys. Res., 76, 2265, 1971.

Hoffman, R. A., and P. A. Bracken, Magnetic effects of the quiet-time proton belt, J. Geophys. Res., 70, 3541, 1965.

Sckopke, N., A general relation between the energy of trapped particles and the disturbance field near the earth, J. Geophys. Res., 71, 3125, 1966.

Sugiura, M., The ring current, in _Critical Problems of Magnetospheric Physics_, Proceedings of the Joint COSPAR/IAGA/URSI Symposium Madrid, Spain 11-13 May 1972, edited by E. R. Dyer, p. 195, IUCSTP Secretariat c/o National Academy of Sciences, Washington, D. C., 1972a.

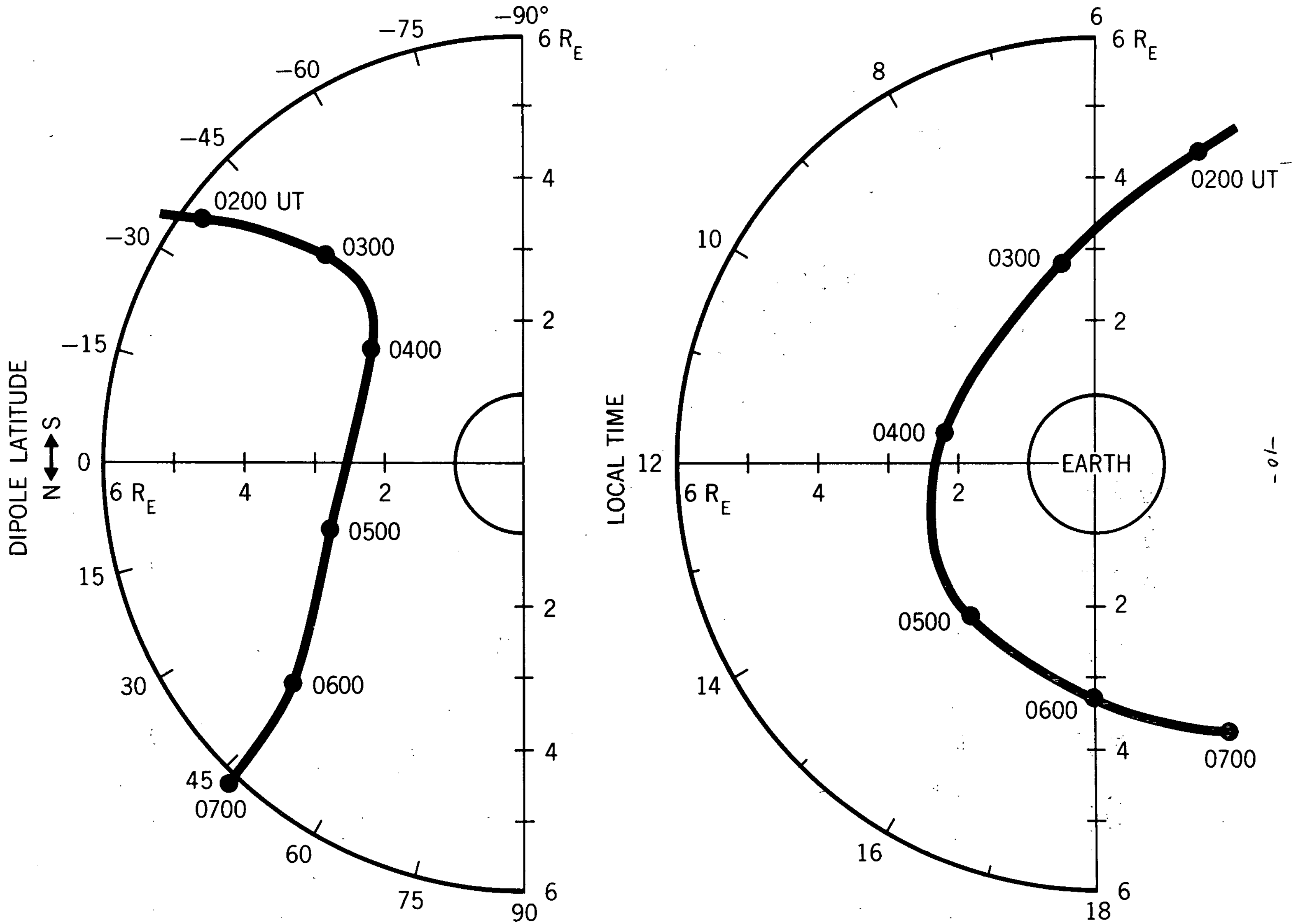
Sugiura, M., Equatorial current sheet in the magnetosphere, _J. Geophys. Res._, _77_, 6093, 1972b.

Sugiura, M., B. G. Ledley, T. L. Skillman, and J. P. Heppner, Magnetospheric-field distortions observed by Ogo 3 and 5, _J. Geophys. Res._, _76_, 7552, 1971.

FIGURES

Figure 1. Description of typcial OGO 5 orbit characteristics near perigee in 1969; the projection onto the geographic equatorial plane on the right and the trajectory in the dipole meridian plane rotating with the satellite on the left.

Figure 2. ΔB minimum near perigee plotted against Dst. The correlation coefficient is 0.87.



OGO 5 ORBIT ON JULY 9,1969

FIGURE 1

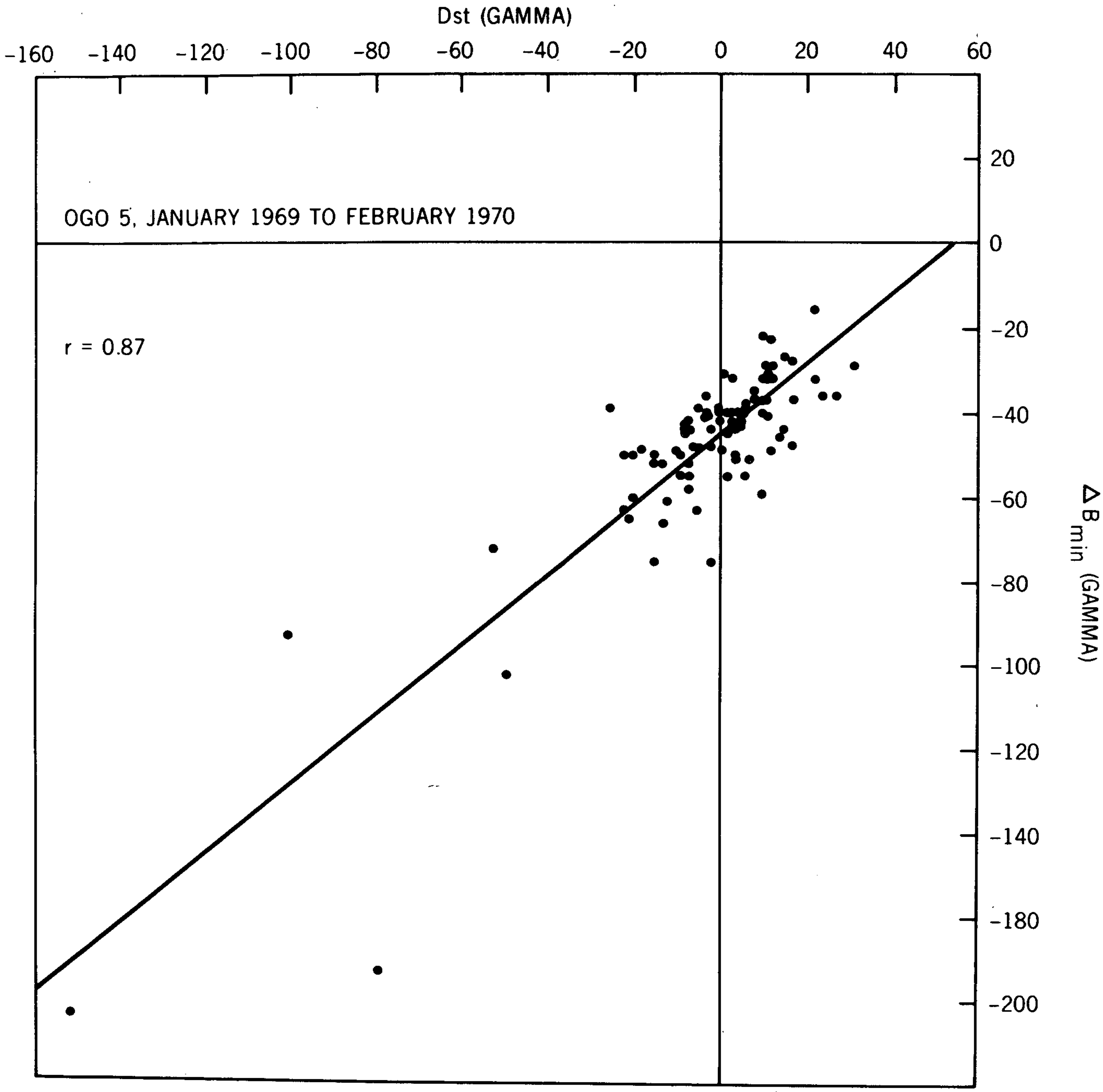


FIGURE 2

NASA-GSFC