The Relation between the Geomagnetic Storms and the Interplanetary Sector Structure

The Relation between the Geomagnetic Storms and the Interplanetary Sector Structure

TOHRU SAKURAI

Geophysical Institute, Tohoku University, Sendai, Japan
(Received September 12, 1966)

Abstract: In this report, the essential condition responsible for causing the geomagnetic disturbances at and near the minimum stage of solar cycle is studied. The data of the interplanetary magnetic field and the incident solar ion current by IMP-1 is used. And further the geomagnetic index, kp, and the photospheric magnetic field data are also used.

The results are as follows:

1. Geomagnetic storms occur almost simultaneously when the earth is passing across the sector boundary.
2. Geomagnetic storms are caused by the impact of the solar wind plasma upon the earth's magnetosphere.
3. The region of the sector boundary on the sun is corresponding to the region of the weak magnetic field.
4. This region of weak magnetic field in the neighbourhood of the sector boundary on the sun would be the source region of the emission of the solar energetic plasma corresponding to the geomagnetic storms.
5. The sector boundary in the interplanetary field forms the simple contact surface at the quiet time, and when it is disturbed it seems to become growing to the turbulence.
6. The asymmetric feature in the activity of the four sectors is shown at the declining phase of the solar cycle, but this feature becomes less evident at the minimum stage of the solar cycle.

1. Introduction

Recently Wilcox and Ness (1964) have shown that the interplanetary magnetic field has a sector structure which is divided into four sectors from the analysis of the satellite IMP-1 magnetic data in the interval from November 27, 1963 to February 13, 1964 and the geomagnetic activity, the values of kp, on the earth's surface becomes maximum, within one or two days after the earth passes across the sector boundary.

The author obtained in this paper the related equations between the geomagnetic index-kp ($\Sigma\, kp$) and the solar wind velocity. Using these results, a further description is given of the sector structure during the epoch from January 1963 to December 1964 as is shown in Figs. 6, and 7.

2. The relation between the interplanetary sector and the geomagnetic storm

Comparing the interplanetary sector structure with the geomagnetic storm (solar sudden commencement and solar gradual storm), the author found that the earth almost rotated past the sector boundary simultaneously at the commencement of the

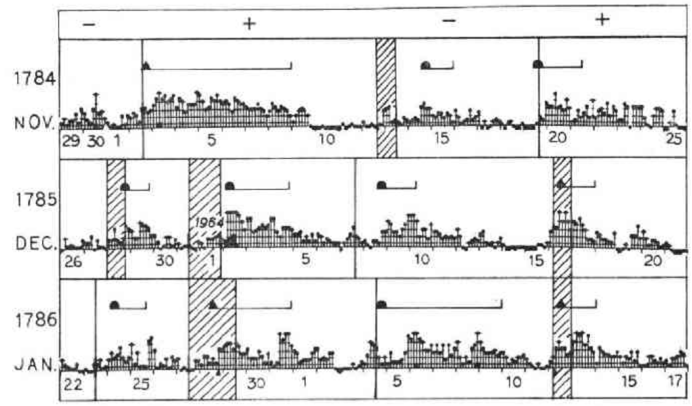

Fig. 1 The magnetic disturbances and the geomagnetic activity index kp are shown during the period November 27, 1963 to February 13, 1964 observed by IMP-1. Triangle and hemi-circle in heavy represents the onset of the storm sudden commencement and solar gradual storm respectively and the bar indicates the duration of the disturbances. The solid line and the cross hatched area indicate the sector boundary and the unidentified sector boundary respectively. The sign of plus and minus represents the positive and the negative polarity magnetic field sector respectively.

geomagnetic disturbance. However sometimes solar sudden commencement preceded the sector boundary and sometimes solar gradual storm was followed by sector boundary after one or two days from the data of the IMP-1, November 27, 1963 to February 13, 1964 as is shown in Fig. 1.

During the period of this observation, IMP-1 satellite crossed six times the sector boundaries in the interplanetary space, and eight times was prevented with the geomagnetic field.

And then in the six-times traversing the sector boundary, five of them the gradual storms occured almost simultaneously with rotating past of it and remaining one the sudden commencement storm occured with overtaking it. In the eight cases of the unidentified sector boundaries, four times of them the solar gradual storms occured and the others the solar sudden commencements. In the above mentioned geomagnetic storms, the author finds two types of storms. The first (Type A) is solar gradual storms (Sg) accompanied with the passage of the sector boundary and for the second (Type B) solar sudden commencement (ssc), more energetic plasma overtakes the sector boundary. For this type A, Sg occurs in the several hours or one or two days after the earth passing across the sector boundary.

Above mentioned time lag would depend on the relation between the sector boundary on the sun and the velocity of the bulk motion of the solar wind in the interplanetary space. At the quiet time the sector boundary would be consisted with the simple contact surface in the interplanetary space.

Here, the magneto-hydrodynamical equilibrium is kept in the pressure at the sector boundary.

At the quiet time;

$\{P_{th}+P_{mag}\}=0$

P_{th}: thermal gas pressure

$P_{th}=nKT$ (T: interplanetary thermal temperature)

$\sim 10^{-10}$ergs/cm^3

P_{mag}: magnetic pressure

$P_{mag}=B^2/8\pi$

$\sim 10^{-10}$ergs/cm^3

($|B|$: intensity of the interplanetary magnetic filed).

When the solar wind speed increased, this equilibrium would not hold further more:

$\{P_b\}\neq 0$

P_b: gas pressure of the bulk motion of the solar stream

$P_b=MNU^2/2\sim 10^{-8}$ergs/cm^3

N: proton number density

M: proton mass

U: radial velocity of bulk motion

Here $P_b \gg (P_{th}+P_{mag})$.

Where $\{p\}$ represents the pressure difference between the sectors. Reynolds number in the solar stream, however, is very large so that turbulence could be easily caused at the neighbourhood of the sector boundary.

For the next type B, there was observed the solar wind with higher velocity at the sector boundary on December 2, 1963 by IMP-1. This new solar stream has the supersonic velocity comparing with the medium of the preceding reversal polarity field. This solar wind would overtake the preceding sector. And this velocity difference could make the turbulent region there. This schematic picture is represented in Fig. 2.

Fig. 3 shows the relation between the geomagnetic disturbances and corresponding the interplanetary magnetic field and the flux of the energetic plasma on December 1, and 2, 1963.

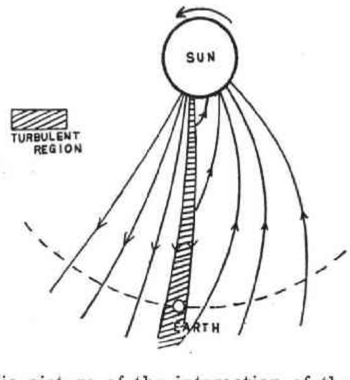

Fig. 2. The schematic picture of the interaction of the solar wind plasma.

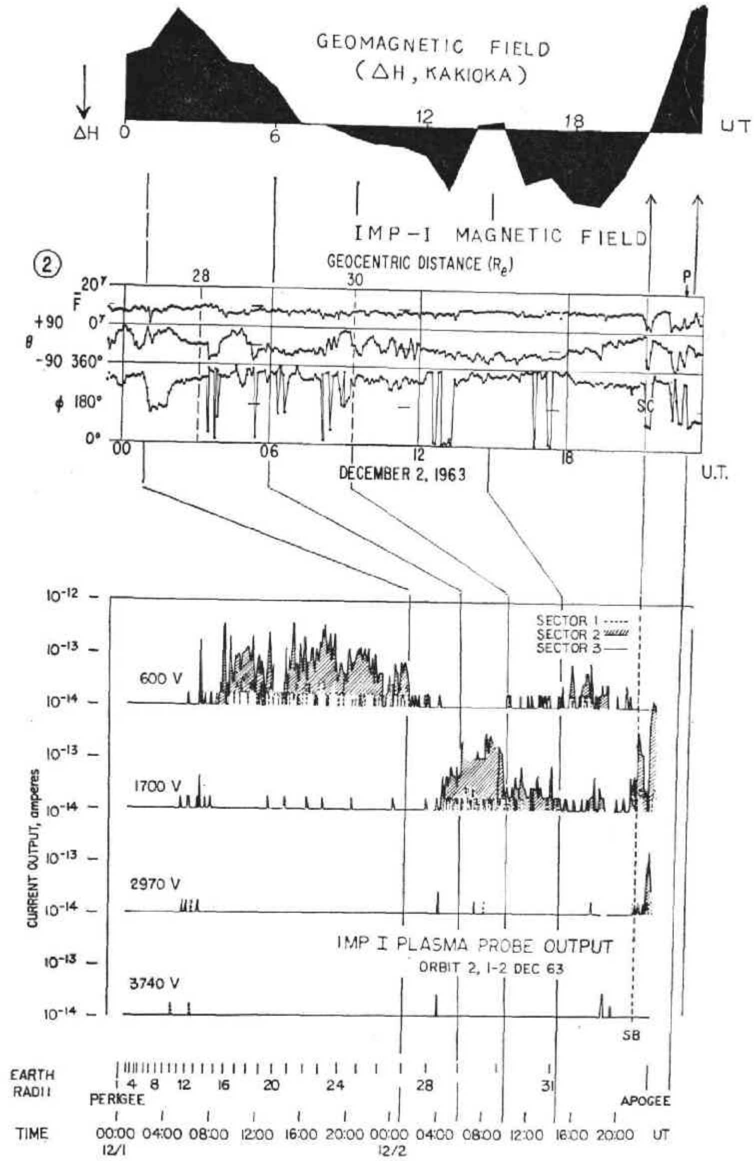

Fig. 3 Upper part shows the geomagnetic field variation at Kakioka, and middle the interplanetary magnetic field variation ($\bar{F}$, total field intensity; θ and ϕ, direction of the magnetic field) on December 2, 1963 (after Ness, 1964) and the lowest indicates the plasma ion current on December 1, and 2, 1963 observed by IMP-1. (after Wolfe et al., 1966)

The geomagnetic variation is seemed to be very good coincident with the variation of the intensity and direction of the interplanetary magnetic field and the incident plasma flux. When the storm sudden commencement occured at 21h 13 m on December 2, 1963 there was the sudden variation of the polarity of the magnetic field and the significant shift on the energy level of the solar plasma. The geomagnetic field was much affected by these interplanetary variations. These evidences lead us to the fact that the geomagnetic disturbances are essentialy caused by the impact of these energetic plasma upon the magnetosphere near the sector boundary, and the turbulence of the interplanetary magnetic field is caused by the velocity differences between the

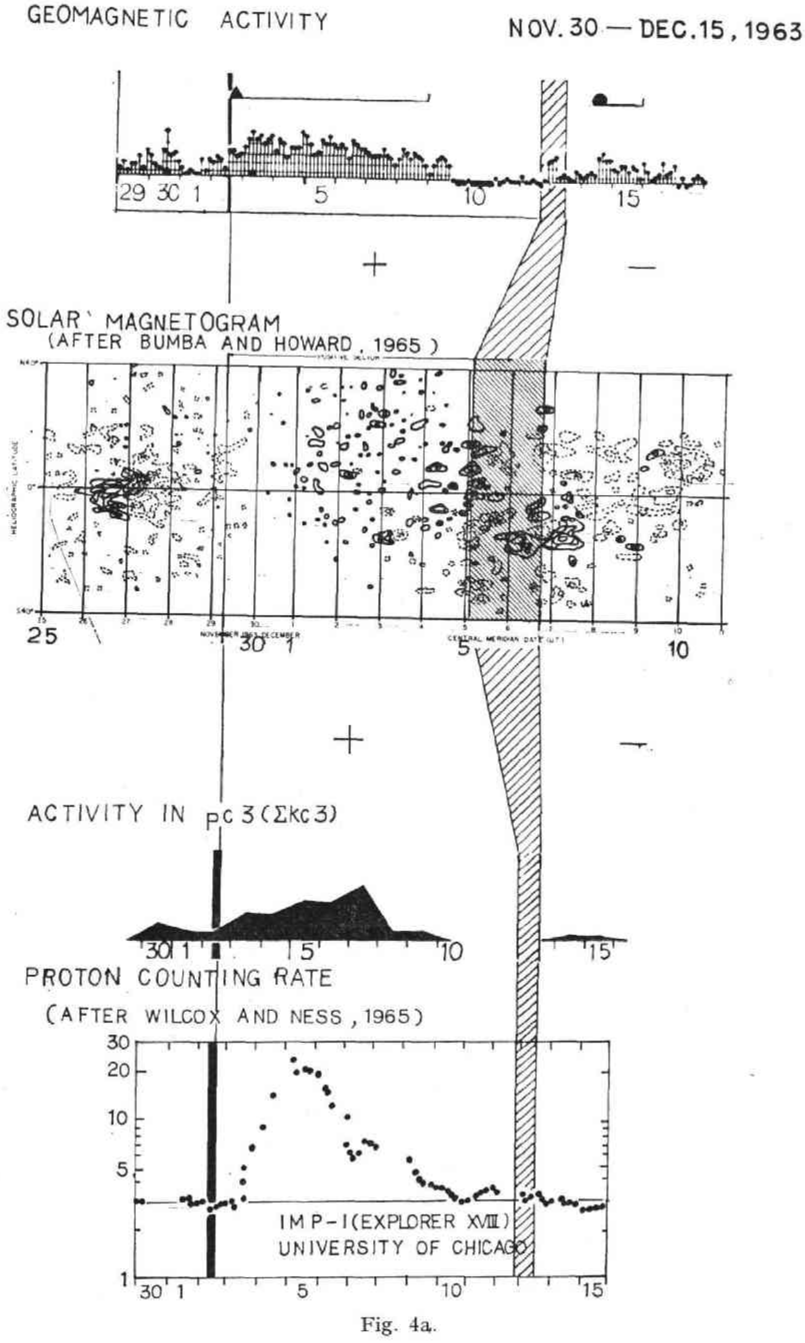

Fig. 4a.

different energy level of the solar stream.

3. The relation between the sector structure in the interplanetary magnetic field and the photospheric magnetic field on the sun

As reported by Ness and Wilcox, the sector boundary of the solar magnetogram corresponded to the sector boundary of the interplanetary magnetic field which was observed by IMP-1. The author also describes the sector structure on the solar magnetogram using the IMP-1 data and the synoptic chart of photospheric field data (Bumba and Howard, 1965).

Fig. 4 (a, b, c) represents the relation between the synoptic chart of photospheric magnetic field (Bumba and Howard, 1965) during the meridian dates February 1, 1964 to February 15, 1964, the geomagnetic activity (kp-index) and the activity of pulsation pc 3 (period-30 sec) (Σ *kc3*) during the dates February 1, 1964 to February 23, 1964. The solid line represents the sector boundary and the cross-batched area on the synoptic chart of photospheric magnetic field also indicates the uncertainty in the

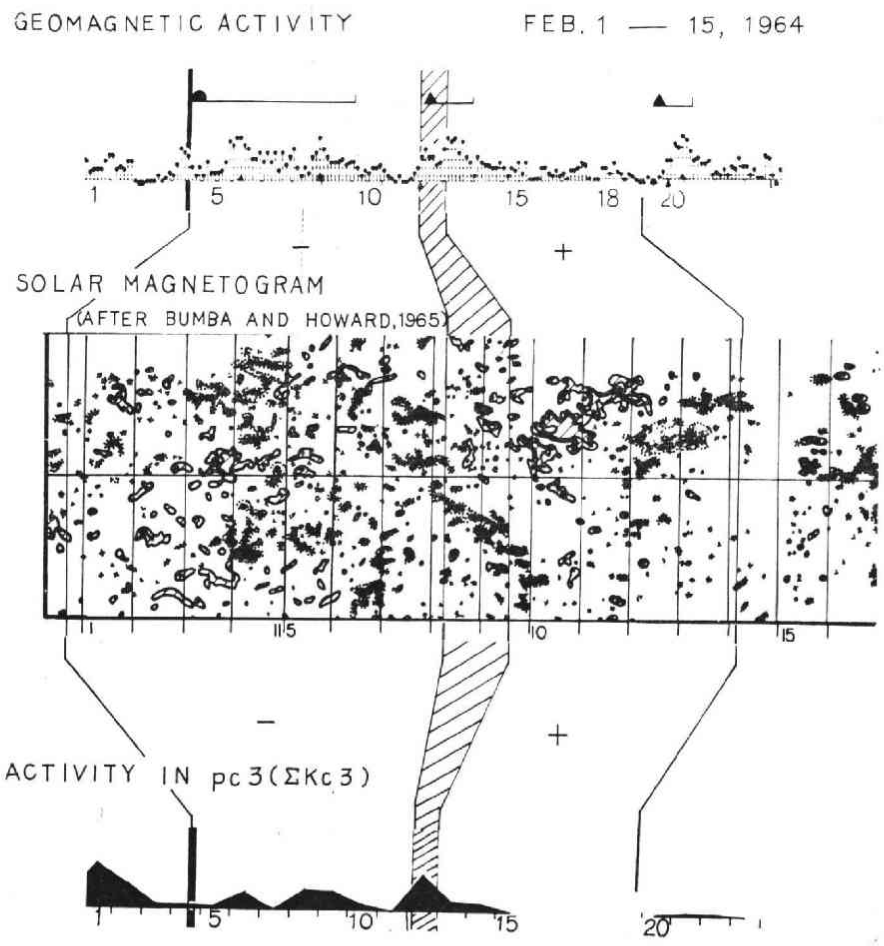

Fig. 4b.

sector boundary associated with the presence of the satellite near perigee. In the solar magnetogram the solid contours represents the positive polarity and heavy contours negative polarity of the magnetic field.

The place of the sector boundary on the sun is estimated from the transit time of the solar stream assuming the relation between the solar wind velocity and the sum of the kp-index ($\Sigma\ kp$) in the available data in this epoch and a constant radial solar wind velocity. Using above mentioned technique the author may identify that these sector boundaries correspond to the region of weak magnetic field on the sun, or the

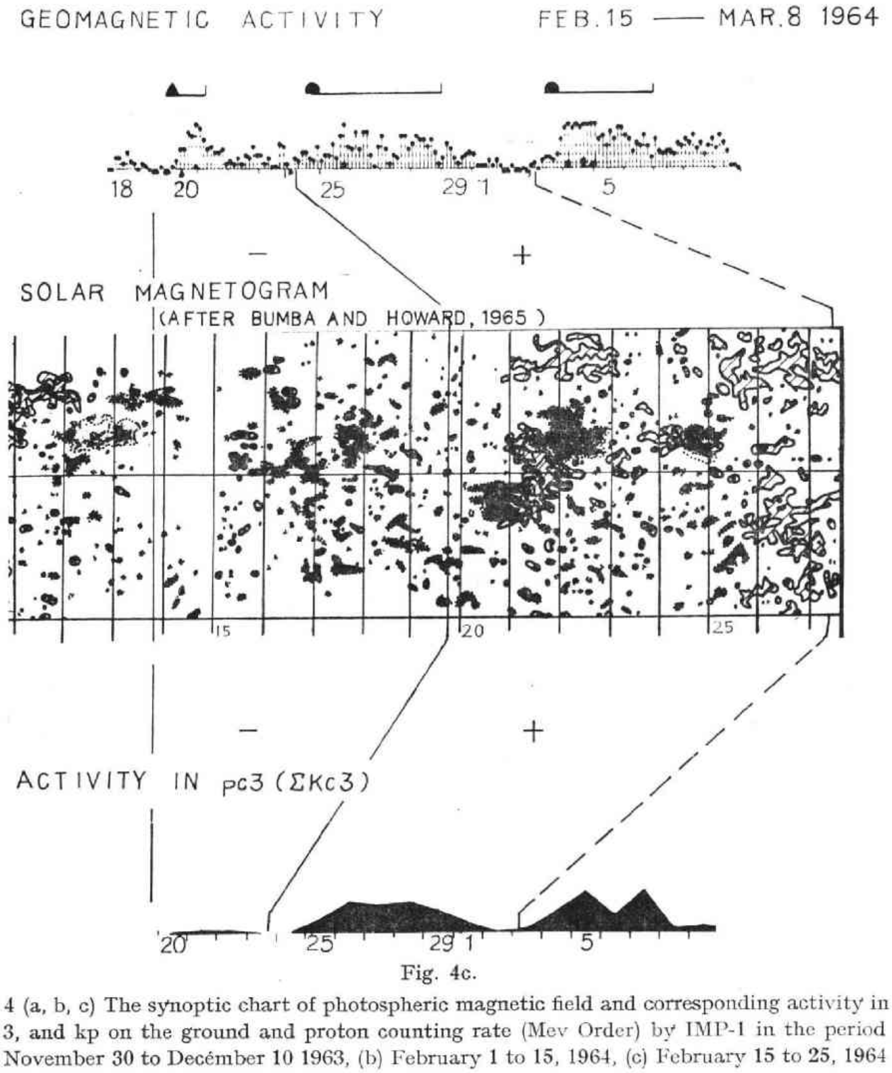

Fig. 4c.

Fig. 4 (a, b, c) The synoptic chart of photospheric magnetic field and corresponding activity in pc 3, and kp on the ground and proton counting rate (Mev Order) by IMP-1 in the period (a) November 30 to December 10 1963, (b) February 1 to 15, 1964, (c) February 15 to 25, 1964 on the solar magnetogram.

In the synoptic chart of photospheric magnetic field on the sun the solid contour indicates the positive polarity magnetic field and the dashed negative polarity, and below indicates Center Meridian Passage (CMP) date. The solid line and cross hatched area represent the sector boundaries respectively.

ghost UMR (leading portion of the Unipolar magnetic field) (Wilcox and Ness, 1965).

And further energetic particles would be easily enhanced in these regions. These facts were shown in plasma flux (Wilcox ans Ness, 1965; Wolfe, Silva and Myers, 1966). On comparing with these energetic plasma data and the solar magnetogram, the position of the source of the energetic plasma on the sun would correspond to these weak magnetic field region near the sector boundary and also to the leading portion of the unipolar magnetic field.

4. The persistence of the sector structure during the period January 1963 to December 1964

The author is now interesting to the interplanetary sector structure and the persistence of the sectors in the quiet solar cycle. As the relation between the interplanetary sector boundary and the geomagnetic disturbance was shown in Fig. 1, the author found that the geomagnetic disturbances occured near the sector boundaries. Fig. 5 represents the rough approximated relations between the solar wind vělocity and the sum of the kp-index in each sector. These equations can apply only to the preceding part of the begining of the disturbances. On account of the simple calculation we rewrite these equations as follows:

$V=22.4\times kp+262.7$ (km/sec) for negative sector
$V=20.8\times kp+270.6$ (km/sec) for positive sector

(where V is solar stream velocity in km/sec).

And assuming a constant radial solar wind velocity, the transit time was substracted from the estimated time of the sector boundary using the geomagnetic kp except the interval observed by IMP-1. From above mentioned technique the position of the sector boundary on the sun has been estimated during the epoch from November 30, 1963 to February 25, 1963. The author found that the magnetic field on the sun can be

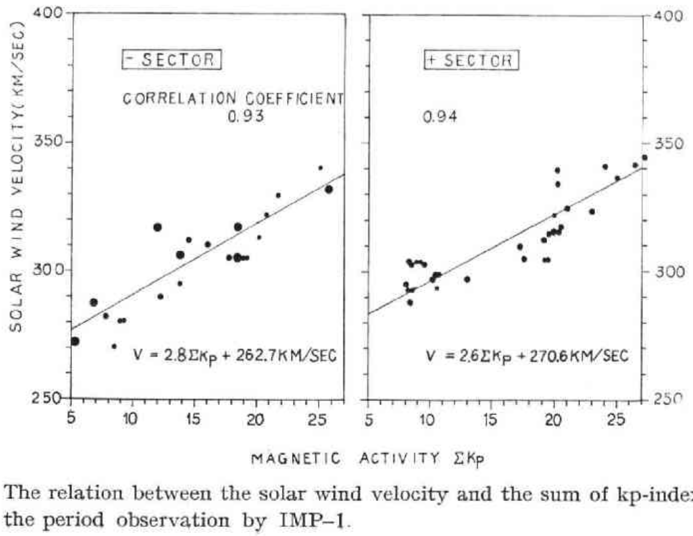

Fig. 5 The relation between the solar wind velocity and the sum of kp-index during the period observation by IMP-1.

systematically divided into the positive and negative polarity parts by the sector boundary. These facts were already represented in Fig. 4 (a, b, c). As was shown in Fig. 1 and Fig. 4 (a, b, c), the epoch time of the sector boundaries does not coincide strictly but moves a few days at the different rotational period. We can now consider why this movement arises. Because the interplanetary sector boundary is made of the transported magnetic field by the solar plasma with the different velocity

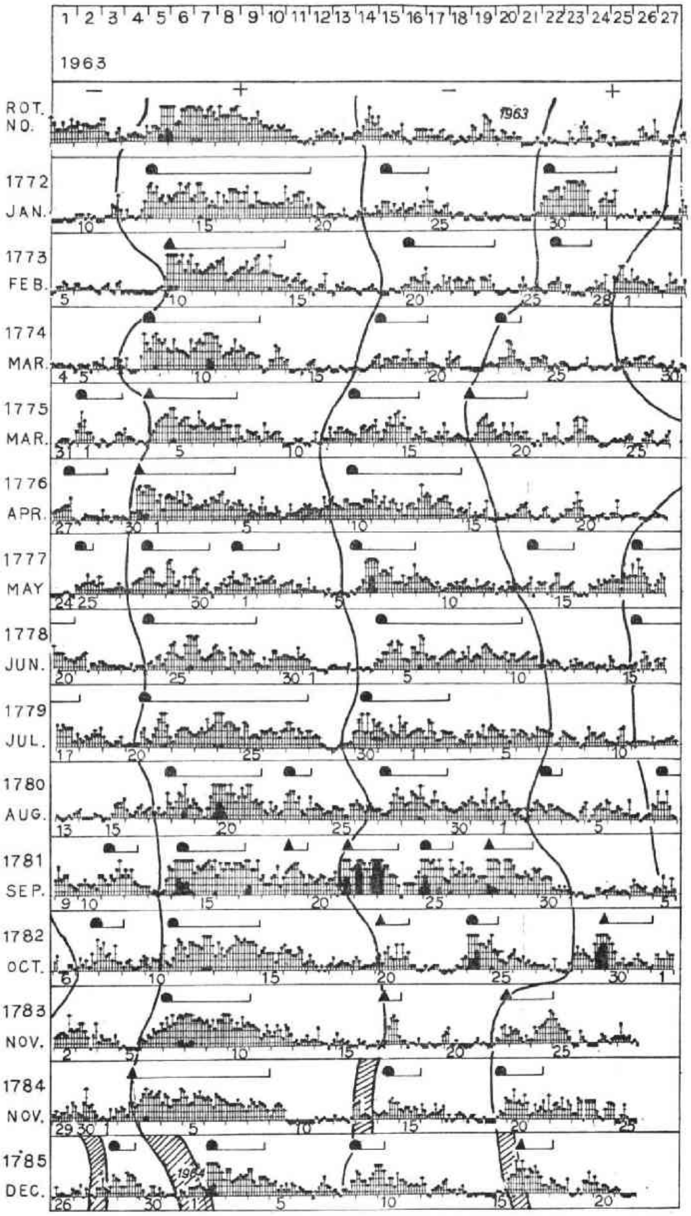

Fig. 6a.

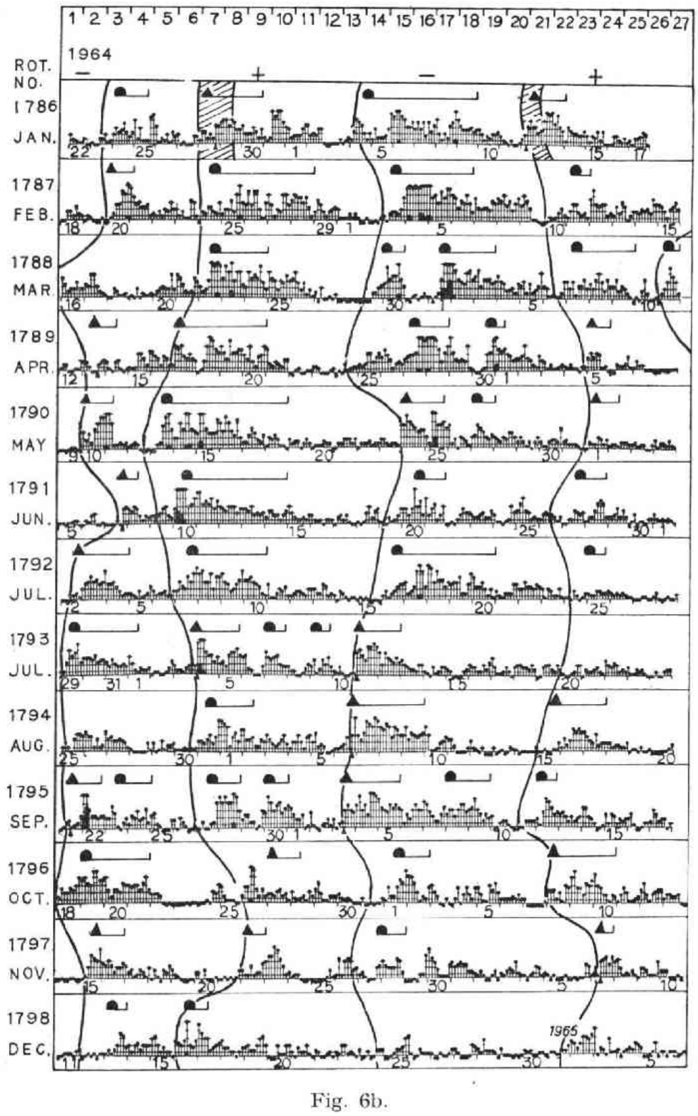

Fig. 6b.

Fig. 6 (a, b) The persistence of the sector structure in the period of rotational number 1772 to 1785 (a), 1786 to 1798 (b) is shown.

even if the root of this magnetic field occupies the same place on the solar surface. Fig. 6(a, b) represents the sectors during the period January 1963 to December 1964.

From January 1963 to May 1963 the positive sector corresponding to that observed by IMP-1 in the interval from December 2, 1963 to December 12, 1963 survives stronger than other sectors.

But from June 1963 to September 1963 the positive and following negative sectors persist clearer than other two sectors. From October 1963 to October 1964, the four sectors have the almost same activity. From November 1964 these sector become weaker than before period. From this history of the solar magnetic field sector the author can consider that the asymmetry of the sector would be servived more significantly in the declining phase of the solar cycle and then in the minimum solar cycle the tendency of this asymmetry becomes very weak.

Fig. 7 (a, b) also represents this tendency with the activity of pc3 ($\Sigma\ kc3$). The activity of pc3 also represents the sector structure from 1963 through 1964. The asymmetry of the sector structure indicated by pc3 is more pronounced than that of the geomagnetic disturbance. But the geomagnetic disturbance would represent the

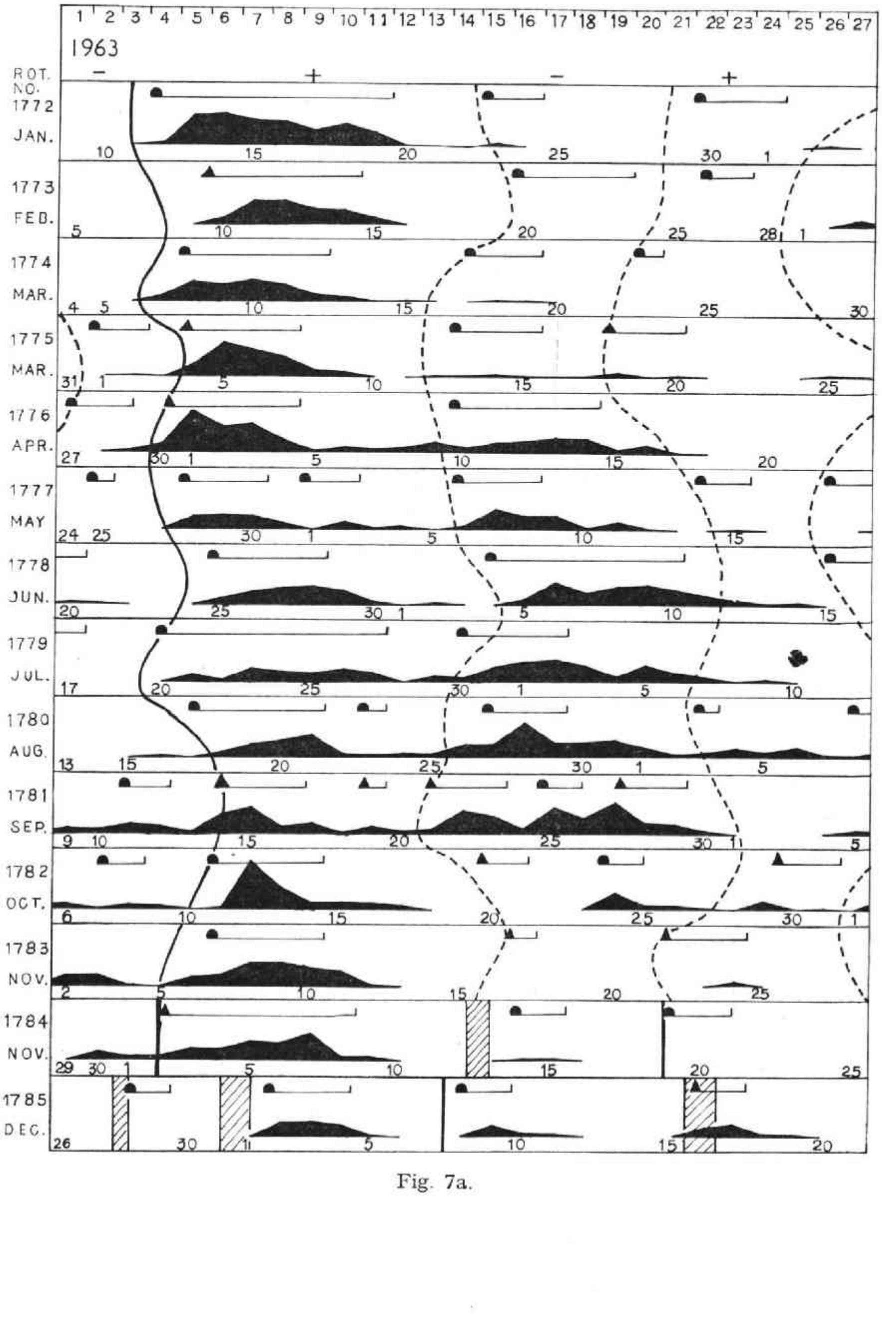

Fig. 7a.

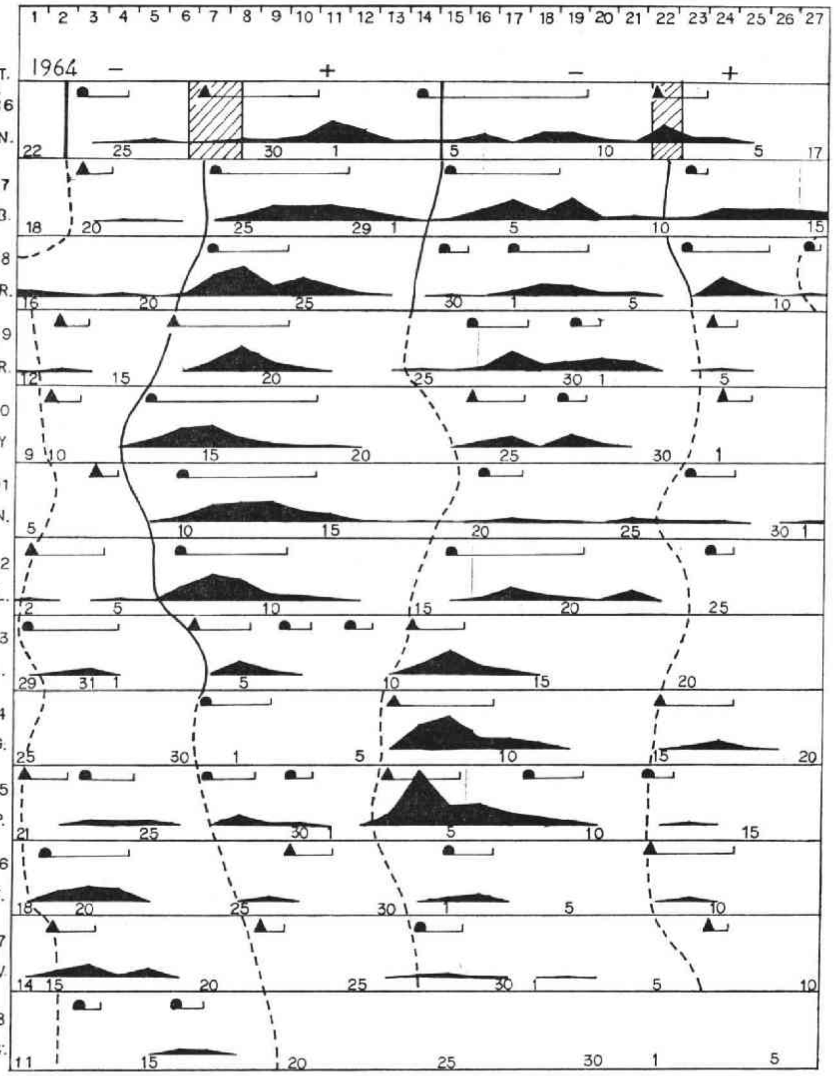

Fig. 7b.

Fig. 7 (a, b) The relation between the activity in pc3 and the expected sector structure for the interval of the rotational number 1772–1785 (a), 1786–1789 (b) is shown. The period observed by IMP-1 is the interval of 1784–1786, in which the solid line and the cross hatched area indicate the observed sector boundaries.
The dashed line also represents the sector boundary which is not well defined since the activity of geomagnetic micropulsation pc3 ($\Sigma\ kc3$) is week.

sector structure more clearly than the activity of pc3.

5. Discussion

A) The author described in this report that the geomagnetic disturbances occured near the interplanetary magnetic sector boundary, and further these sector boundaries corresponded to the weak magnetic field regions on the photospheric magnetic field of the sun.

It is important that the positions of the source of the geomagnetic disturbances seem to be the weak solar magnetic regions.

Bumba and Howard (1965) previously indicated that solar magnetic field was consisted with the unipole magnetic field with either positive or negative polarity and the leading and following positions of these unipole magnetic region were coincide with the G-UMRs and UMRs, respectively. And previously pointed out by K. Sakurai (1966) these G-UMRs would be coincide with the so called M-region as the source region by which 27-days period geophysical phenomena were occured. During the declining and minimum phase in the solar cycle (January 1963-December 1964) there were two main source regions on the sun which caused the geomagnetic disturbances. And these regions were significantly exhibited in the leading portions of the adjacent positive and negative polarity regions.

B) Relation between the geomagnetic distrubances at Kakioka, corresponding interplanetary magnetic field and flux of the energetic plasma stream on December 1, and 2, 1963 was already pointed out by us in Fig. 3. And there, we have emphasized that the geomagnetic disturbances mainly occured at the sector boundary.

However the geomagnetic flucutations (for example si) did not always occure near the sector boundary but also there were often found in the sector. We think that these flucutations are caused by the variation of the interplanetary magnetic field resulting from the interaction between the different energy level plasma streams. The storm sudden commencement at 21h 13m December 2, 1963 was caused by the overtaking with the stream in the following sector. The details of this event was described by Nishida in his report (1966).

We note that the energy level of the plasma stream at this storm shifted much significantly to the higher level. And further there were frequent energy variations of the plasma in the sector structure.

On taking account of above mentioned discussions, we concluded that the geomagnetic main disturbances would be caused with the impact of the different energy level plasma streams to the magnetospheric boundary.

Acknowledgement: The author wishes to express his gratitude to professor Yoshio Kato, Tohoku Umiversity, for his constant guidance of this work.

REFERENCES

Bumba, V., and R. Howard, 1965: Large-scale distribution of solar magnetic fields. *Ap. J.* **141**, 1502–1512.

Nishida, A., and L.J. Cahıll, 1964: Sudden impulses in the magnetosphere observed by explorer 12. *J. Geophs. Res.*, **69**, 2243–2256.

Nishida, A., 1966: Geomagnetic effects of the interplanetary sector structure. *Rept. Ionosph, Space Res. Japan*, **20**, 36–41.

Ness, N.F., and J.M. Wilcox, 1964: Solar origin of the interplanetary magnetic field. *Phys. Rev. Lett*,. **13**, 461–463.

Sakurai, K., 1966: On the large-scale structure of the sun's and the interplanetary magnetic fields during the minimum phase of the solar activity cycle. *Rept. Inosph. Space Res. Japan*, **20**, 33–35.

Sakurai, K., 1966: The persistence of solar flare regions related to the production of energetic protons and the interplanetary magnetic fields. *Pub. Astron. Soc. Japan*, **19**.

Wilcxo, J.M., and N.F. Ness, 1965: Quasi-stationary corotating structure in the interplanetary medium. *J. Geophys. Res.*, **69**, 5793–5806.

Wolfe, J.H., R.W. Silva, and M.A. Myers, 1966: Observations of the solar wind during the flight of Imp. 1. *J. Geophys. Res.*, **71**, 1319–1340.