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THE SUN AND THE HELIOSPHERE IN FEBRUARY–MARCH, 1986

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Abstract

Conditions of the sun and the heliosphere are studied in relation to the intense disturbances of the earth's and cometary magnetospheres in February and March, 1986. In this sunspot minimum phase, the sun had essentially the southward axial dipole which was to produce a weak northward IMF. However, one bipolar magnetic region in the northern hemisphere of the sun was connected by "southward" magnetic loops to another bipolar magnetic region in the southern hemisphere, because the two regions were near the equator by the Maunder's butterfly law. The meridional connection on 60° heliolongitude formed an abnormal giant bipolar magnetic region (GBMR), which made a local and strong warp of the general equatorial neutral line on the solar source surface. Magnetic energy was deposited and confined by the southward magnetic loops from the meridional GBMR, from which a slow-speed solar wind blew for a few months. Then, an abnormally active flare cluster started suddenly at the center of the meridional GBMR and the high-speed flare plasma broke the meridional magnetic loops, conveying the southward magnetic field towards the earth. After the flares, the GBMR decayed and the local warp of the neutral sheet was dissolved. Abnormally large-amplitude diurnal anisotropy of cosmic ray neutron intensity during the earth storm is explained by a combination of the minimum-phase effect and the storm effect. On the other hand, abnormally intense magnetic storm is explained by the high-speed flare plasma with southward IMF. The flattened interplanetary neutral sheet is discussed to explain the reported disconnection events of the plasma tail of comet Halley.

1. Anticipated situation of the sun and the heliosphere in February–March, 1986

In February, 1986, abnormally large sunspots were associated with active flare clusters, which gave rise to a series of abnormally intense earth storms. In March, 1986, comet Halley displayed marvelous disturbances of its plasma tail, in other words, of its magnetosphere.

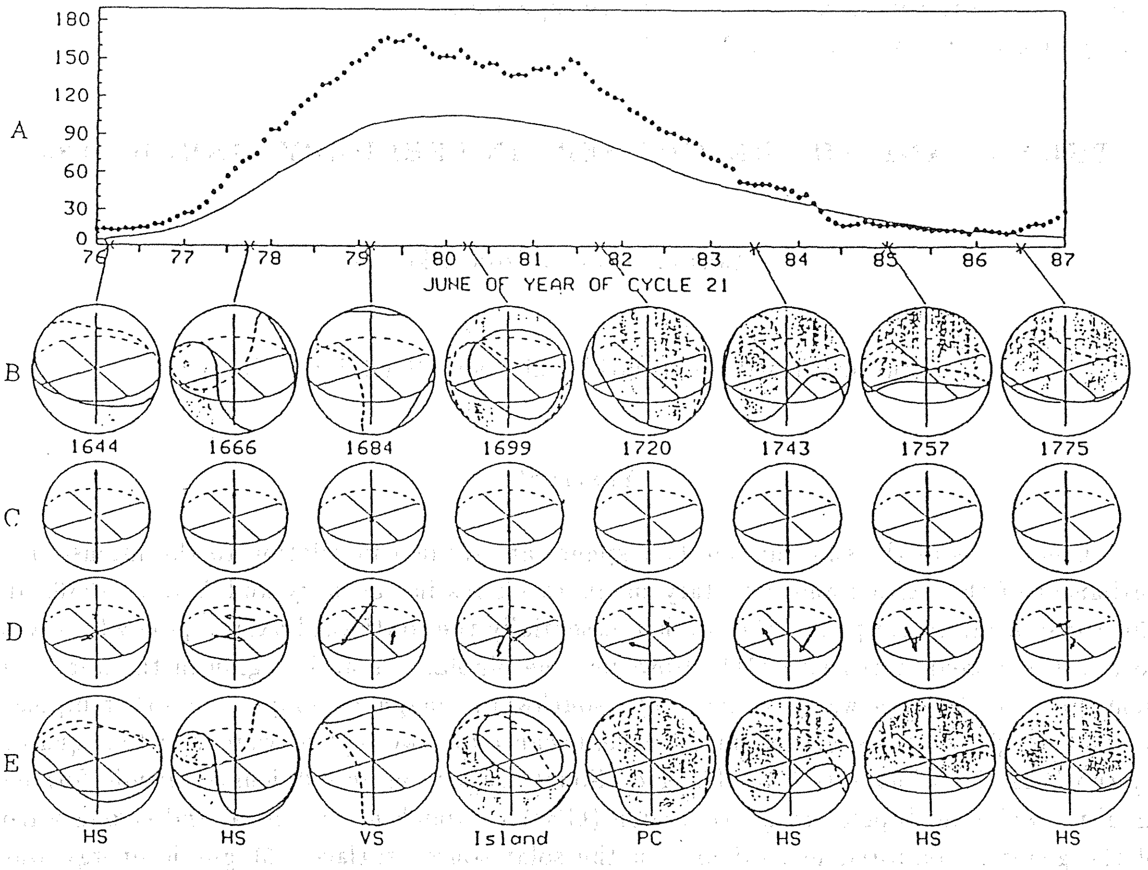


Fig. 1

Both the earth storms and the cometary disturbances resulted in interactions of the flare plasmas or the solar winds with the earth's and cometary magnetospheres. The purpose of the present paper is to discuss the sun and the heliosphere in February and March, 1986 as the sources of the disturbances.

Most disturbances of both earth's and cometary magnetospheres are strongly dependent on solar cycle phase. Hence, when the magnetospheric disturbances are discussed in this symposium, their peculiarities for the solar cycle phase must be taken into consideration in contrast to their ordinariness.

Figure 1B shows the eight magnetic neutral lines observed on the source surface that are to represent each period in one solar cycle. According to the triple-dipole mode, each of the observed neutral lines can be theoretically expressed by the triple dipoles: one axial dipole (Figure 1C) and two photospheric dipoles (Figure 1D). Figure 1E shows the theoretical neutral line calculated from the triple dipoles. The good coincidence between the observation in Figure 1B and theory in Figure 1E assures validity of the model. It must be noted here that the equivalent centered axial dipole was clearly "southward" in 1986.

The year 1986 in question was near the middle of the sunspot minimum phase as shown in the smoothed relative sunspot number in Figure 1A. If the sunspots were really null in 1986 as in 1954, the two representative photospheric dipoles had to be null. In this case, the observed and the expected neutral lines must be really flat in the year. However, both the solar and the heliospheric situations in 1986 were not ordinary but quite abnormal as will be discussed in the following sections.

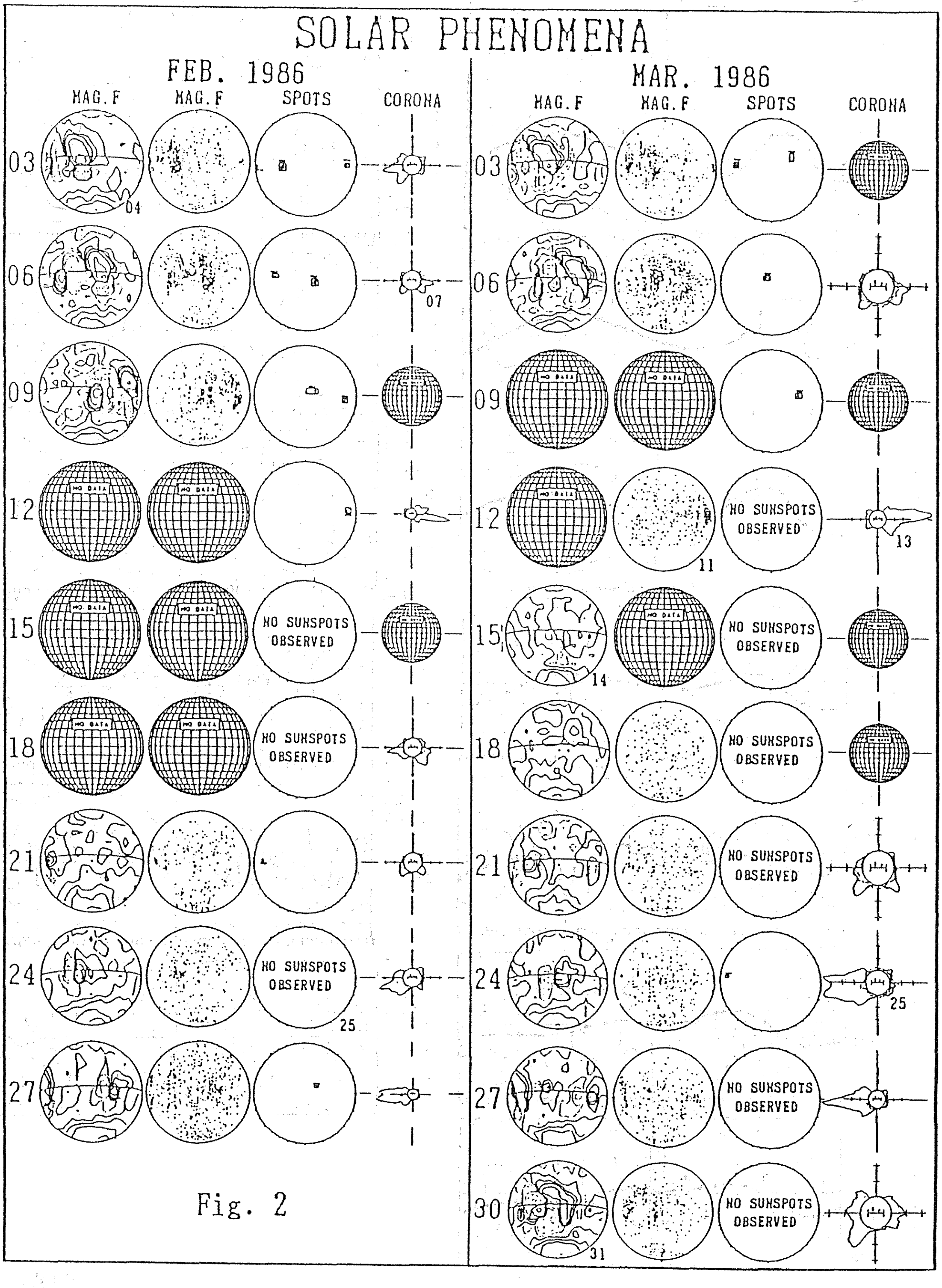
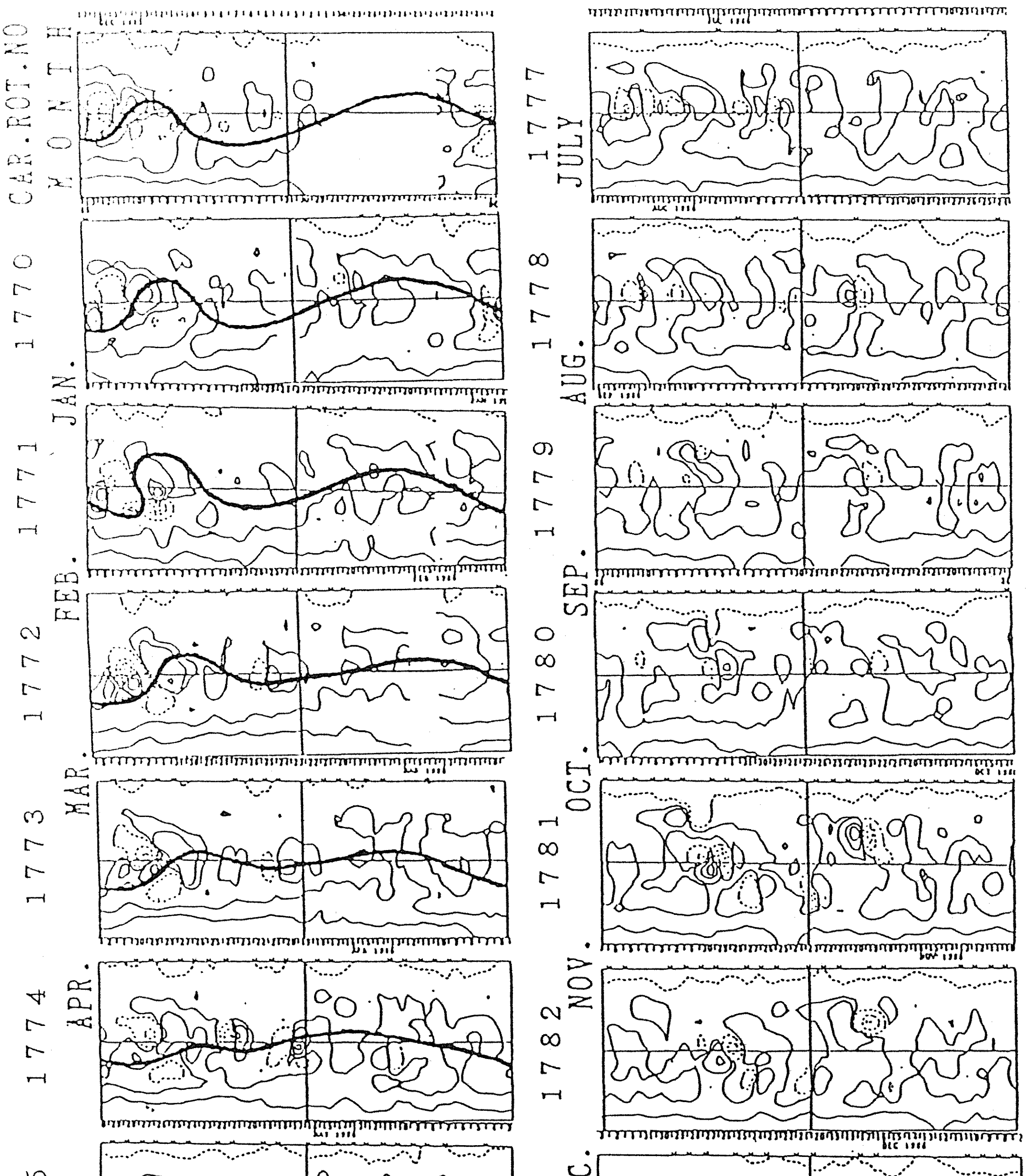


Fig. 2



CAR.ROT.NO
MONTH
1770 JAN.
1771 FEB.
1772 MAR.
1773 APR.
1774 MAY
1775 JUNE
1776
1777 JULY
1778 AUG.
1779 SEP.
1780 OCT.
1781 NOV.
1782 DEC.
1783

Fig. 3

2. Photospheric phenomena in February and March, 1986

Coarse and fine photospheric magnetic fields, sunspots, and coronal intensity at 1.1Rs are displayed in Figure 2 for February and March, 1986. The observed data are extracted from Solar-Geophysical Data. As exhibited in the figure, almost all the photosphere was covered by weak magnetic fields with almost no visible sunspots as found in the ordinary sunspot minimum phase. However, the figure shows that abnormally strong GBMR's (giant bipolar magnetic regions) appeared and made the central meridian passages on about 5th of February and March, respectively. It was also abnormal in the ordinary minimum phase that the sunspots from these GBMR's were actually able to be watched without a telescope and gave rise to an active flare cluster including the flare with 3B X1 at 0618 that was associated with a geomagnetic solar flare effect (sfe) on 6th of February. The flare triggered further the large earth storm, namely, an intense cosmic ray storm from about 12h UT and an intense magnetic storm from 1312UT on the next day.

Essentially, the polarity axis of the general bipolar magnetic region (BMR) is nearly parallel to the solar equator and forms equivalently the photospheric equatorial dipoles as shown in Figure 1D. When two BMR's appear near the same meridian in different latitudes, the coupled GBMR's show the magnetic axis nearly perpendicular to the equatorial plane as sometimes occurs in sunspot maximum. (See, for example, the case of solar rotation

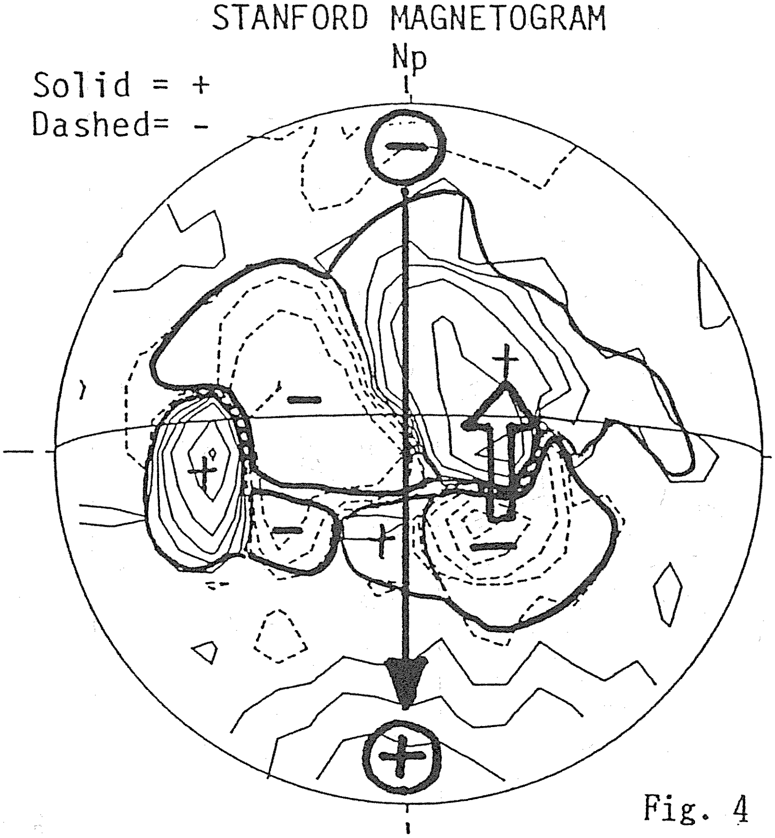


Fig. 4

No. 1699 in Figure 1.) When a BMR in the northern hemisphere and the other BMR in the southern hemisphere are in low latitude enough by the Maunder's butterfly effect in sunspot minimum phase, the axis of the coupled GBMR's becomes perpendicular sometimes to the equatorial plane. The intense solar flare at -7° latitude and 60° longitude occurred at the center of such vertical GBMR. The polarity of the photospheric dipole equivalent to the vertical GBMR was "northward" as shown in the synoptic chart of rotation No. 1771 in Figure 3, which is further illustrated by the hollow arrow in Figure 4. It must be noted here that the hollow arrow of the equivalent photospheric dipole is antiparallel to the solid arrow of the equivalent centered axial dipole as shown in the figure.

The northward photospheric dipole gives rise to the southward magnetic arcades in the coronal region. It is possible that from the vertical GBMR, the flare plasma conveyed the southward magnetic field which gave rise to the intense geomagnetic storm.

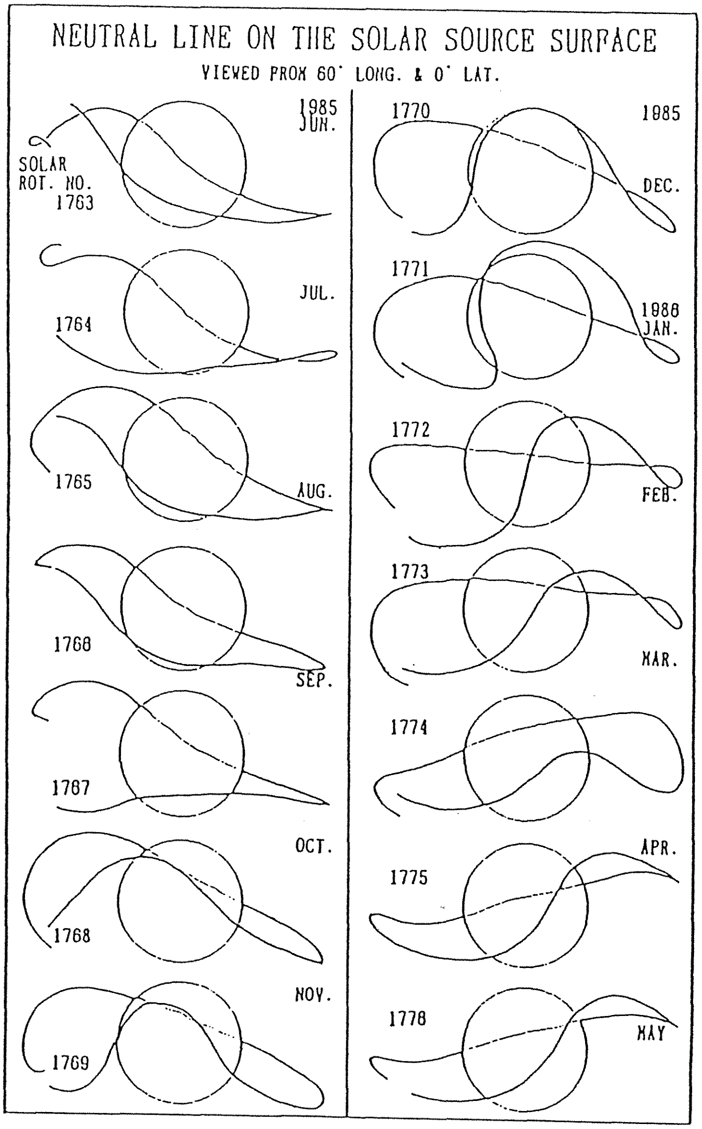


Fig. 5

3. Time variation of the source-surface neutral line in 1985 and 1986

In the previous chapter, we learnt that the equivalent centered axial dipole was southward, while the photospheric dipole equivalent to the vertical GBMR was northward in early February, 1986. The observed time variation of the source-surface neutral line from 1985 to 1986 will be explained by the time variation of the centered and the photospheric dipoles in this chapter.

An effect of the GBMR's can be seen in Figure 3, where magnetic fields on the photosphere and the neutral line on the source surface are superposed on the same 15 panels from Carrington rotation No. 1769 to 1783. The figure shows that the neutral line was locally warped above the strong vertical GBMR in question. The local warp of the neutral line is expressed as a time sequence display from June 1985 to May 1986 in Figure 5. (Owing to the time variation of the photospheric magnetic fields, the starting point of the neutral line at 360° longitude does not coincide generally with the ending point at 0° longitude.)

The gradual westward movement of the neutral line structure in the figure suggests the rotation of the magnetic fields, whose rotation speed depends on the longitudinal scale (m-number) of the fields.

Owing to the centered aligned dipole, the neutral line in the source surface was generally parallel to the equatorial plane as in the ordinary minimum phase. Since the photospheric vertical dipole on 60° heliolongitude was northward and opposite to the centered dipole, the source-surface neutral line was warped near the 60° meridian. Associating with the growth of the vertical GBMR, the warp was intensified from 1985 to early February, 1986 as shown in Figure 3.

The flare clusters at the center of the vertical GBMR in early February conveyed the southward magnetic field from the photospheric northward dipole and weakened the GBMR. The southward magnetic field was conveyed to the earth and excited the intense magnetic storm. On the other hand, the warp of the source-surface neutral line was dissolved after the flares owing to the weakening of the GBMR as shown in Figs. 3 and 5.

4. The typical heliomagnetospheric structure in February–March, 1986

The disconnected neutral line as we saw in Figure 4 can be connected smoothly by the pasting method as shown in Figure 6. Applying the pasting method to the neutral line of rotation 1772 in February and that of 1773 in March, the connected neutral line of rotation 1772.2 representative for February–March can be obtained. Then, let us use the pasted neutral line in the next figure.

The relations among the photospheric neutral lines (thin lines), the source-surface neutral line, and the neutral sheet in the inner and outer heliomagnetosphere, respectively, are exhibited in Figure 7. Figure 7A shows the solar situation viewed from 28° latitude and 60° longitude. The solid and broken thick lines mean the positive and negative magnetic fields, respectively. It is seen from the figure that the vertical GBMR near the central meridian is deforming the neutral sheet.

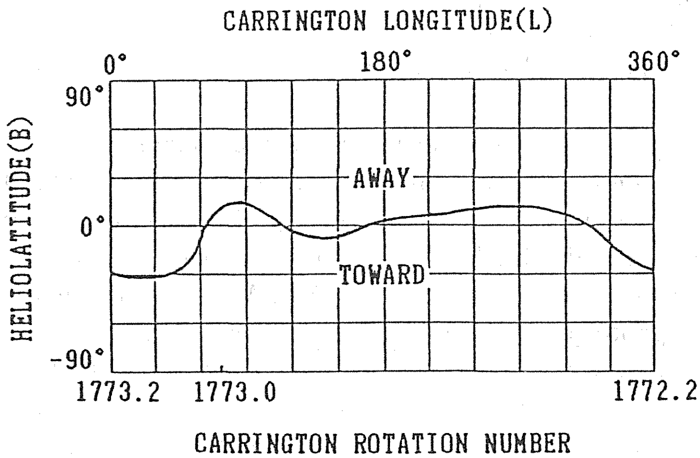


Fig. 6

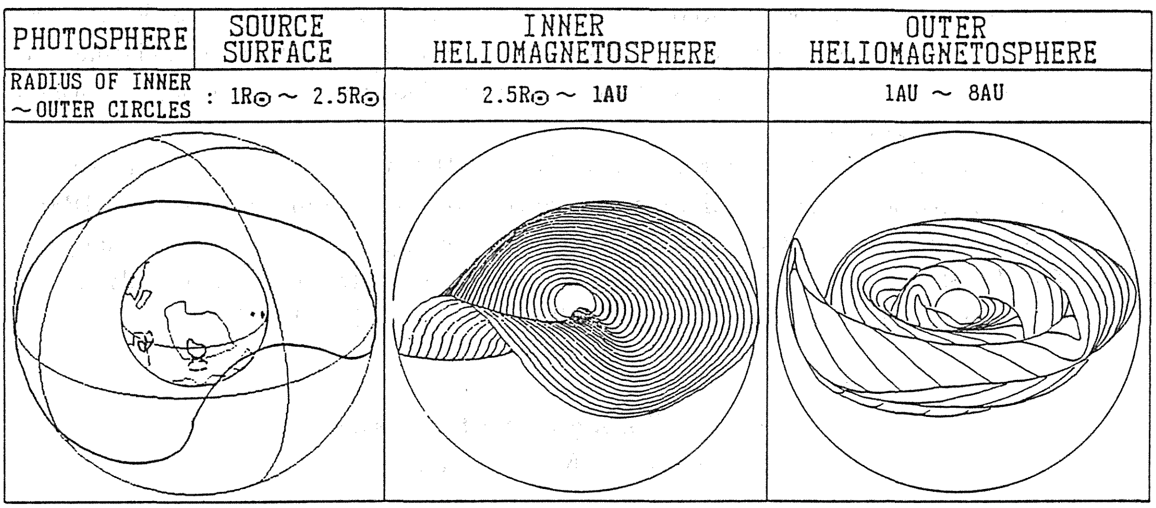


Fig. 7

The neutral line obtained from the minimum-velocity method being based on the interplanetary scintillation (IPS) data is superposed on the neutral line obtained from the scanning method based on the SAKIGAKE/IMF data in Figure 8. The two neutral lines are close to each other, although these two lines in Figure 8 are flatter than the source-surface neutral line obtained from the potential method in Figure 6 based on the photospheric magnetic fields. The fattening effect is very important when the disconnection events of comet Halley are discussed (see Saito and Oki, 1986).

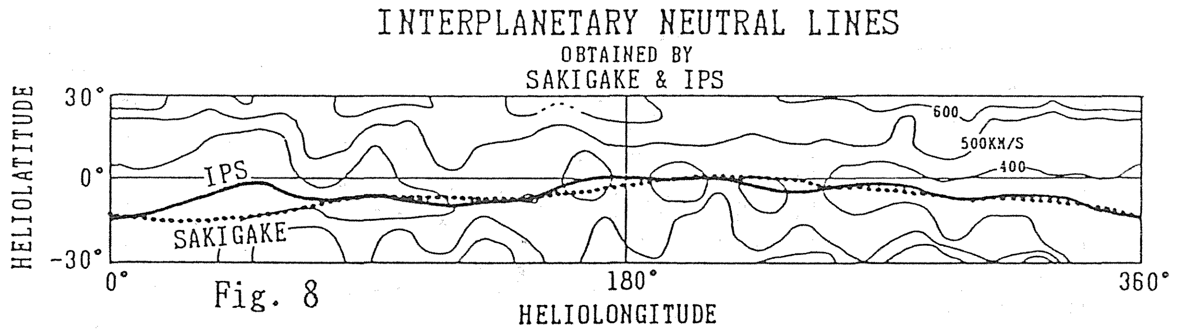


Fig. 8

5. Heliomagnetospheric effects on cosmic ray and geomagnetic disturbances

Since the year 1986 was in the aligned phase of the heliomagnetosphere, Saito (1989) proposed that diurnal amplitude of cosmic ray neutron intensity was to show a distinct semiannual variation due to the minimum phase effect and confirmed observationally as shown in Figure 9.

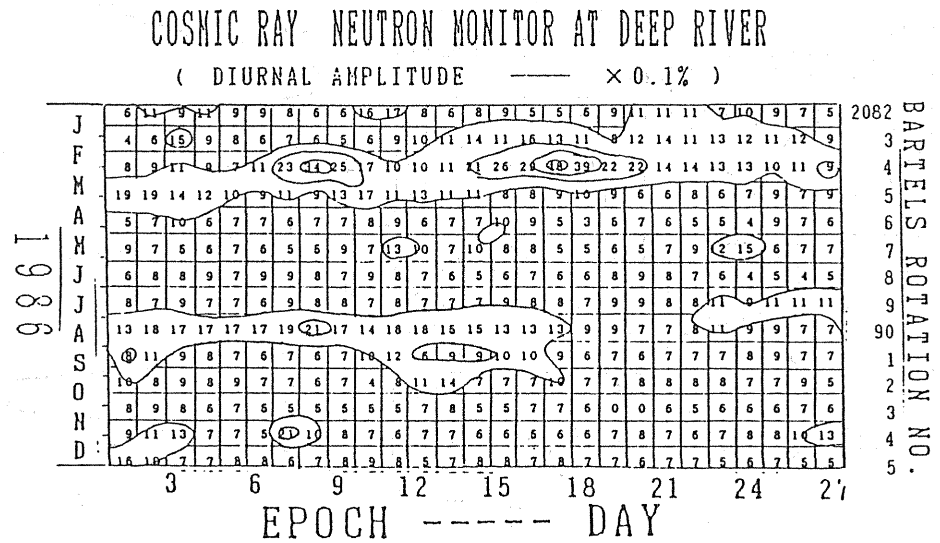


Fig. 9

The cosmic ray storm triggered by the solar flare cluster occurred during the very period of one of the intense semiannual variations. The abnormally large-amplitude diurnal variation of the neutron flux during the cosmic ray storm could be due to a superposition of the storm effect with the minimum phase effect.

This minimum phase effect on cosmic ray is derived from the northward component of the IMF (Saito and Swinson, 1986), while the southward component of the IMF gives rise to the semiannual variation of geomagnetic disturbances with a period of 22 years as shown in Figure 10. The abnormally intense magnetic storm occurred on 7 February in such situation.

The C9 = 7, 9, 8 in the second row in the 1986 recurrence diagram shows the large February storm. Because of the 22–year variation of geomagnetic disturbance, the February storm was not superposed by the semiannual variation as is substantiated in Figure 10.

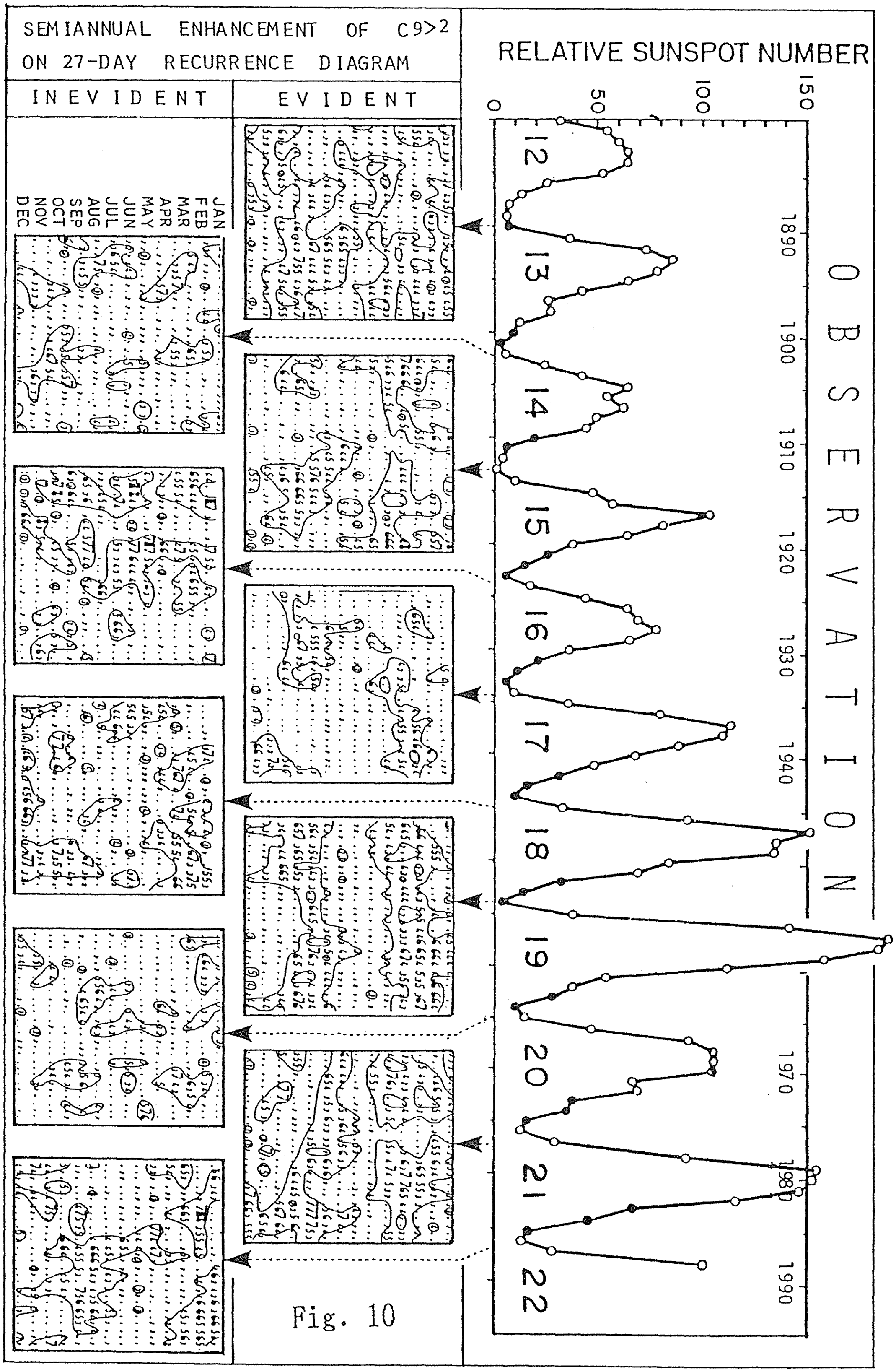

SEMIANNUAL ENHANCEMENT OF C9>2 ON 27-DAY RECURRENCE DIAGRAM
INEVIDENT
EVIDENT
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
RELATIVE SUNSPOT NUMBER
0
50
100
150
OBSERVATION
12
13
14
15
16
17
18
19
20
21
22
1890
1900
1910
1920
1930
1940
1970
1980
1990

Fig. 10

The GBMR had grown for a few months at 60° longitude until it was twisted so as to be vertical. The solar wind from the region was, therefore, having slow speed throughout these months.

The strong warp of the neutral line in rotation 1771 was restored by the flare cluster in 1772 associated with the disruption of the outstanding vertical GBMR at 60° longitude as shown in Figure 3. The disruption implies a drastic release of the magnetic energy associated with the solar flares. The high velocity stream with ~ 1000km/s as observed by IMP–J could be caused by the drastic disruption of the GBMR. The southward magnetic field from the vertical GBMR could be conveyed to the earth by the flare plasma. It can be concluded, therefore, that the abnormal contraction of the earth's magnetosphere during the intense magnetic storm could be excited by the high dynamic pressure and the southward IMF of the flare plasma from the vertical GBMR.

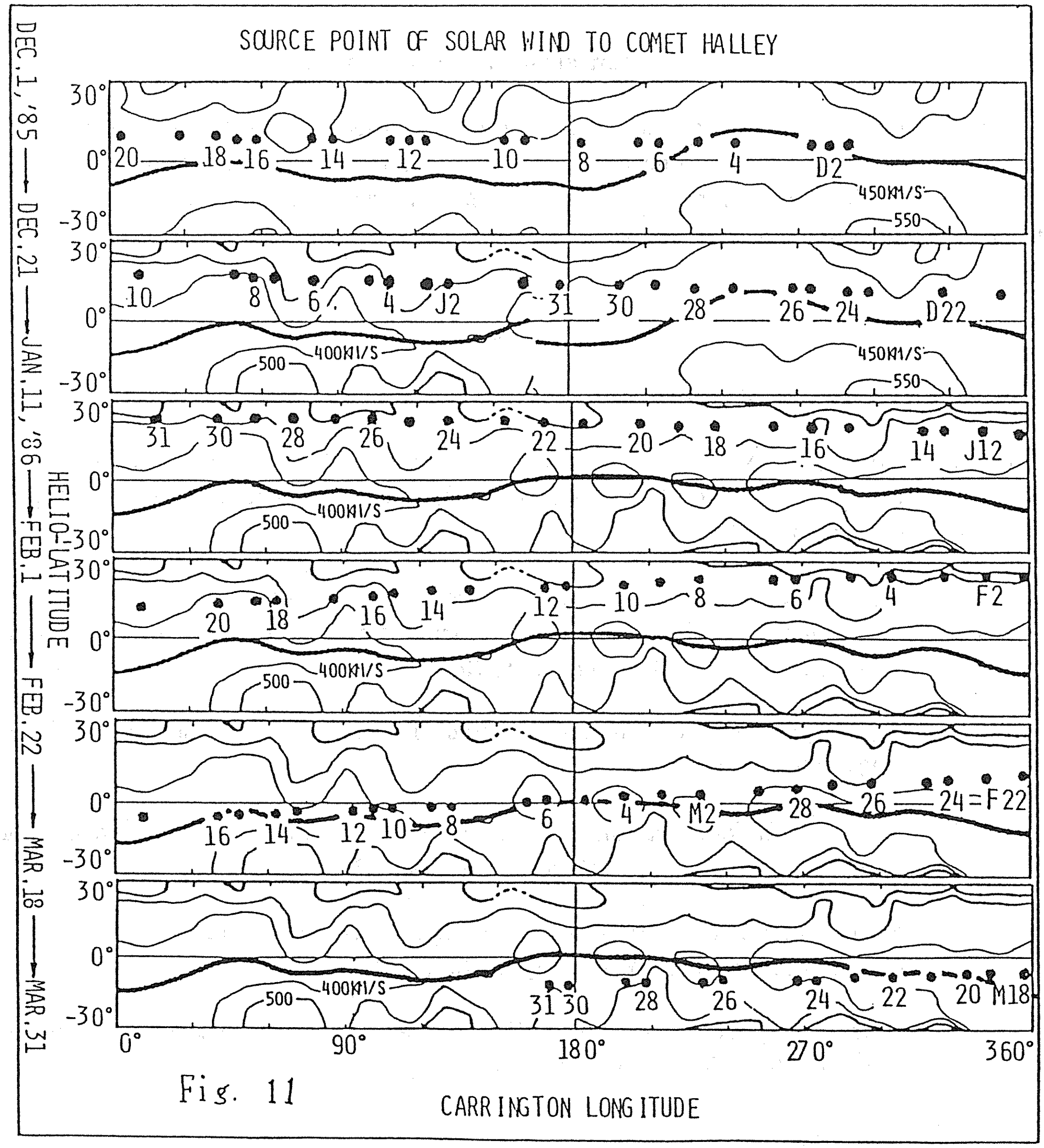


Fig. 11

6. Heliomagnetospheric effects on plasma tail disturbances of comet Halley

Disturbances of cometary plasma tail cannot be discussed without taking into account the solar cycle variation of the heliomagnetosphere as in the case of the earth's magnetosphere. The most outstanding disturbance of the cometary magnetosphere is a disconnection event, which is abbreviated to DE. According to the model by Niedner and Brandt (1983), DE occurs by the dayside reconnection only when a comet crosses the interplanetary sector boundary about once every week. However, in most cases of reported DE's, comet Halley actually did not cross the heliomagnetospheric neutral sheet as shown in Figure 11. The reader may refer to Saito and Oki (1989) and Saito (1989) for a more detailed discussion on this topics.

7. Discussion and conclusion

When a terrestrial phenomenon is sequentially studied, it is quite important to discuss it in relation to the solar cycle phase, because the phenomenon is generally quite dependent on the solar cycle phase. Hence, the February–March events in this symposium are worth studying when discussed from the viewpoints of ordinary or peculiar solar cycle phase.

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