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REMARKS ON THE INTERPRETATION OF LUNIK 10 MAGNETOMETER RESULTS

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Introduction

Recently direct measurements of the magnetic field in the vicinity of the Moon have been performed on the USSR satellite Lunik 10 (Dolginov al, 1966). These observations failed to reveal the presence of an intrinsic lunar magnetic field of dipole nature with any significant intensity. In addition, it was concluded that the earth's magnetic tail did not extend to distances of 60 R_E with magnitudes exceeding a level of 5γ. Finally a positive correlation was deduced between the intensity of the near lunar magnetic field and the index of planetary magnetic activity.

These results were obtained between 3 April and 4 May 1966. During this same time interval detailed measurements of the earth's magnetic tail were being performed by the USA satellite IMP 3 (Explorer 28). This spacecraft was launched on 29 May 1965 into a highly elliptical orbit with an initial apogee of 260,777 kilometers (approximately 41 R_E), and initial apogee-earth-sun angle 124° East of the Sun. It is the purpose of this letter to compare simultaneous measurements of the earth's magnetic tail on IMP 3 with those performed by Lunik 10.

This comparison is necessary since very recently the USA satellite Explorer 33 established the existence of the earth's magnetic tail and neutral sheet at and beyond the lunar orbital distance (Ness et al, 1967). This satellite, with apogee between 450,000 and 510,000 kilometers (70 to 80 R_E) was launched on 1 July 1966 at an initial apogee-earth-sun angle of 118° West of the Sun. From July to October 1966 the satellite swept through the magnetospheric tail of the earth once each two week orbital period.

Previous comprehensive measurements of the earth's magnetic tail and its imbedded neutral sheet were performed by IMP 1 in 1964 (Ness, 1965), and revealed a tail of the distorted geomagnetic field extending to distances half way to the Moon with magnitudes between 10 to 40 γ (median $\sim 16\gamma$). The transverse width of the tail was measured to be approximately 40 R_E. A detailed study of magnetic storm phenomena in the geomagnetic tail from these data by Behannon and Ness (1966) established a direct correlation between geomagnetic activity and magnetic tail field magnitude. In particular it was noted that the magnitude of the earth's magnetic tail field increased significantly simultaneous with increases in the planetary magnetic activity index Kp. Subsequently, during 1966 IMP 3 swept through the geomagnetic tail region and confirmed these earlier findings.

Observations by IMP 3

The instrumentation for the magnetic field experiment on the IMP 3 satellite was essentially identical to that of the IMP 1 satellite launched in 1963 (Ness et al, 1964). Briefly, measurements of weak magnetic fields were performed by fluxgate magnetometers with maximum dynamic ranges of $\pm$ 40γ and sensitivities of $\pm$ 0.4γ. The sensors were placed at the extreme ends of booms 2 meters in length to remove contaminating effects of spacecraft generated magnetic fields.

Of particular interest on the IMP 3 satellite are the observations obtained during orbits 54 and 59 in April-May 1966. IMP 3 was imbedded well within the geomagnetic tail and on orbit 54 apogee occurred while the satellite was very close to the midnight meridian plane. The magnetic field measurements obtained by IMP 3 during these two orbits are presented in Figures 1 and 2. The data are presented in solar ecliptic coordinates in which θ measures the latitude of the field vector relative to the plane of the ecliptic and ϕ the longitude with the earth-sun line = 0° longitude. In addition parameters pertinent to the satellite position in its orbit are included.

Inspection of these two figures reveals that during both orbits the satellite measured magnetic fields whose direction was usually parallel to the earth-sun line. It is seen from these data that at geocentric distances greater than 20 R_E the field magnitude is characteristically 10 to 20γ when the satellite is not in close proximity to the neutral sheet. When the satellite was below the neutral sheet

the field was directed away from the Sun and when above the neutral sheet the field was directed toward the Sun. Multiple sheet crossings are observed in orbit 54 on April 7 and in orbit 59 on May 5 and 6. These measurements were performed during full Moon when Lunik 10 was performing magnetic field measurements in the vicinity of the Moon.

Thus at the time of Lunik 10 measurements the earth's magnetic tail extended at least to 38 R_E and the neutral sheet was well developed as a region of rapid field direction reversal and small magnitude. The position of the neutral sheet during these observations is important in the interpretation of observations from Lunik 10. Figure 3 presents the position of the IMP 3 satellite as measured by Z_{SM} in solar magnetospheric coordinates during orbits 54 and 59. The time at which neutral sheet crossings were observed is indicated by the arrows. It is noted that generally the neutral sheet is observed close to or slightly above the equatorial plane of the solar magnetospheric coordinate system. It is also clear that the neutral sheet is moving since its relative position in either solar ecliptic or magnetospheric coordinates is not constant.

These results are in general agreement with the model of the neutral sheet position and motion deduced from a detailed study of the IMP 1 data by Speiser and Ness (1967). Due to the obliquity of the earth's spin axis to the ecliptic, during the summer the neutral sheet in the earth's magnetic tail will be located slightly above the solar magnetospheric equatorial plane. In winter the neutral sheet correspondingly will be below this equatorial plane.

Interpretation of Lunik 10 Data

In the interpretation of the Lunik 10 magnetometer data Dolginov et al (1966) conclude that the earth's magnetic tail does not extend to the lunar distance with the upper limit of 5γ as its contribution to the measurements. However, on the same satellite Gringauz et al (1966) have concluded from low energy charged particle trap data that they detected the plasma associated with the neutral sheet (magnetic field reversal region). It is possible to verify the interpretation of the plasma data by investigating the orbital characteristics of the Moon in solar ecliptic and solar magnetospheric coordinates. Since Lunik 10 is in a very close lunar orbit this will then yield a good estimate of its location in space while these measurements were performed.

Figure 4 presents the position of the Moon in the two coordinate systems for the two time intervals of interest. It is seen that the Moon is mainly above the ecliptic plane during these times. Superimposed on the plots are time intervals A and B corresponding to data transmission times when electron fluxes characteristic of the plasma associated with the neutral sheet were detected (Gringauz et al, 1967). It is noted that during both transmissions, the Moon is seen to be located extremely close to the solar magnetospheric equatorial plane. This figure also shows that the satellite distance from this equatorial plane depends upon the time very critically.

Thus for these transmission periods (A,B), weak magnetic fields associated with the earth's neutral sheet are to be expected. Dolginov et al (1966) did not take this into account in their interpretation and it is reasonable to assume now that the conclusion of Gringauz et al (1966) is correct and that the earth's magnetic tail does extend to the orbit of the Moon.

A positive correlation was also noted between magnetic activity on the earth's surface and the magnitude of the near lunar magnetic field. This was interpreted as evidence of the dependence of interplanetary magnetic field magnitude on solar flare activity (Greenstadt and Moreton, 1962). The Lunik 10 comparisons were made at the time of successive full Moon periods. According to Lincoln, (1966 a,b) the planetary magnetic activity index for April 5 was 12^- and for May 4 was 21^-. For the same times the magnitude of the near lunar field was observed to be 12γ larger on 4 May than on 5 April. These results are in complete agreement with earlier studies by Behannon and Ness (1966) showing a positive correlation between planetary magnetic activity and magnetic tail field magnitude. Thus the variability of the near lunar field is not evidence of the presence of the interplanetary magnetic field and the absence of the geomagnetic tail.

Conclusions

Initial interpretation of the Lunik 10 magnetometer data obtained in April-May 1966 led to conclusions that the earth's magnetic tail was absent at the lunar orbital distance. This was not in agreement with results obtained subsequently by Explorer 33 measuring the earth's magnetic tail at and beyond the lunar orbital distance in July-October 1966. Measurements of low energy plasma fluxes on Lunik 10 indicated traversal through the earth's neutral sheet.

Observations of the earth's magnetic tail and the position of the imbedded neutral sheet in April and May 1966 by IMP-3 demonstrate the existence of the tail and neutral sheet simultaneous with the Lunik 10 measurements. Thus, it is necessary to investigate the position of the Moon in solar magnetospheric coordinates in order to interpret the Lunik 10 data. When this is done it is found that the magnitude and temporal variation is consistent with the satellite being imbedded in the earth's magnetic tail during full moon periods.

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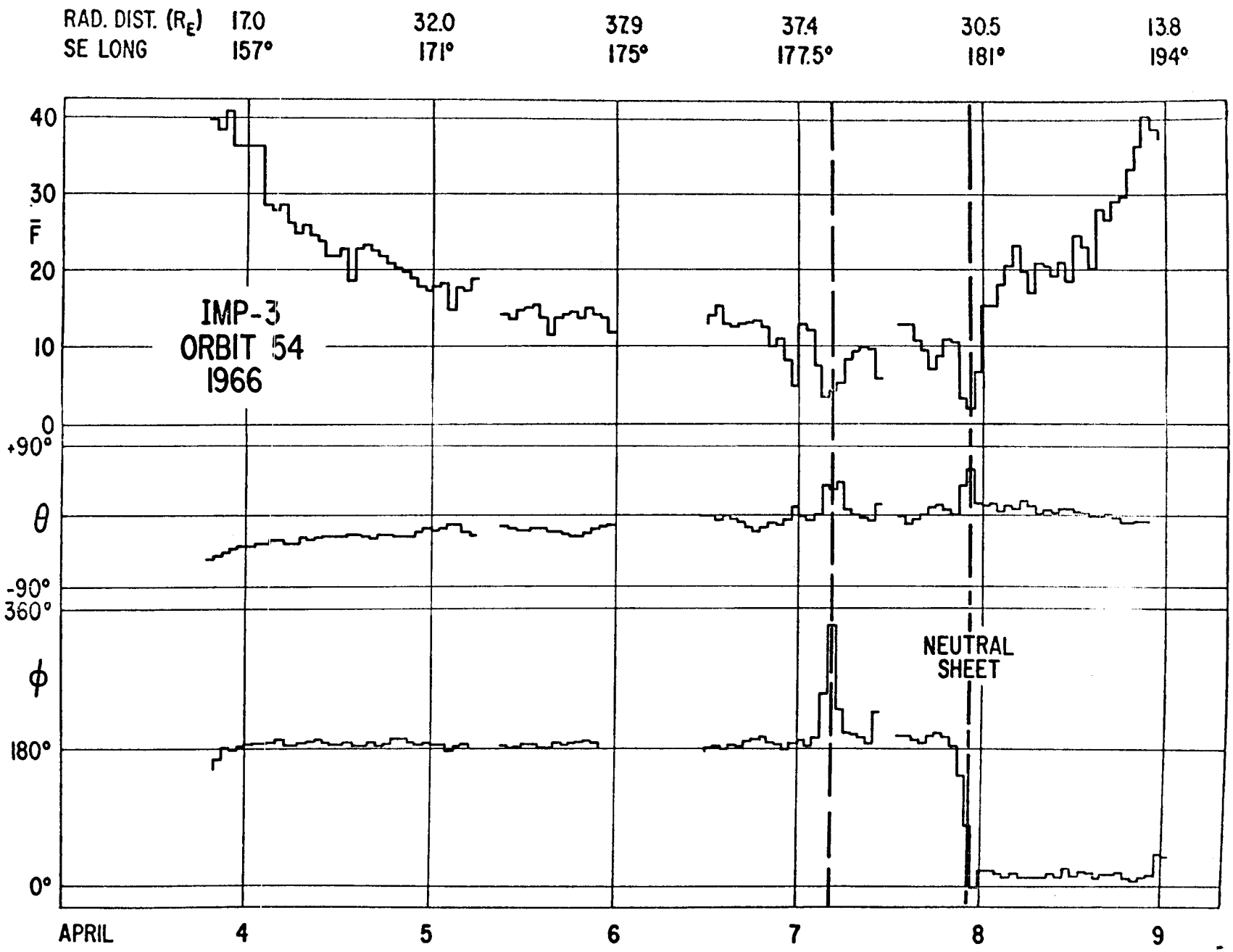
FIGURE CAPTIONS

Figure 1 Measurements of the earth's magnetic tail by IMP 3 in April 1966.

Figure 2 Measurements of the earth's magnetic tail by IMP 3 in May 1966.

Figure 3 Relative position of the IMP 3 satellite in solar magnetospheric coordinates during orbits 54 and 59 in 1966. The daily "wobble" of the earth's magnetic dipole axis is readily evident modulating the distance of the satellite from the equatorial plane.

Figure 4 Relative position of the Moon (and Lunik 10) during the full Moon periods in April and May 1966. The horizontal scale references the position of the satellite transverse to the earth-sun line in the ecliptic plane. The vertical axis represents the distance in solar ecliptic (SE) or solar magnetospheric (SM) coordinates of the satellite from the equatorial plane of the corresponding coordinate system. All dimensions in Earth Radii (1 R_E=6378.1 Km).


RAD. DIST. (R_E)
SE LONG
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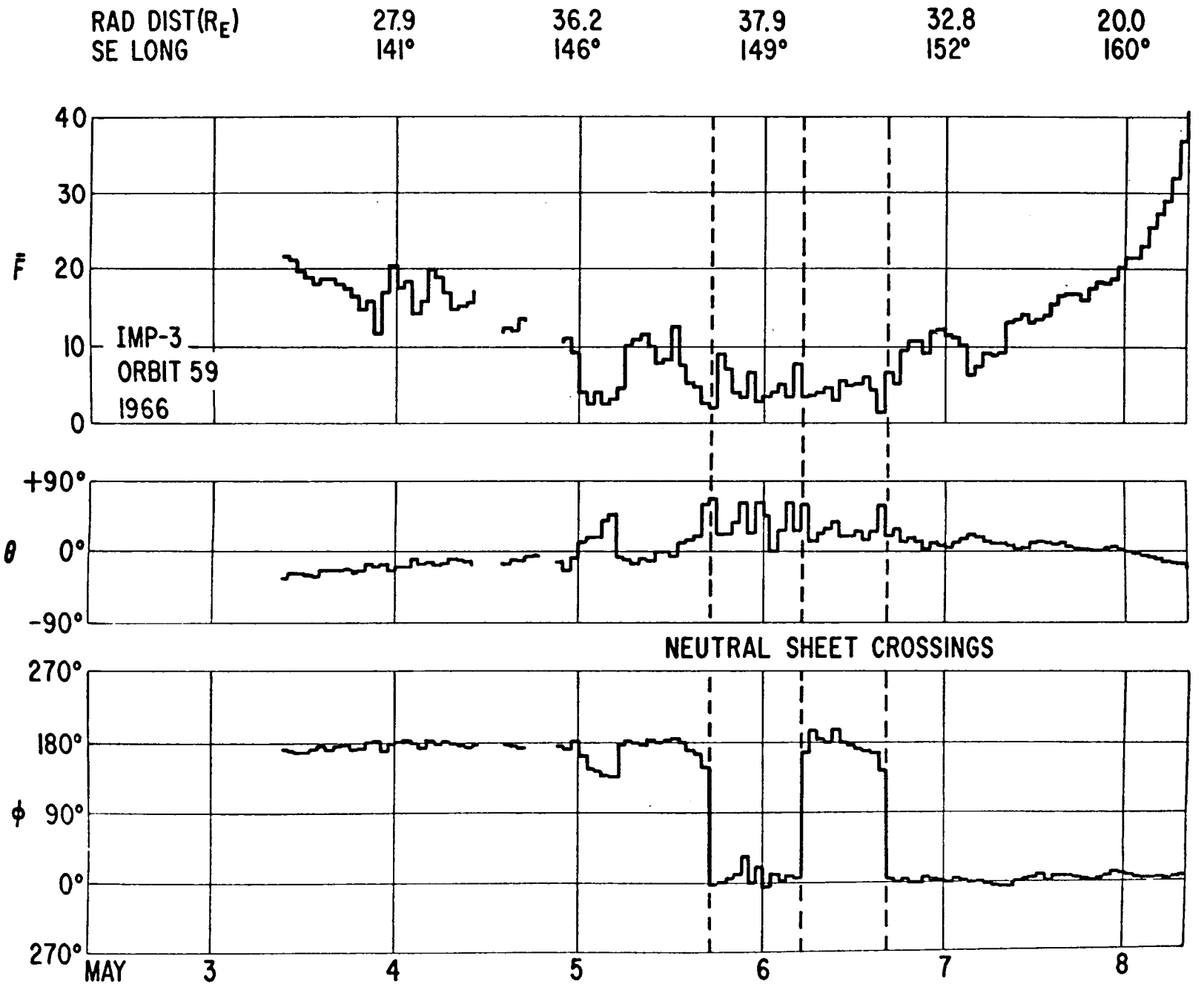
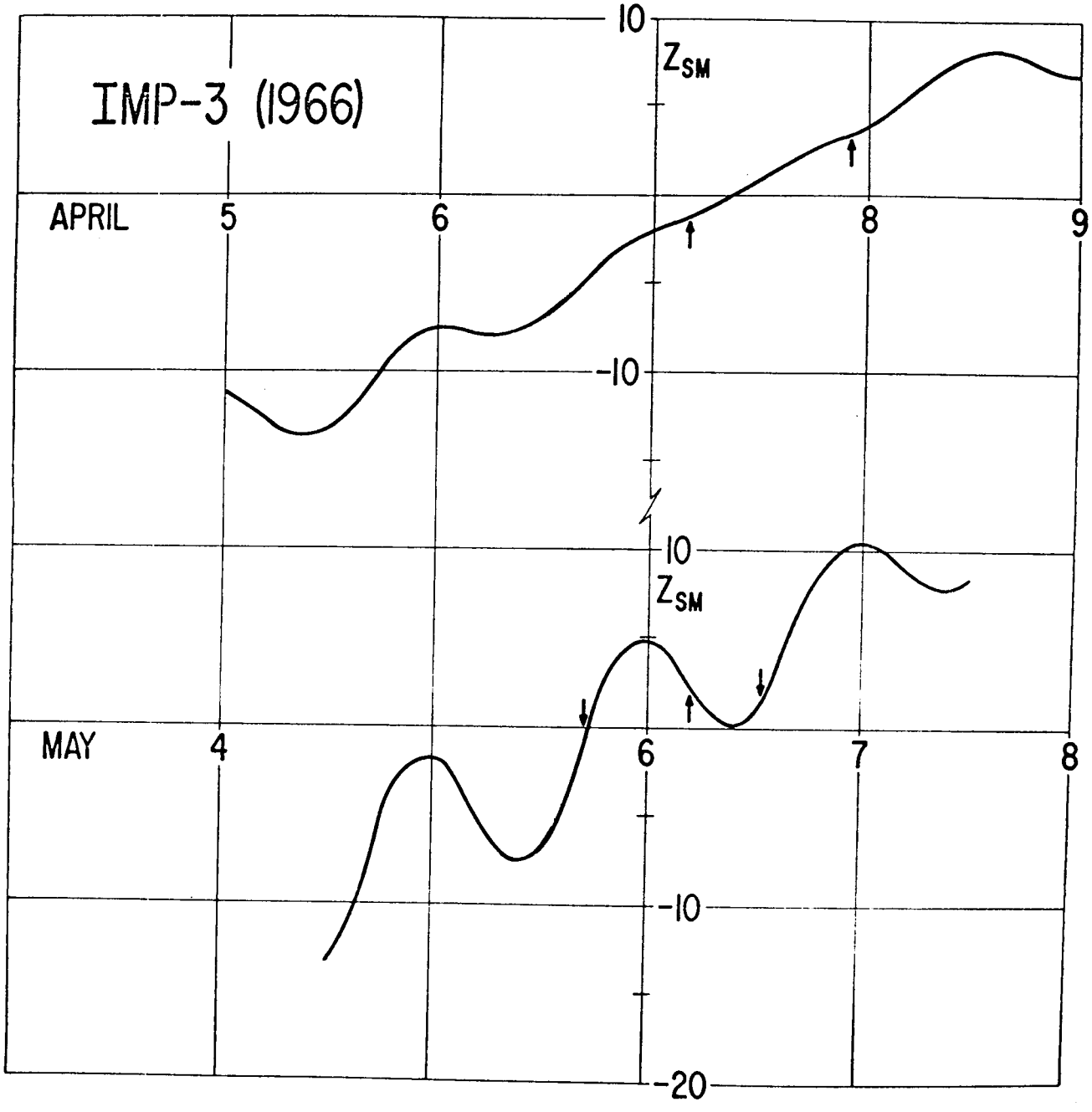
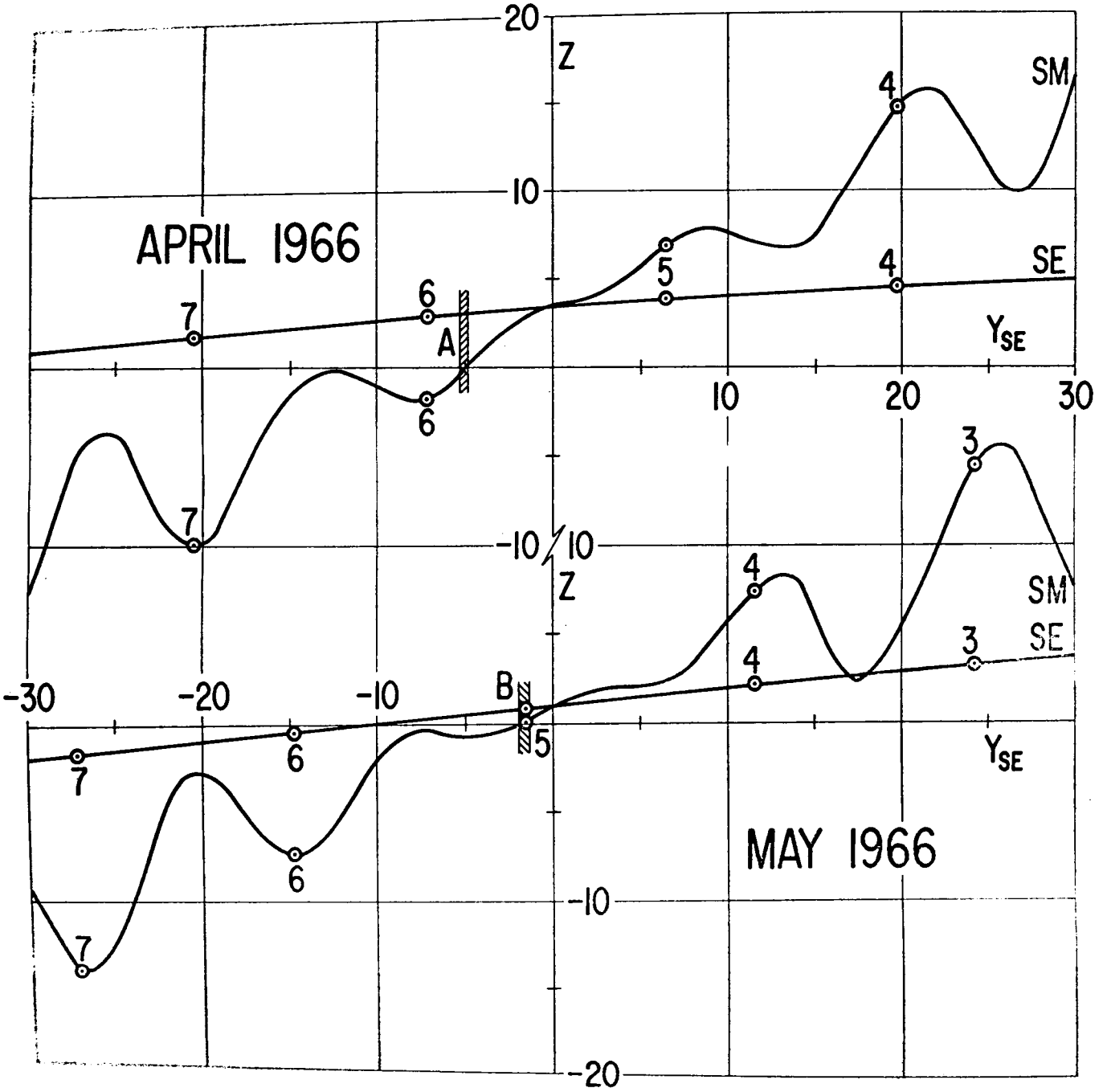
157°
32.0
171°
37.9
175°
37.4
177.5°
30.5
181°
13.8
194°
40
30
$\bar{F}$
20
10
0
+90°
θ
-90°
360°
ϕ
180°
0°
IMP-3
ORBIT 54
1966
NEUTRAL
SHEET
APRIL
4
5
6
7
8
9


RAD DIST(R_E)
SE LONG
27.9
141°
36.2
146°
37.9
149°
32.8
152°
20.0
160°
40
30
$\bar{F}$ 20
10
0
IMP-3
ORBIT 59
1966
+90°
θ 0°
-90°
NEUTRAL SHEET CROSSINGS
270°
180°
ϕ 90°
0°
270°
MAY
3
4
5
6
7
8


IMP-3 (1966)
APRIL
5
6
8
9
10
-10
Z_{SM}
MAY
4
6
7
8
10
-10
-20
Z_{SM}


APRIL 1966
MAY 1966
Z
SM
SE
Y_{SE}
A
B
20
10
-10
-20
-30
-20
-10
10
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30
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6
7