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MAGNETIC FIELDS AND SOLAR WIND

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1. Introduction:

The solar influences on the geomagnetic field can be divided into two classes: (i) corpuscular radiation and (ii) electromagnetic radiation in ultra-violet and X-ray regions. Major magnetic effects produced by these solar agencies are summarized in Table 1.

This resource paper concerns only with the interaction of solar corpuscular radiation with the geomagnetic field. In this paper it is not intended to give a complete review of the subject, but rather only highlights in several selected topics are discussed. No attempt is made to give exhaustive reference to relevant papers.

2. Solar Wind:

The existence of steady solar wind has been well established by the plasma experiments by Explorer 10 (Bonetti et al., 1963), Mariner 2 (Neugebauer and Snyder, 1962; Snyder, Neugebauer and Rao, 1963), and more recently by IMP-I (Bridge et al., 1964; Wolfe and Silva, 1964).

According to Snyder et al. (1963) the Mariner 2 plasma measurement showed that daily mean velocity of solar wind is highly correlated with the daily sum of Kp index. The correlation between plasma velocity and Kp was still high when averaged over intervals shorter than one day, for instance, over 6 hours. No increased variability was observed in plasma velocity when the velocity was high. Snyder et al. thus concluded that within the time resolution attainable with their instrument Kp is a measure of plasma velocity. Earlier, Dessler (1962) and Dessler and Fejer (1963) suggested, from a consideration of the stable nature of the magnetospheric boundary, that Kp might represent the time rate of change of plasma (plus magnetic) pressure.

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A preliminary study made by Snyder et al. (1963) indicates that the density, flux, kinetic pressure or temperature of the plasma did not have as good a correlation with Kp as the plasma velocity.

By a least square method they derived a linear equation relating the plasma velocity v to the daily sum of Kp.

$$v \ (\mathrm{km/sec}) = (8.44 \pm 0.74) \sum \mathrm{Kp} + (330 \pm 17)$$

They suggested however that $\sum$ Kp may well be related to some power of the velocity.

When $\sum \mathrm{Kp} = 0$, $v = 330$ km/sec. During the Mariner 2 mission the geomagnetic field was quiet for a period only once, for 18 hours, Kp remaining zero. The plasma velocity at this time was between 315 and 360 km/sec.

An extrapolation to Kp = 9 gives a plasma velocity of 938 km/sec. The average plasma velocity over the four months of the Mariner 2 measurement was 504 km/sec.

Preliminary IMP-I results give a plasma velocity of 300 to 500 km/sec and a particle density of 3 to 13 particles /cc (Bridge et al., 1964; Wolfe and Silva, 1964).

Snyder et al. (1963) found a series of 27 day recurrent peaks in the plasma velocity. They attributed these high velocity plasmas to the 'M-regions'.

There was no strong correlation between the plasma velocity and the sunspot number or the 10.7 cm radiation flux. No dependence of plasma velocity on solar distance was found between 1.0 to 0.7 AU where the Mariner 2 measurement was made.

Solar wind has been found to be supersonic relative to both sound waves and Alfvén waves. This is inferred from the fact that the thermal velocity of solar plasma was much less than the bulk velocity, and that the kinetic energy density for the bulk motion was greater than the magnetic field energy density (Bonetti et al., 1963).

The IMP-I plasma measurement by Bridge et al. (1964) indicated that the Mach number for solar wind was 5 to 6 and occasionally greater.

3. Interplanetary magnetic fields:

Explorer 10 magnetic field measurements by Heppner et al. (1963) show that the magnetic field energy outside the magnetosphere is typically a factor of 5 to 10 less than the observed plasma energy density, and hence the magnetic field is carried by the solar wind. Both small- and large-scale variability was observed in the solar wind.

The recent IMP-I magnetometer measurement by Ness et al. (1964) indicates that the interplanetary magnetic field is typically a few to 7 gammas and has a filamentary structure.

4. Magnetospheric boundary:

By IMP-I Ness et al. (1964) have made definitive observations of the magnetopause, the stationary shock front and the transitional region between them. Their results confirm the formation of a shock front previously proposed by Kellogg (1962) and Axford (1962).

For a collisionless shock the existence of a magnetic field in the streaming plasma is essential, and the required magnetic field has been actually observed. However, no complete theoretical treatment of a collisionless shock is as yet available. It is remarkable, however, that the observed features show a striking analogy to an aerodynamical shock.

In the transitional region the magnetic field is irregular; this characteristic has been observed by Pioneer 1 (Sonett, Smith and Sims, 1960; Sonett, Judge, Sims and Kelso, 1960); Pioneer 5 (Coleman et al., 1960); Explorer 12 (Cahill and Amazeen, 1963) and IMP-I (Ness et al., 1964) all on the sunlit side. According to the IMP-I plasma measurement, the particles are thermalized in this transitional region and the velocity distribution is frequently isotropic (Bridge et al., 1964).

According the IMP-I measurement by Ness et al. (1964) the position of the magnetopause on the equatorial plane is about 10 earth-radii in the subsolar region and the shock front is situated at about 13.4 earth-radii. Toward the morning meridians the projections of the magnetopause and the shock front onto the equatorial plane extend to greater distances than in the noon meridian. Figure 1. (after Ness et al., 1964, unpublished material; not reproduced in this paper) shows a schematic picture of the magnetospheric boundary, the transitional region and the stationary shock front as observed by IMP-I. It also shows the direction of the interplanetary magnetic field.

5. Heating of the upper atmosphere by solar wind:

To account for the diurnal breathing of the atmosphere Harris and Priester (1962) sought an energy source for the atmospheric heating in solar corpuscular radiation. The satellite drag data give evidence for the existence of some heating mechanism operating in the upper atmosphere that derives its energy from solar wind; namely, the upper atmospheric temperature appears to increase with increasing magnetic activity (Jacchia, 1959; Jacchia, 1963; Jacchia and Slowey, 1964).

Dessler (1959) proposed an ionospheric heating mechanism by hydromagnetic waves generated by solar wind at the magnetospheric boundary and propagated through the magnetosphere down to the ionosphere where the waves are absorbed. However, for this process to be solely responsible for the heating we have to require an almost continuous flow of hydromagnetic waves of such large amplitude as to make it difficult to reconcile with the fact that such large amplitude waves have not been detected by satellite measurements.

Recently, Jacchia and Slowey (1964) have shown that such atmospheric heating is more pronounced in the polar regions than in low latitudes. This suggests that Joule heating, as suggested by Cole (1962), and possibly direct heating by precipitating particles are important in high latitudes.

More work is needed to clarify the problem of the atmospheric heating by solar wind.

6. Sudden changes in solar wind pressure:

World-wide sudden magnetic changes,in particular, step-function like sudden level changes of the magnetic field observed on the earth have been interpreted as due to sudden changes in solar wind pressure (Nishida and Jacobs, 1962; Sugiura, Davis and Heppner, 1963). Figure 2 (after Sugiura, Davis and Heppner, 1963) shows an example of such changes.

With the data from Explorer 12, Nishida and Young (1963) have shown that these sudden magnetic changes are observed in the magnetosphere and confirmed the above interpretation. For the sudden impulses examined by these authors a shock wave structure was not observed in the magnetosphere.

Sudden commencements of magnetic storms are also good examples of such sudden changes of the magnetic field. When the impact of a cloud of solar plasma is strong enough the compressional wave produced by the impact initiates oscillation of the magnetic field lines that are anchored in high latitudes and crossing the equatorial plane at large geocentric distances, say, beyond 5 earth-radii.

Figure 3 shows an example of the sudden commencement of a magnetic storm observed at Honolulu (geomagnetic latitude 21°N) and at Byrd Station (geomagnetic latitude 71°S) in Antarctica. The change is an approximately linear increase of the magnetic field at Honolulu, whereas the perturbation observed at Byrd Station indicates an oscillation of the magnetic field lines.

Very low frequency hydromagnetic waves have been detected in the magnetosphere by Explorer 6 by Judge and Coleman (1962) and by Explorer 12 by Patel and Cahill (1964). These observations are in agreement with the model proposed earlier by Sugiura (1961) from a study of conjugate magnetic records obtained at ground level.

The theoretical study of the propagation of hydromagnetic perturbation in the magnetosphere is still in a rudimentary stage.

7. Magnetic activity indices.

Magnetic storm variations consist of two major parts, Dst and DS. The part Dst includes the initial increase of the magnetic field due to the compression of the magnetosphere by an intensified solar plasma and the subsequent large decrease of the field by a ring current. The second part, DS, is mainly due to auroral electrojets.

Though there have been several mechanisms proposed for the generation of the ring current and auroral electrojets, no definitive observational evidences exist to substantiate these models.

Kp index describes gross magnetic activity on a global scale. Phenomenologically, it expresses the degree of magnetic activity mainly due to polar disturbances.

For some time it has been felt by Chapman and others that it is desirable to make some index for the ring current intensity available on a continuous basis. Thus, as a trial, hourly values of equatorial Dst have been computed for the IGY 1957-8 and for 1961, and a plan is being made by IAGA to publish such data on a regular basis as Kp. Figure 4 shows a part of the Dst plots for 1958 (Sugiura, 1963).

Recently, Davis and Sugiura (1964) proposed a planetary index for the intensity of auroral electrojets, named AE index. Figure 5 (after Davis and Sugiura, 1964) shows an example; it refers to a six day period including the great magnetic storm of February 11, 1958. If such indices as Dst and AE are regularly published the planetary magnetic activity can be described more fully than with Kp alone, giving a greater time resolution and more direct reference to the source of disturbance.

In order to attain an adequate efficiency in deriving these indices and in making ground magnetic data available to workers in space sciences much improvement is desired in the existing scheme for data collection from the observatories all over the world and for data processing.

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TABLE

Table 1. A summary of solar influences on the geomagnetic field.

FIGURES

Figure 1. After Ness et al., private communication; not reproduced in this paper.

Figure 2. An example of world-wide sudden magnetic changes due to sudden changes in solar wind. After Sugiura, Davis and Heppner, 1963.

Figure 3. The sudden commencement of a magnetic storm observed at Honolulu and Byrd Station. The record from Byrd Station suggests a ringing of the magnetic field lines in the outer regions of the magnetosphere.

Figure 4. The equatorial Dst, representing the intensity of the magnetic field of the ring current observed at the earth's surface.

Figure 5. Auroral electrojet index AE. After Davis and Sugiura, 1964.

Questions and Answers:

Dr. Kellogg: I would like to ask what is probably an elementary question to those who are in the business, but it is something that puzzled me for a long time. When you speak, Dr. Sugiura, of a solar wind, is this the mean motion of the particles and are they carrying along magnetic fields? How are these solar winds measured by Mariner II?

Dr. Sugiura: The solar wind is the bulk motion of the particles. Since the magnetic energy density is less than the kinetic energy density, the magnetic fields must be carried by the particles. In Mariner 2 the solar wind was measured by an electrostatic spectrometer.

Col. De Giacomo: In one of your slides you showed the interplanetary field as being at some angle, not perpendicular to the solar wind but at some skewed angle. Is there any significance to the measurements made to determine what was the direction of the magnetic field?

Dr. Sugiura: (Added in proof) The stream lines of the solar wind make an angle of about 45 degrees with the sun-earth line at the earth's orbit because of the garden hose effect due to the rotation of the sun, though the particle velocity vector is directed approximately radially outward from the sun.

Mr. Russak: What is the total composition of the solar intensity of the heavier component and have any measurements been made of this?

Dr. Sugiura: I think that Dr. Snyder indicated the presence of helium, but I do not know of any measurements made of heavier particles.