THE ORIGIN OF M-REGION GEOMAGNETIC STORMS

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Abstract: The recent solar wind theory of Parker can be invoked to explain certain statistically persistent traits of recurrent geomagnetic storms of M-region type. To do this it is necessary to suggest a configuration of the solar atmospheric temperature distribution near moderate or weak active solar regions characterized by lower radial temperature gradients at the peripheries of the regions than at their centers.

Recent work of E. N. Parker (1964) regarding the origin of the "solar wind" suggests a new approach to the old and yet-unsolved problem of the solar location of the source of geomagnetic storms with marked 27-day recurrence, the so-called M-region magnetic storms. Bartels (1939) originally suggested that the 27-day recurrence of such storms comes about as a consequence of the successive presentations towards earth of a source region on the sun emitting a beam of charged particles that sweeps the earth and produces a geomagnetic storm once per solar rotation.

Years of effort to identify the source regions, the hypothetical M-regions, have failed to discover any solar feature that can unequivocally be assigned responsibility. It has, however, been widely assumed that such solar streams are probably identical with certain of the faint white streamers of continuous emission so spectacularly visible in the sun's outer corona at total eclipse. Eclipse observations, however, have failed to provide a long enough time-base for us to locate these streamers along the line of sight, nor have we been able to assign a clear correspondence between the streamers seen at eclipse and features of the solar disk.

Several things emerge, however, from the many statistical studies that have been made. Three facts are particularly relevant to the matter considered here: (1) there is a decline in the frequency of occurrence of M-region magnetic storms when active regions of the sun's face have passed the solar central meridian two or three days* before, provided the active regions are not highly disturbed nor major flare producers; (2) there is a tendency, noted by C. W. Allen (1944) and others (Pecker and Roberts, 1955) for the minimum frequency of M-region storms three days after the central meridian passage of weak active

* The two or three day lag-time is widely accepted to be the transit time for the solar particles responsible for geomagnetic fluctuations.
regions to be flanked at either side by maxima about four days of solar rotation away from the minima; (3) M-region geomagnetic storms appear to arise from a different source of solar particle emission from that responsible for the so-called "sporadic storms" following great flare events in major active regions of the sun, which are presumed to be produced by ejecta from the active regions (Saemundsson, 1962; Bell, 1963).

We suggest that these characteristics of M-region storms are a consequence of the interaction of magnetic field configurations in the corona and the solar wind. Parker's solar wind theory (Parker, 1964) shows that if sufficient heat is applied at the base of the corona to maintain its temperature at one million degrees or more, thermal conduction will, in a model with a radial coronal magnetic field, distribute the heat in such a manner that the coronal matter will be accelerated outward from the sun. The rate of expansion will be determined both by the temperature at the base of the corona and the temperature gradient within a critical radius, namely that radius where the rate of expansion changes from subsonic to supersonic. The solar wind is enhanced by a low temperature gradient in this region.

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Fig. 1.
The presence of a magnetic field in the solar atmosphere may be expected to influence the temperature at the base of the corona, the temperature gradient, and the rate of expansion. Kulsrud (1955) and Osterbrock (1961) have pointed out that energy transport from the hydrogen convective zone into the solar atmosphere is enhanced by the presence of a magnetic field. Moreover, the thermal conductivity normal to a magnetic field is negligible compared to that along lines of force. Thus the temperature at the base of the corona should be higher within the magnetic field of an active region than outside, but the temperature gradient will be lower in the radial than in the tangential portions of the magnetic field.

Figure 1 shows a plausible magnetic field pattern for a long-lived active region of the corona of the type that may be expected to produce a minimum in the M-region storm frequency. The isothermal surfaces are depressed above the center of the pattern (a) because the heat flux must traverse a longer path along the curved flux tubes to reach a given altitude in the solar atmosphere, (b) because the cross-sections of these flux tubes increase strongly with distance above the sun, and (c) because the radiative dissipation of energy, being proportional to the square of electron density, is much greater in the center of the region. Outside the region of the magnetic field the isothermal lines drop downward because of the lower energy input. The weak solar wind at the center of the configuration is thus a consequence of a high temperature gradient and the effect of the magnetic field to constrain the expansion. The stronger solar wind at the edges is a consequence of the low temperature gradient and the absence of a restraining force by the field.

Present observational data on which coronal temperatures are based are too ambiguous to confirm directly that such thermal configurations as shown in Figure 1 actually exist in the corona. However, the three characteristics of M-region magnetic storms described above can be explained if such configurations exist. Thus a search for independent verification is merited.

Manuscript received, January 13th., 1964.
References.


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