GEOMAGNETIC EFFECTS ASSOCIATED WITH ACTIVE SOLAR REGIONS

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THE relationship between solar activity and terrestrial magnetic and associated auroral, ionospheric and cosmic ray effects has been intensively investigated in the last few decades. During the IGY and subsequent years there has been a substantial addition to our knowledge of solar wave and particle emission, effects of conditions in the interplanetary space on the propagation of solar plasma and the interaction of this plasma with the earth's magnetic field. In a recent review, Cole[1] has discussed the phenomenon of magnetic storms in terms of 'quiet' and 'disturbed' conditions of the magnetosphere. The 'quiet' condition is marked by red auroral arcs, green (λ 5577) coloration of auroras and maintenance of ionospheric F region in winter over the polar caps in the absence of solar ionizing radiation. Polar magnetic substorms, auroral substorms and sudden influx of energetic particles in the magnetosphere are the main features of disturbed conditions of the magnetosphere. The origin on the sun and the nature of several types of particles responsible for terrestrial magnetic and related effects are given in Table I.

TABLE I

Particle radiation from sun

Solar activity	Nature of emitted particles	Velocity	Travel time of particles	Nature of associated solar radio events	Terrestrial magnetic and associated effects
Quiet sun ..	Slow particles (quiet-sun wind composed of protons and electrons)	300– 350 km./s.	Several days	..	Deformation of terrestrial magnetosphere and confining it to a cavity, red polar cap glow, perpetual agitation of the magnetic field in the polar regions, maintenance, in winter, of F region in polar caps
M-regions, coronal streamers	Slow particles	700 km./s.	2–4 days	..	Recurrent moderate magnetic storms during declining part of the solar cycle
Important flares concentrated in the northern solar hemisphere ; flares located close to the central meridian and in magnetically complex spot regions	Storm plasma (protons and electrons)	1,000–2,000 km./s.	12–72 hrs.	Types II, III and IV	Great SC storms, Forebush decrease, ionospheric storms, increase in cosmic rays at middle and low latitudes (decrease of cut-off rigidities of incoming cosmic rays because of depression of geomagnetic field)
Exceptionally important (CR) flares. Flares associated with ground level increase of cosmic rays concentrated in western solar hemisphere	Energetic protons	100,000 km./s.	15 mts. to a few hrs. (delay times longer for events close to peak of solar cycle)	Types II, III and IV	Polar cap absorption, ground level increase of cosmic rays limited to higher latitudes by prevailing geomagnetic cut-off

2. STEADY SOLAR WIND

The terrestrial magnetic field, if it existed in vacuum, could be approximated by a dipole field. In reality, this field is immersed in a time-variable flux of solar wind. Some years ago Biermann[2] showed that the behaviour of cometary tails could be accounted for by postulating that a stream of high-speed particles was being continuously emitted from the sun. Recent space probes have measured the ion flux and energy and have confirmed the existence of an outward flow of plasma. The solar wind penetrates to a distance r where the magnetic pressure inside the boundary is equal to the impact pressure of the wind :

$$\frac{B^2}{8\pi} = 2\,Nmv^2 \cos\theta ,$$

where B is the value of the field at the boundary, N, m and v are the number per cm.^{3}, mass and velocity of particles respectively and θ is the angle between the incident flux and the normal to the surface. If B_0 is the field at the earth's surface, R_e the radius of the earth and P the plasma pressure, the radius r of the geomagnetic 'cavity' at the equator is given by

$$r = 1{\cdot}37\left[\frac{B_0^2}{8\pi P}\right]^{\frac{1}{6}} R_e$$

Using measurements made by explorer 10, the boundary should be located at about 9·6 R_e. The shape of the cavity under constant plasma pressure has been discussed in detail by Slutz.[3]

Deep space probes have indicated two principal regions, the magnetosphere (geomagnetic cavity) and the transition region called the magnetopause. Observations from IMP-I satellite show that on the anti-solar side the tail of the magnetosphere may extend to a considerable distance, perhaps several A.U. (Astronomical Unit). In the sun-earth line the magnetic field is relatively stable—both in magnitude and in direction out to about 10 R_e. This is followed by a region, about a few earth radii deep, in which the magnetic field is disturbed. This turbulent magnetopause has been identified as the standing shock layer in front of the cavity. Beyond this region the magnetic field is constant (4 to 7 γ) and is the interplanetary magnetic field. Preliminary results of more recent measurements of interplanetary field on Pioneer 6 space probe have been recently published by Ness *et al.*[4]

The perpetual agitation of the magnetic field in the polar regions, associated with the influx of solar wind and consequent disturbance of lines of force meeting the earth within 20° to 25° of the geomagnetic poles, provides a direct geophysical evidence of quiet-sun wind.

3. FLARE-ASSOCIATED ACTIVITY

Important flares are generally accompanied after 12 to 72 hours by severe storms.[5] There are, however, many class 3 and 3^+ flares not followed by storms and severe storms not preceded by important flares. Extensive work has been done in the past decade to identify the optical, radio and other characteristics of storm generating flares. Bell[6] showed that source flares for great storms were concentrated towards the central part of the solar disc and showed a rather unexpected concentration in the northern solar hemisphere. Bell also found that storm-generating flares showed a conspicuous occurrence in magnetically complex spots (γ and $\beta\gamma$) rather than in unipolar (α) or bipolar (β) groups. A strong association has been shown to exist between flares with radio bursts of spectral type IV (continuum radiation) and magnetic storms. Further, the probability of a flare being followed by a storm was still greater[7] when both type IV and type II (slow drift) bursts are present. Wild[8] has suggested that the presence of type IV radiation may be an indication of the amount of matter transported from the flare by type II phase of the disturbance.

4. PARTICLE EMISSION FROM FLARES AND TERRESTRIAL MAGNETIC DISTURBANCES

Within a day or two (with an average of about 22 hrs. for class 3^+ flares and 34 hrs. for class 3 flares) some, but *not* all, flares produce a sudden increase of 20 to 30 γ in the horizontal force which is observed, simultaneously, all over the world. The sudden commencement owes its origin to the impact of solar plasma consisting of protons and some electrons in the KeV range and moving with a velocity of 1,000 to 2,000 km./sec. The compression is believed to be communicated to earth's surface through the action of hydromagnetic waves. Within hours, the magnetic field drops and remains subnormal during next one or two days (the main phase). This phase, during which the field remains in varying degrees of agitation, is followed by recovery with a half life of about 5 to 10 hours.

A small proportion of flares, usually of importance 3 and 3^+ emit energetic particles responsible for Polar Cap Absorption (PCA) and increase of cosmic rays at ground level (GLE). The less energetic (MeV range) particles are detected by riometers and the more energetic ones (BeV range) by neutron monitors. The emission of these energetic particles is generally accompanied by type II (slow drift) and type IV (continuum) radiation. Cosmic ray flares associated with emission of particles in BeV range usually appear in the western solar hemisphere and avoid the peak of solar activity. The delay times of particles from flares nearer to peak solar activity are considerably higher. The phenomena of acceleration of the protons, their trapping and release has been extensively studied during the IGY and subsequent years. In a recent investigation,[9] geomagnetic sudden commencement amplitudes have been examined in relation to optical, energetic particle and radio characteristics of source flares and the results have been utilized to identify about 50 cosmic ray flares during solar cycles 12-18.

Reviews of theories of magnetic storms and auroras have appeared frequently in literature; the most recent one is by Cole.[1] Cole has also observed that the method of analysis of magnetic storms with SC as the origin of time has no physical basis and that the time of enhanced geomagnetic noise as an origin of time is considered to have physical validity.

5. ULTRAVIOLET AND X-RAY EMISSION AND SIMULTANEOUS EFFECTS

The more important and centrally located flares give rise to magnetic crochet (SFE) seen as a temporary increase superposed on the normal daily variation. The phenomenon, confined to within 70° of the sub-solar point, is caused by the photo-ionization by X-rays and far ultraviolet and resulting increase in the electrical conductivity of the ionosphere between 60 and 100 km. Recent studies indicate that X-rays of 1 to 20 Å from the hot coronal regions are more efficient ionizing agents in the region of 60 km. The related ionospheric effects are the SWF (increased absorption of obliquely reflected short-wave signal); SEA and SES, sudden enhancement of low frequency signals from distant thunderstorms and long wave signals (increased reflectivity of D region); SPA, sudden phase anomaly (decreased reflection height and consequent phase change of sky-wave propagated signal; SFD, sudden frequency deviation (change in the frequency of reflected high-frequency signal) and SCNA, sudden cosmic noise absorption (increased absorption of galactic noise in the lower ionosphere). Excellent survey of the flare X radiation including results of rocket and satellite observations has been made in several recent review articles.[10,11]

6. SOLAR ACTIVITY AND RECURRENT MAGNETIC STORMS

Magnetic activity during the declining part of the solar cycle is composed of weak storms which have a tendency to recur at intervals of about 27 days, the rotational period of the sun. No visible solar activity can be associated with recurrent magnetic activity. Bright coronal regions,[12] unipolar magnetic fields,[13] filaments,[14] chromospheric plages[15] and bright 21 cm. solar regions[16] have been associated with recurrent storms. The regions emitting plasma responsible for recurrent storms have been called M-regions by Julius Bartels. The phenomena of recurrent storms, M-regions and solar wind have been reviewed by Piddington,[17] Allen[18] and Hirshberg.[19] Several hypotheses for explaining principal features of recurrent storms have been proposed and these have been discussed recently by Obayashi.[20] Mariner II observations[21] during the later part of 1962 indicate a velocity of about 700 km./sec. and a strong 27-day recurrence for the plasma originating from the M-regions.

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