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Temporal and spatial covariation of high-latitude geophysical phenomena

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Abstract. A possible mechanism for the unification of regular and irregular fluctuations in high-latitude geophysical phenomena has been given. In view of this mechanism the simultaneity of various geophysical fluctuations has been discussed.

During the past few years a number of ground-based balloon, rocket and satellite measurements have been made to study high-latitude geophysical phenomena. The detailed morphological studies of these phenomena and their intercorrelation have been reported. Some interesting features observed in geophysical phenomena prompted many investigators to look for finer details which could reveal their origin. The regular and irregular fluctuations in visual aurora, the intensity of the 5577 Å line, geomagnetic field variation, earth currents, and in the excitation of infrasonic waves, have been studied in considerable detail. The correlation studies of temporal and spatial occurrences of some of the above-mentioned phenomena have been carried out and fairly good correlation between simultaneously observed fluctuations has been reported from time to time (Parthasarathy and Hessler 1964). The improved resolution of x-ray detectors has revealed the fine structure of x-ray emission known as x-ray microbursts (Anderson *et al.* 1966). The occurrence of electron influx precipitation in the auroral zone and associated x-ray microbursts are recent observations which lend support to the proposed mechanism. Some of these microbursts show no correlation with simultaneous geophysical phenomena (Anderson and Milton 1964, Venkatesan *et al.* 1968) and there is another class of microbursts which shows good correlation with simultaneous geophysical phenomena (Parks *et al.* 1966, Milton *et al.* 1967, Cliven and Gurnett 1968, Oliven *et al.* 1968). The electron influx is known to generate vlf waves by Čerenkov radiation. The periodic fluctuations in vlf intensity and their association with other geophysical phenomena were recently reported by Kitamura *et al.* (1969). In view of these detailed features we propose here a unified mechanism for the formation of regular and irregular fluctuations. We propose the present mechanism in terms of solar plasma stream interaction with the geomagnetic field. The theoretical foundation of the present mechanism has been worked out by Watanabe (1964).

It is fairly well established that the incoming solar plasma stream pushes the geomagnetic field and is stopped where the kinetic pressure of the plasma stream is equal to the magnetic pressure. This interaction produces transverse oscillations in the geomagnetic tubes of force (Dungey 1958, Sugiura and Wilson 1964). The magnetic field is frozen in the magnetospheric plasma, therefore the magnetospheric plasma oscillates with the same frequency. The trapped particles satisfy a set of invariant conditions and move along, and perpendicular to, the geomagnetic lines of force. The trapped charged particles from the solar wind constitute the normal radiation belt. The solar events only excite the normal radiation belt and increase the particle density which is characteristic of the solar event. A schematic diagram of the proposed mechanism is shown (see figure 1). The magnetic tube of force is shown to execute transverse vibrations in which a particular cross section of the geomagnetic tube of force undergoes periodic compression and rarefaction. Such a compression and rarefaction is assumed to set up longitudinal oscillations in the electron density along the equatorial radiation belt (see figure 1). Watanabe (1964) has shown that one component of the plasma (electrons) having velocity v and pitch angle ψ, in the presence of a steady magnetic field, will relax to a particles distribution with a distribution function f given by

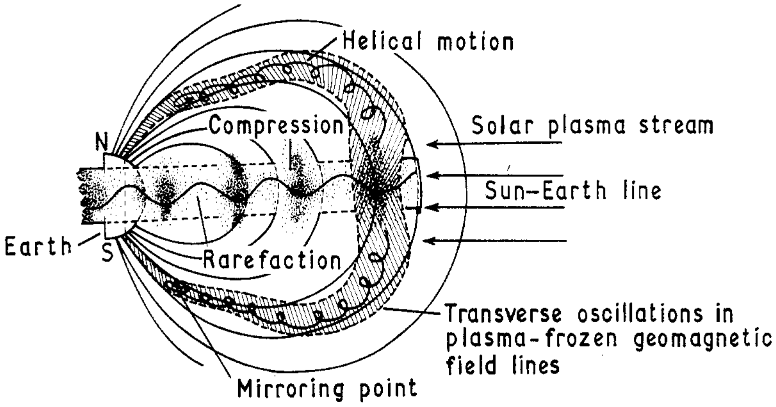

Figure 1. Schematic diagram of the proposed interaction mechanism for simultaneous fluctuations in various geophysical phenomena.

$$\frac{\partial f}{\partial t}+v\cos\psi\frac{\partial f}{\partial l}+\tfrac{1}{2}v\sin\psi\frac{1}{B}\frac{\partial B}{\partial l}\frac{\partial f}{\partial \psi}=0. \tag{1}$$

When transverse hydromagnetic wave disturbances propagate along the magnetic lines the magnetic field undergoes periodic fluctuation of the form

$$B(l,t)=B_0(l)+b(l,t). \tag{2}$$

The distribution function changes accordingly and is written as

$$f=f_0+f_1(b/B_0)+f_2(b/B_0)^2+\dots \tag{3}$$

where f_1 and f_2 are small-amplitude perturbations in the original distribution function Assuming the distribution function f_0 to be isotropic with respect to the pitch angle ψ and to be homogeneous in space, Watanabe arrived at a differential equation for f_1:

$$\frac{\partial f_1}{\partial t}+v\cos\psi\frac{\partial f_1}{\partial l}+\tfrac{1}{2}v\sin^2\psi\frac{1}{B_0}\frac{\partial b}{\partial t}\frac{\partial f_0}{\partial v}=0 \tag{4}$$

where f_0 is a function of v only. We now consider the propagation of a perturbing magnetic field along the geomagnetic field

$$b=b_0\cos(\omega t+kl) \tag{5}$$

where l is the distance measured along the geomagnetic tube of force. The conservation of magnetic flux during the propagation of magnetic perturbation is written as

$$B_0 S_0 = \{B_0 + b(l, t)\}\, S(l, t) \tag{6}$$

where S is the cross-sectional area during compression and rarefaction and S_0 is the original area of cross section. With the assumed compression and rarefaction in the magnetic tubes of force, the solution of equation (4) for the initial condition $f_1 = 0$ when $t = 0$ was obtained by Watanabe (1964):

$$f_1 = \tfrac{1}{2}\frac{b_0}{B_0} v \frac{\mathrm{d}f_0}{dv} \frac{\omega \sin^2\psi}{\omega + kv\cos\psi} \{\cos(kl - kvt\cos\psi) - \cos(\omega t + kl)\}. \tag{7}$$

The second-order perturbation f_2 was also given by Watanabe:

$$f_2 = \tfrac{1}{8}\frac{\omega k^2 b_0^2}{B_0^2} v^3 \frac{\mathrm{d}f_0}{\mathrm{d}v} \frac{\sin^4\psi}{(\omega + kv\cos\psi)^2} t[\sin\{2kl + (\omega - kv\cos\psi)t\} - \sin(\omega + kv\cos\psi)t] + \text{periodic terms}. \tag{8}$$

With the help of these solutions the total number of electrons trapped in the magnetic field can be calculated. Let $(f_0 + f_1 + f_2 + \ldots)\sin\psi\,\mathrm{d}\psi$ be the number of particles per unit volume whose pitch angle falls between ψ and $\psi + \mathrm{d}\psi$. Therefore, the total number N of trapped electrons confined to a portion $(l, l + \mathrm{d}l)$ of the magnetic tube of force is expressed as

$$\begin{aligned} N &= \left\{\int_0^\infty v^2\,\mathrm{d}v \int_0^\pi (f_0 + f_1 + f_2 + \ldots)\sin\psi\,\mathrm{d}\psi\right\} S(l, t)\,\Delta l \\ &= N_0(l, t) + \Delta N_1(l_1, t_1) + \Delta N_2(l_2, t_2) + \ldots . \end{aligned} \tag{9}$$

The total number of electrons in a portion of the tube of force at any time is given by equation (9). Each of the three terms on the right-hand side shows spatial and temporal variations in the number of electrons trapped in the tubes of force. $N_0(l, t)$ has the periodicity of the compression and rarefaction in the cross section of the tube $S(l, t)$. $\Delta N_1(l_1 t_1)$ and $\Delta N_2(l_2, t_2)$ possess the periodicities which are also governed by f_1 and f_2 given by equations (7) and (8). It is seen from equation (8) that f_2 is proportional to time. Hence, the net effect of these three factors, which are varying with different frequencies and have different amplitudes, will result in a quite irregular distribution (quasi-periodic) of electrons in the tubes of force. In other words, electrons are bunched along the tubes of force. The periodicity of proposed bunching in electron influx will therefore be governed by the frequency of magnetic perturbations which are propagated along the geomagnetic tubes of force. The proposed mechanism envisages the bunching of electron influx moving along the geomagnetic tubes of force and mirroring between the north and south hemispheres. The bunched electrons, when precipitated into the lower ionosphere, give rise to a variety of geophysical phenomena—which have been discussed at the beginning of this paper.

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