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Latitude-Dependent Waves and Impulse-Produced Waves

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Recently in this journal there have been two short papers (Kupfer, 1974; Siebert, 1975) discussing the very interesting observations made by Voelker (1962, 1963, 1965) of the latitude dependence of the frequency of certain geomagnetic pulsations as observed on the ground in the European sector. In an earlier discussion of these observations, Siebert (1964) attributed the latitude dependency of the pulsation frequencies to the excitation of the poloidal hydromagnetic wave mode in a "lamellar plasma structure" in the earth's magnetosphere. In his short paper, Kupfer (1974) pointed out via an idealized model that the hypothesized lamellar plasma structure could probably not maintain such poloidal wave modes. Siebert (1975) commented that indeed, while a poloidal wave mode may not be maintained, nevertheless plasma density gradients with narrow spacings in L-value have been observed in the earth's magnetosphere by spacecraft (e.g., Chappell et al., 1971; Bewersdorff and Sagalyn, 1972) and that such gradients are undoubtedly important in establishing the conditions for the pulsation characteristics which have been reported by him and by Voelker.

Several years ago Rostoker and Samson (1972) reported the results of a search for such latitude-dependent pulsation events using data from the University of Alberta high latitude magnetometer chain. They reported the observation of two such events in the time period for which they had data. They pointed out that the normal condition in the magnetosphere seems to be that which they had reported earlier (Samson et al., 1971). That is, an individual pulsation event appears to have essentially the same frequency at all latitudes. At subauroral latitudes, however, near $L=4$ and further south, it has become increasingly clear in recent years that a dependence on latitude is indeed seen in the predominant pulsation frequency (e.g., Orr, 1973, 1975; Webb and Orr, 1975; Fukunishi and Lanzerotti, 1974). The changes in pulsation frequency in the region of $L=3$ to $L=4$ have been attributed to the sharp change in the Alfvén velocity V_A in the magnetosphere that comes about because of the plasmapause.

The purpose of this brief communication is to point out that recently developed theory (Chen and Hasegawa, 1974a; Southwood, 1974) appears able to explain dayside latitude-dependent pulsation events. The theory as developed by Chen and Hasegawa (1974a) and by Southwood (1974) envisions surface waves, probably generated at the magnetopause by the solar wind flow, evanescent inward into the magnetosphere. These surface waves can couple to resonant field lines to produce standing shear Alfvén waves where the field line resonant frequency

$$F=[2\int ds/V_A] \quad (1)$$

is equal to the frequency of the surface wave. The coupling of the surface wave to the resonant field line occurs at a plasma density gradient in the magnetosphere; at the resonance the wave is linearly polarized. On either side of the resonance region the wave is elliptically polarized with an opposite sense of polarization on either side. The sense of polarization depends upon the direction of the azimuthal wave propagation k_x as shown by the expression

$$H/D=ik_x\xi_y(d\xi_y/dy)^{-1}=\alpha+i\delta$$

where ξ_y is the plasma displacement in the radially inward (y) direction and α and δ give the orientation of the major axis of the wave ellipse and the sense of wave polarization, respectively (Chen and Hasegawa, 1974; Lanzerotti et al., 1974).

Thus, Voelker's observations (Voelker, 1962, 1963, 1965) can be readily explained if the surface wave source is composed of several discrete frequencies and if the magnetosphere has a series of plasma density gradients at increasing altitudes (perhaps produced by magnetic storm conditions). In this case waves with several different frequencies could be excited at different latitudes (altitudes) in the magnetosphere. The fact that Siebert (1964) reported the events predominantly polarized in the north-south component on the ground would suggest that the coupling conditions for waves at closely spaced density gradients may be somewhat different than for coupling when distinct tilts in the ellipse orientation angles are observed. However, it should be pointed out that recent important work on the propagation of hydromagnetic waves from the magnetosphere through the ionosphere to the ground (Hughes, 1974; Hughes and Southwood, 1976) suggests that there will be a 90° rotation in the major axis of the wave ellipse from the magnetosphere to the ground. Therefore, if these theoretical results are correct, then the predominant north-south orientations observed by Siebert would correspond to essentially purely east-west orientations in the magnetosphere. Such polarizations in the magnetosphere would correspond very closely to the excitation of shear Alfvén waves in what was formerly called the toroidal mode.

In his letter to this journal Siebert (1975) additionally points out that the local time dependence of the latitude-dependent pulsations is similar to that of pulsation single events (PSE) reported by Voelker (1966). That is, the latitude-dependent pulsations tend to be confined to the day side of the magnetosphere, as are the PSE. Such a local time dependence, of course, is entirely consistent with the above discussions of the solar wind/magnetopause origin for the exciting sources of the latitude-dependent pulsations. It is quite likely, however, that the pulsation single events are not related to the latitude-dependent waves, even though the local time dependences are similar.

A large number of day side, damped hydromagnetic wave events which have properties that are different from those discussed above were studied by Lanzerotti et al. (1973, 1975). They showed that these events seem to be excited at plasma density gradients in the vicinity of the plasmapause. The work of these authors, together with that of Chen and Hasegawa (1974b), would suggest that these damped waves in the Pc 4 frequency band are probably related to the excitation of surface waves at plasma density gradients in the vicinity of the plasmapause or even at the plasmapause itself.

Shown in Figure 1 is the statistical distribution as a function of local time for the PSE (Voelker, 1966) as observed simultaneously at Wingst ($L=2.5$) and at Göttingen ($L=2.3$) and for the damped Pc 4 events observed at Durham ($L=3.2$) by Lanzerotti et al. (1975). The PSE are more broadly distributed during the local day than the damped events. Nevertheless, the similarity of these local time distributions, together with the similarities of the reported wave characteristics, strongly suggest that the origins of the two sets of observations are very similar. Voelker (1966) attributes the PSE to the occurrence of sudden commencements (SC) and sudden impulses (SI) in the magnetosphere which he identified from low latitude magnetograms. Lanzerotti et al. (1975) cannot identify their events with tabulations of such SC's and SI's; they attribute this failure to the simple fact that, in general, observatory magnetograms are not sufficiently sensitive to record very small (few γ) changes in magnetospheric conditions. It is amplitude changes of this magnitude that are observed by Lanzerotti et al. (1973, 1975) to accompany the damped oscillations at $L\sim3.2$. Lanzerotti et al. speculate that more sensitive low latitude ground level magnetometers might indeed show that the damped oscillations are related to small

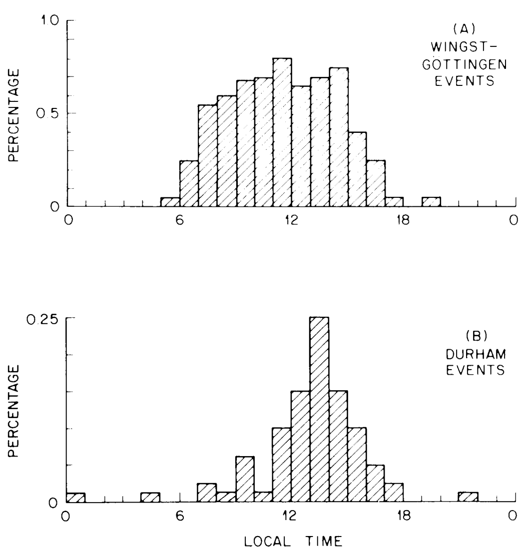

Fig. 1. A Percent PSE events observed simultaneously at Wingst and Göttingen (Voelker, 1966) as a function of local time.
B Percent damped waves observed at Durham as a function of local time

impulsive-like changes in the magnetospheric boundary. They also speculate that these small changes may be the cause of drift echos as seen in energetic particle fluxes by synchronous altitude satellites (e.g. Lanzerotti et al., 1967; Brown, 1968).

Thus, it seems quite likely that the pulsation single events and the lower latitude damped oscillations of Lanzerotti et al. (1975) may be both produced by the same exciting mechanism but with different amplitudes. Fukunishi (1975) has further discussed in more detail the relationships between SC- and SI-excited waves and damped pulsations near $L=4$ and also attributes the multiple-peaked spectra in the SC- and SI-excited waves to differences in the magnitude of the driving force. Both sets of waves, therefore, could be interpreted as damped surface waves excited at plasma density gradients in the magnetosphere (Chen and Hasegawa, 1974b).

In summary, the observations of Voelker (1962, 1963, 1965) and Siebert (1964) would seem to be consistent with the excitation of sheer Alfvén waves at plasma density gradients within the magnetosphere by multi-frequency spectrum surface waves evanescent into the magnetosphere from the magnetospause. These density gradients may well have a lamella nature as postulated originally by Siebert (1964). Secondly, the pulsation single events are probably not directly related to the latitude-dependent pulsation events but rather may well be related to the excitation (at plasma density gradients) of damped surface waves produced by either small sudden changes in the magnetosphere boundary or by larger disturbances such as sudden commencements or sudden impulses. Simultaneous observations between solar wind conditions and hydromagnetic wave conditions inside the magnetosphere are needed to further explore these various possibilities that have been opened by the recent theoretical and experimental developments.

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