MODES OF PULSATING AURORAS AND RELATED GEOMAGNETIC PULSATIONS

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Abstract: Display modes of pulsating auroras were examined in reference to classifications previously proposed. It is concluded that the pulsating auroras are reasonably classified into, 1) pure pulsations, 2) poleward propagation, 3) streaming along structures, 4) flooding beyond patch boundaries, 5) equatorward propagation, and 6) flash, all in horizontal structures or movements. Most of the modes are related to concurrent geomagnetic pulsations with a peak-to-peak correspondence, within a few seconds. The magnetic pulsations observed under the pulsating aurora are thus concluded to be consequences of the fluctuation in the ionospheric electric current caused by fluctuations in electric conductivity due to pulsating auroral precipitations.

1. Introduction

Pulsating auroras show so many varieties of displays that at first one is about to give up any effort to establish a classification. Close examination of pulsating aurora, however, suggests that the pulsating auroras may be classified into, several characteristic modes of displays, or combinations of these, by considering both temporal and spatial structures. A number of authors for example CRESSWELL and BELON (1966), SCOURFIELD and PARSONS (1971) and ROYRVIK and DAVIS (1977) have proposed classifications of pulsating auroras, on the other hand, the present author has proposed six categories 1) pure pulsation, 2) poleward propagation, 3) streaming along structures, 4) flooding beyond patch boundaries, 5) equatorward propagation and 6) flashes in horizontal structures along with flaming mode along the magnetic field (OGUTI 1981).

Intention of this paper is to describe and illustrate the fundamental modes of pulsating auroras, previously proposed, on the basis of all-sky TV records, and to show the relation of each mode of auroral pulsations to concurrent geomagnetic pulsations. The observations used in this study were obtained by all-sky TV cameras operating in Canada during January and February 1980.

2. Display Modes of Pulsating Auroras

The auroral pulsations are first classified into non-moving forms and moving forms.

a) The non-moving form is a pure pulsation which is defined by the pulsation in luminosity of a certain patch having a rather sharp stable boundary, independent from other pulsating patches. The boundary sometimes remains dark in the course of the brightening of adjacent patches and usually is unchanged for up to ten repetitions of the pulsation.

b) The moving form is usually called "streaming" in the horizontal plane and "flaming" along the magnetic field direction. Close examination, however, suggests that there are several subclasses of horizontal "streaming" which may be due to other physical mechanisms. For example, the poleward propagation mode, which might be a kind of streaming in a broad sense of the word, being a lateral propagation of structures, is definitely different from the "streaming" of this study which consists of movements of bright parts along auroral structures like a boat moving along a stream.

3. Modes of Pulsating Aurora

The following classification has been adopted.

a. Pure pulsation

As mentioned above, the pure pulsation is a pulsation in luminosity of a patch with a rather stable boundary which lasts for a period of several up to ten repetitions of the pulsations. The pure pulsation is dominant in the midnight sector just after an auroral expansion (OGUTI, 1981; YAMAMOTO, 1981). The patch size is usually small, not larger than 100 km in extent. The shape can be widely variable, from thin striations, to intricately shaped patches. The expansion mode reported by SCOURFIELD and PARSONS (1971) and ROYRVIK and DAVIS (1977) can be included in this category, because usually the pure pulsating patch has a tendency for expansion when it brightens. The pure pulsation has a broad spectral peak around 10 s, with a range from a few seconds to 20 s. An important point is that the spectral peak near 10 s appears not to depend much on geomagnetic latitude (*e.g.* YAMAMOTO, 1981).

The pure pulsation often has higher frequency fluctuation components superposed with 0.3 to 0.1 s periods, so that the peak luminosity of the pulsating patch appears to fluctuate with these periods (OMHOLT, 1969; OGUTI, 1976; ROYRVIK and DAVIS, 1977).

Correlation with geomagnetic pulsations is observed under or near the pulsating patches, but the correlation between them is often not good, since a number of independently pulsating small patches may affect the geomagnetic field in a incoherent fashion.

b. Poleward propagation mode

The poleward propagation mode is often seen in the vicinity of the poleward boundary of pulsating auroras. This mode is characterized by a lateral poleward propagation of elongated, east-westerly, structures, in contrast to the movements of bright parts along structures in the "streaming" mode described in a later section. The period of the luminosity of this mode is usually in a range of several seconds to hundreds of seconds. The poleward propagation speed of the visual aurora is in a range of several km/s to a hundred km/s. The distance of propagation is about 200 to 300 km, and the propagating band fades out before it reaches the region of discrete arcs in higher latitudes.

The period of this mode is usually longer than the period of a concurrent pure pulsation mode at a lower latitude. A very close relationship to geomagnetic pulsations but a lack of relationship to VLF emissions are important characteristics of this mode (OGUTI and WATANABE, 1976).

The propagation of this mode sometimes is not smooth but somewhat stepwise. The luminous band appears to be relayed to an adjacent more poleward structure, however it propagates smoothly within a certain range in one structure.

The poleward propagation mode is a common feature of radar aurora. KANEDA *et al.* (1964) have shown examples of pc 5 period range in the data from College, Alaska. On the basis of radar aurora observed from Ottawa, McDIARMID and McNAMARA (1972) have shown that this mode exists in the dawn and in the afternoon sectors as well, with a wide range of periods from 10 s to hundreds of seconds. The poleward propagation aurora at Syowa Station (OGUTI and WATANABE, 1976) shows a characteristic linear relationship between repetition frequency and propagation speed as was found for radar aurora by McDIARMID and McNAMARA (1972). The identity of the two propagation phenomena for the same event is not yet confirmed, but the similarity of the characteristics appears to be sufficient to claim the identity. A typical example of this mode seen over Rabbit Lake on January 17, 1980, are reproduced in Fig. 1 in a form of latitude-time display (center) along with the concurrent magnetic variations at Rabbit Lake (top) (Corrected geomag. lat. 68.1, long. 311.9) and La Ronge (bottom) (Corrected geomag. lat. 64.8, long. 311.0). The latitude-time display aurora in the center panel evidently shows that the aurora switched from random pulsation to coherent poleward propagation (up-going black traces) at 1222 UT, and it returned to random pulsation again at 1225 UT. Corresponding to the changes in auroral pulsations, the magnetic pulsation at Rabbit Lake shows a definite enhancement for the period of coherent auroral propagation, with a peak-to-peak relationship. The magnetic deflections are eastward as the aurora passes over the zenith. On the other hand, the magnetic variations at La Ronge, about 350 km south of the pulsating aurora, has little relation to the auroral variation at Rabbit Lake. This result is consistent with that reported previously (OGUTI and WATANABE, 1976) on the data from Syowa Station, Antarctica.

c. Streaming mode

As has been shown by ROYRVIK and DAVIS (1977), the streaming condition in the aurora is very common in the dawn sector. It may be worth repeating here that the "streaming" in this study is different from "streaming" in broad sense of the word. Here, it is limited to movements of bright parts of aurora only within and along the structure.

Streaming is usually seen along structures elongated in the E-W direction, for small activities, whereas for high activities it takes place along omega shaped striations when "omegas" or "auroral torches" are formed (OGUTI *et al.*, 1981). Streaming is usually limited in this type of structure to a width of 10 km or less, but the streaming distance along the structure can be as much as 1000 km, with a streaming speed in a range 20 km/s to 200 km/s (YAMAMOTO, 1981).

In the case of poleward propagation, the magnetic effect is very clear, but not

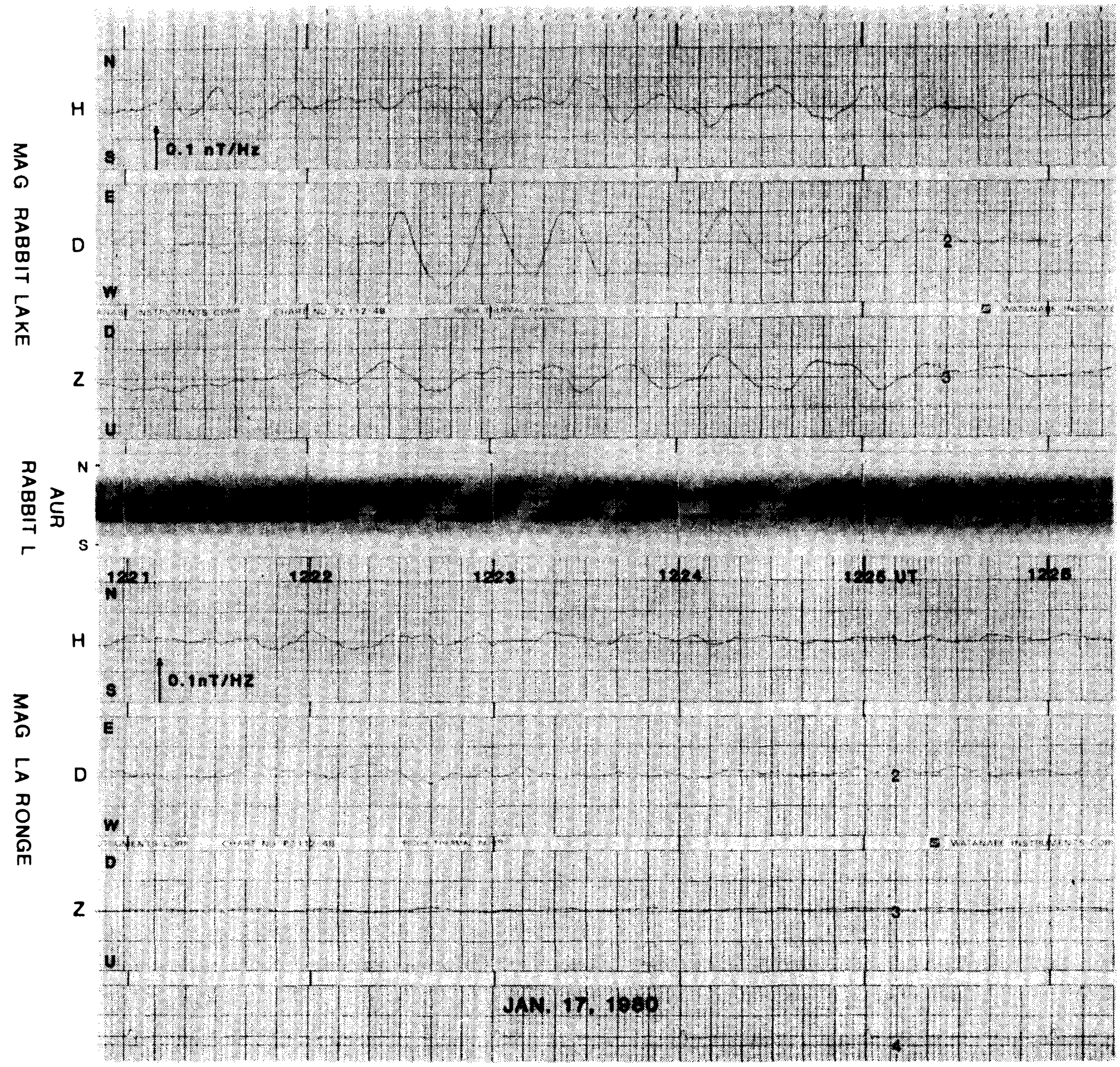

Fig. 1. Meridian-time display of aurora over Rabbit Lake (Corrected geomag. lat. 68.1, long. 311.9), along with the concurrent geomagnetic variations at Rabbit Lake (top) and at La Ronge (bottom) (Corrected geomagnetic lat. 64.8, long. 311.0). In the middle panel, reproduced from an all sky TV record, the dark areas indicate auroras. It is evident that the magnetic pulsations at Rabbit Lake are enhanced with peak to peak correspondences during the period when auroras showed regular poleward propagation between 1222 and 1225 UT, and that the geomagnetic pulsations at La Ronge are almost independent of the auroral propagation over Rabbit Lake.

so for streaming aurora. Many independent streamings may take place at once. Narrow pulsating movements in various directions and with different phases produce combined magnetic effects which are not simple. Figure 2 shows an example of streaming along torch structures that occured over Park Site (Corrected geomag. lat. 61.5, long. 309.8) on February 16, 1980. As seen on the zenith photometric record, in the middle panel, the central areas of the torches show rapid fluctuation in luminosity corresponding to the streamings along the torch structures. The magnetic variation, in the top panel, also shows fluctuations, but it is evident that the period of the

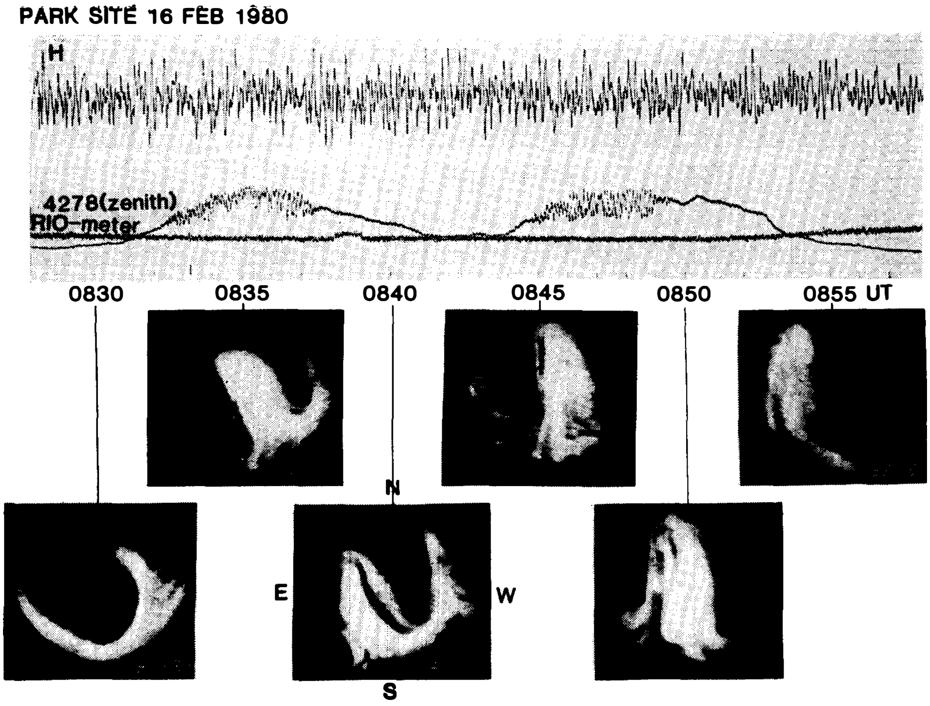

Fig. 2. Magnetic variations (top), auroral fluctuations at the zenith measured by a photometer (middle) and sequential TV pictures of torch structures that appeared over Park Site (Corrected geomagnetic lat. 61.5, long. 309.8) on Feburuary 16, 1980. Comparing the photometric record with pictures, it is found that the pulsations of auroral luminosity are concentrated in the central regions of torch structures. Note that there is no correlation between magnetic pulsations and auroral pulsations.

magnetic fluctuations is quite different from that of the auroral fluctuations. Moreover, the auroral fluctuation is seen only near the central part of the torches as can be seen by comparing with the sequential pictures in the bottom panel, whereas the magnetic variation does not show any tendency for enhancement in fluctuations for the period when the fluctuations in aurora are over the zenith. The magnetic fluctuations appear to be related to the auroral pulsations at lower latitudes, where the scale sizes of the patches are much larger.

d. Flooding mode

"Flooding" mode in this study is defined as a movement of brightening beyond patch boundaries, involving a lot of patches. Figure 3 shows an example of flooding over La Ronge on February 15, 1980, in a N-S section and in an E-W section time display (top). The flooding width was about 50 km, and the flooding length was sometimes as larger as 1000 km. The repetition time of the flooding was 15 to 25 s in this particular example. Flooding is an active mode of pulsating aurora and is seen mostly in active parts of the pulsating aurora, such as the core region of torch structures. The flooding in this particular example is dominantly in E-W direction, with little movement in N-S direction. Magnetic effects of this flooding are extremely clear. For example, small and irregular magnetic deflections are seen for the period when the flooding is small and irregular, while the magnetic fluctuations become larger and

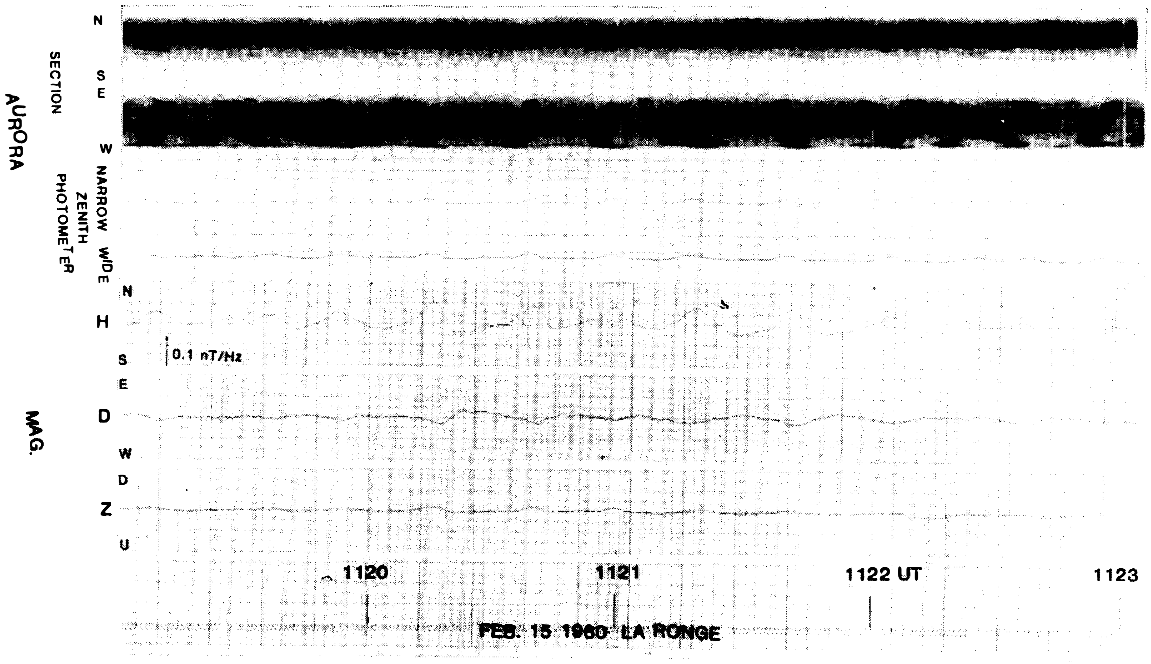

Fig. 3. La Ronge 1119–1123 UT February 15, 1980. N-S and E-W sections from the all-sky TV showing a flooding aurora (top), photometer records of the zenith (middle) and the three components of geomagnetic field (bottom). The correspondence between auroral flooding and magnetic pulsations is evident. Magnetic deflection corresponding to the floodings is almost northward for this particular example.

more regular when the flooding becomes larger and regular, *i.e.* for the period 1120 to 1122 UT. Magnetic deflection corresponding to the flooding is northward in this example.

e. Equatorward propagation mode

The "equatorward propagation" mode is usually seen in the equatorward region of pulsating auroral activities. This mode was called "fast auroral wave" by CRESSWELL and BELON (1966). As stated by CRESSWELL (1968), this mode is really a fast wave-like propagation of faint arc fragments usually elongated in the east-west direction, several tens of km long and about 10 km wide. The propagation speed is in a range from tens of km/s to 200 km/s, and the repetition time is usually in a range from 1 to several seconds.

This mode is often seen concurrent with the poleward propagation mode; the former in the equatorward region of and the latter in the poleward region of pulsating auroral activities (OGUTI *et al.*, 1981).

A typical example of the concurrence of the two modes is shown in Fig. 4. In this example, the centre of the pulsating auroras was located between Rabbit Lake and La Ronge. Over Rabbit Lake, the northern part of a pulsating aurora display frequently shows a tendency for poleward propagation (up-going traces), while the equatorward propagation of faint auroras (faint down-going traces) is seen over La Ronge near the equatorward boundary of the pulsating aurora display. The magnetic deflections corresponding to the equatorward propagation of faint auroras are very small as is seen in the bottom panel, but the peak to peak correlation between them

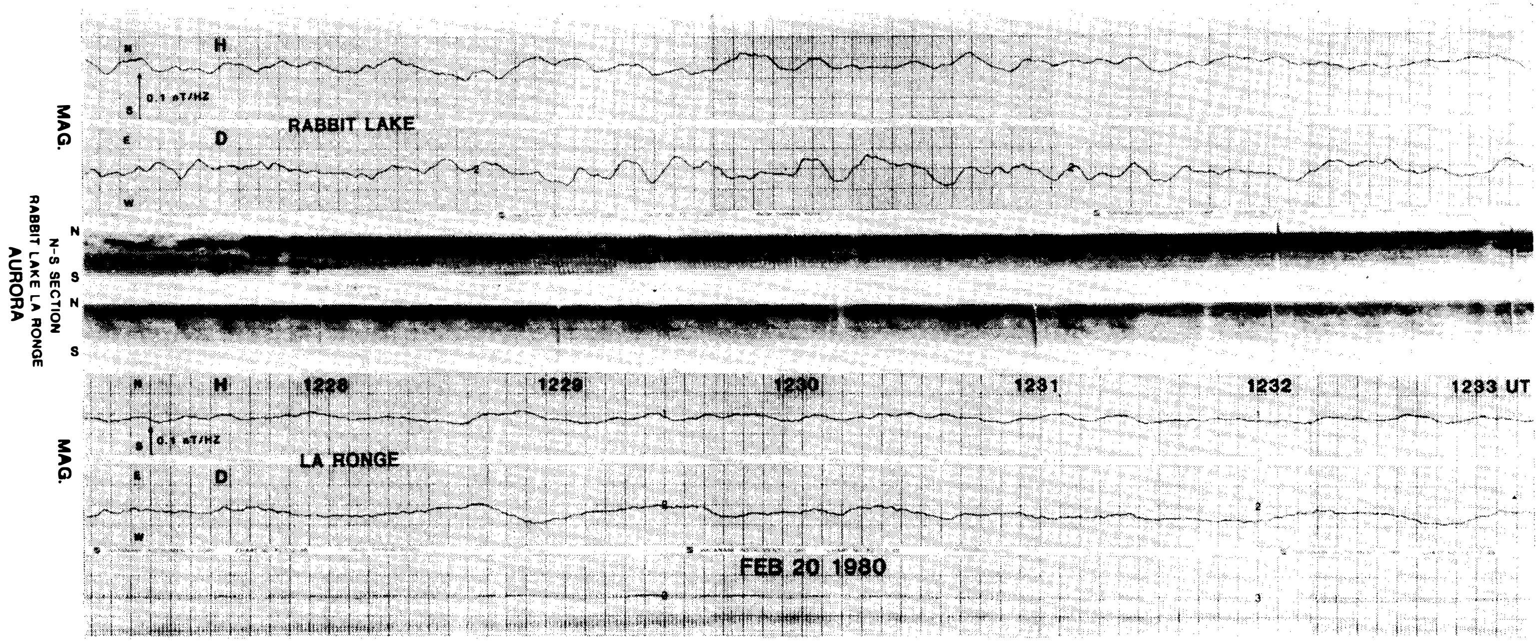

Fig. 4. An example of concurrence of the poleward propagation mode in the northern region (Rabbit Lake) with the equatorward propagation mode in the southern region (La Ronge). Auroras are shown in the meridian-time displays in the middle panel, and magnetic pulsations at Rabbit Lake and La Ronge are shown in the top and bottom panels respectively. Poleward propagation occurs to the north of Rabbit Lake and the southward propagation occurs from the north to the zenith of La Ronge. The magnetic deflections corresponding to the northward propagations are eastward and a little northerly at Rabbit Lake, and the magnetic deflection corresponding to the equatorward propagation are almost directly northward at La Ronge.

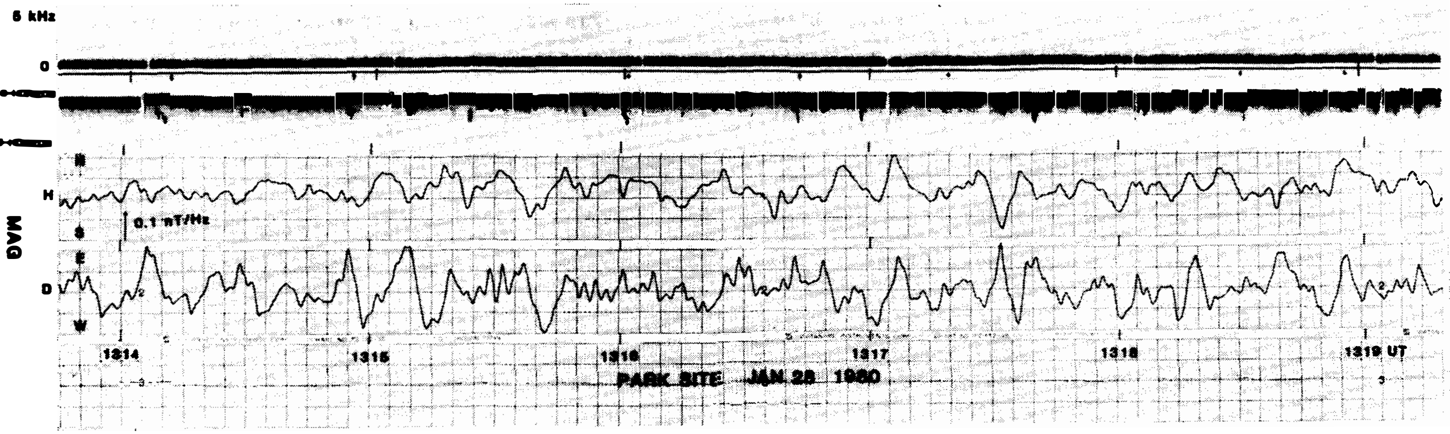

Fig. 5. Frequency-time spectrogram of chorus emissions (top), meridian-time display of aurora (middle) and magnetic variations (bottom) for 1314-1319 UT on January 28, 1980, at Park Site. Seven chorus risers occurred during this period (indicated by arrows), all of these are coincident with the flash mode display of aurora observed near the zenith. It is also noted that the flash aurora is related to an eastward deflection peak of the geomagnetic pulsation.

is still seen. The contrast between the poleward propagation mode and the equatorward propagation mode, along with the contrast between the magnetic variations under the two modes of aurora, is very clear in this example.

f. Flash mode

The "flash" mode might be an extreme case of equatorward propagation mode with an extremely fast propagation speed, or it might be an extreme case of pure pulsation with large faint diffuse patches. The temporal characteristics of this mode are similar to those of the pure pulsation but in the flash mode a faster modulation than the 10 s period of the pure pulsation is usual. It is very likely that the fast modulation is the distinctive feature of the flash mode which could modulate the "switch-on" level of the pulsating patches by overlapping with the patches, whereas the 10 s period is characteristic of the pulsating patches themselves.

It is worth noting that the flash mode is sometimes related to VLF chorus risers (TSURUDA *et al.*, 1981). Figure 5 shows the frequency-time spectrogram of VLF emissions (top panel), the auroral flash in a meridian-time display (middle panel), and the corresponding geomagnetic pulsations (bottom panel). Not every auroral flash is associated with chorus risers but some of them, for example, those which occurred at 1314: 09, 1314: 52, 1316: 02, and 1316: 42 UT are concurrent with chorus risers within a fraction of second. This fact suggests that the chorus emissions were amplified by the energetic electrons which in turn are scattered in pitch angle by the chorus waves near the magnetospheric equatorial plane. The relation of magnetic pulsations to the auroral flash is also evident. Almost every flash of aurora is related to an eastward deflection of magnetic field. In contrast to the equatorward propagation mode, the magnetic correspondence of the flash is much more evident than the magnetic correspondence of the equatorward propagation mode, although the flash luminosity is as faint as that of the equatorward propagation mode pulsation.

4. Discussion

Examples shown in this study strongly suggest that auroral pulsations of various kinds are very often related to concurrent respective geomagnetic pulsations. As seen in the examples, the geomagnetic pulsations under the pulsating auroras often correspond to the pulsations of aurora in a peak-to-peak fashion, within a few seconds. Although the representations here are fairly qualitative, it can be claimed definitely that the best correlation is found with the lag of the geomagnetic pulsation peak always less than 1 s behind the corresponding auroral pulsation peak.

The pulsating auroral precipitations are often accounted for in terms of pitch angle scattering of energetic electrons in the magnetospheric equatorial region interacting with VLF waves, with a modulation in pitch angle anisotropy caused by HM waves (CORONITTI and KENNEL, 1970). The geomagnetic pulsations observed on the ground are often understood to be the result of earthward propagation of HM waves generated in the magnetosphere as well. If so, the magnetic fluctuations, which caused the modulation in pitch angle anisotropy and accordingly the modulation in auroral precipitations, must arrive at the auroral zone ionosphere about 30 s at least behind the precipitations. Of course, HM waves that are responsible for the modulation in pitch angle anisotropy must be in the compressional mode, but the compressional mode inevitably is coupled with shear Alfvén mode in a highly heterogeneous magnetosphere, and must be transferred to the auroral zone ionosphere. Hence, the result in this study shows, that most of the geomagnetic pulsations occurring under the auroral pulsations are not the consequence of propagation of HM waves from the magnetosphere. Instead, it strongly suggests that they are the result of fluctuations in ionospheric electric current, caused by the fluctuations in electric conductivity and accordingly fluctuations in electric field in the ionosphere due to pulsating auroral precipitations. Even though the HM waves which modulate auroral precipitations in the magnetosphere propagate down to the auroral zone ionosphere, their effect in producing magnetic fluctuations at the ground must be very small. In order to confirm the conclusion, quantitative analyses of pulsating auroras and concurrent geomagnetic pulsation will be a crucial point in the next step.

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