ON-OFF CHARACTERISTICS OF LUMINOSITY FLUCTUATIONS OF PULSATING AURORAS

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***Abstract*:** Characteristics of on-off switchings in luminosity of a single point within the pulsating auroral displays were studied on typical three examples. The most striking feature in luminosity fluctuations is the remarkable consistency in pulsation "on" intervals in comparison with "off" intervals. Amplitude maxima in each pulsation cycle were fairly constant throughout a continuous train of pulses. No relationships were found between "on" and "off" intervals. These observations suggest that the pulsation "on" interval is the essential time constant of the phenomena, and the luminosity fluctuations of pulsating auroras consist of individual isolated pulses.

1. Introduction

Optical emissions during pulsating auroral events vary quasi-periodicaly with period in the range 0.1–100 s, although the most common periods are 2–20 s. DUNCAN *et al.* (1981) reported that, while there was no consistent, simultaneous change in period with latitude, in a statistical sense periods at lower latitudes were shorter than those at higher latitudes. YAMAMOTO and OGUTI (1982) found that apparent periods of luminosity fluctuations measured at a certain fixed point can vary according to whether the measuring point is located at the center or at the edge of the auroral patch. These ambiguities which exist in the relation between various physical parameters and the pulsation periods must be due to complexity of the phenomena, such as fast motions of auroral patches synchronized with luminosity changes, and bewildering varieties of the shapes (amoebiform patch, striation, arc). In this regard it is difficult to discuss the phenomena in detail by making one-to-one correspondence to the theoretical models proposed so far.

Therefore, it is necessary to find out the most consistent and essential parameter of the pulsating auroras, and to clarify its relationships to the physical conditions. In this short report the author presents initial results of detailed analyses on the temporal fluctuations in optical emissions of pulsating auroras, proposing that the pulsation "on" interval is one of the most important parameters.

2. On-Off Switchings of the Auroral Luminosity

The data used in this study are all-sky video records obtained at La Ronge (64.8°N, 311.0°W, geomag.) and Park Site (61.5°N, 309.8°W, geomag.) in Canada, 1980. Magnetic local time for this meridian is given by subtracting 8 h from UT. Intensity recordings were made directly from video signal, using a "multichannel video sampler" of an electronic circuit.

In the pulsating auroral displays examined here, the luminosity at a spatially fixed point switched on and off rapidly, so that sometimes the intensity rose to a full luminosity on one frame but was at the background level on the previous frame. Thus the lower limit of the time taken to rise to its maximum from the ground level is less than the exposure time of the TV system, *i. e.* 1/60 s. The fall from maximum to the ground as the luminosity switches off is equally rapid.

Figures 1–3 are intensity recordings of auroral luminosity observed at La Ronge on February 15, 1980, showing some of the diversity which exisits in the temporal character of pulsations. Four sampling points, A, B, C and D, equivalent to 2° of arc in the sky, were set in order along the auroral structure on the TV picture from the zenith (point A) to the west. In these periods the maximum intensity of 4278 Å emission was about 600 *R*. From the viewpoint of the luminosity fluctuations, pulsating auroras can be classified into three types as follows.

Type 1 variations: Pulsation sequence consists of abrupt increases in luminosity from the background to its maximum and subsequent rapid decreases to the ground, "on" intervals being shorter than "off" intervals. "On" interval is defined as the time taken for luminosity from rising to falling, and "off" interval as the time from falling to rising.

Figure 1 shows an excellent example. In the figure, intensity recordings show rather regular wave forms with rapid on-off switchings, and all the pulses have one-to-one correspondence with pulses measured at adjacent points as indicated by dashed

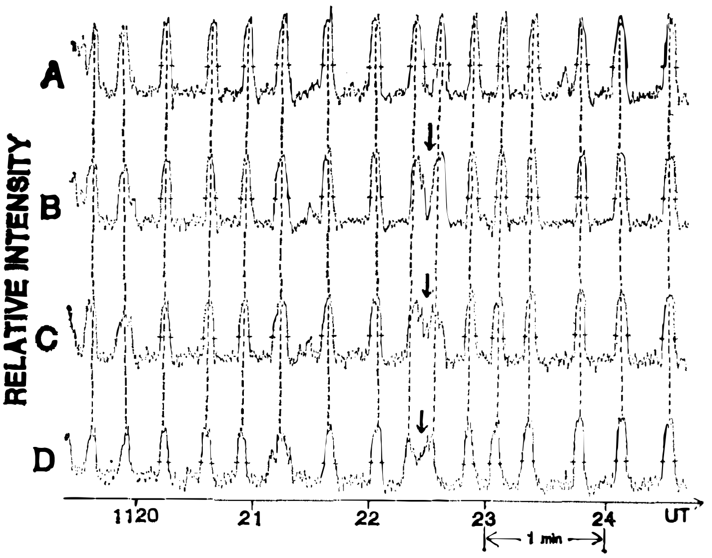

Fig. 1. Intensity recordings of auroral luminosity observed at La Ronge on February 15, 1980. Four sampling points, A, B, C and D, equivalent to 2° of arc in the sky, were set in order along the auroral structure on the TV picture from the zenith to the west. Intensity recordings show rather regular wave forms with rapid on-off switchings (Type 1 variations), and all the pulses have one-to-one correspondence with pulses measured at adjacent points. A phase slipping at 1122: 25 UT in B, C and D, indicated by arrows, appears to correspond with two individual pulses in A.

lines. The pulsation period for the interval 1120–1122 UT was about 20 s, but between 1122: 30 and 1123: 30 UT it was about 12 s after indicating a phase slipping of pulse trains at 1122: 30 UT. In this phase slipping the auroral luminosity at B, C and D does not show full intensity changes. Temporal variations of D especially look like one irregular pulse. However, they appear to correspond with two individual pulses in A.

Type 1 pulsations can be said to be stable pulsations, and are observed in the early morning to morning hours.

Type 2 variations: Pulsation sequence consists of quasi-periodic fade-outs or decreases in luminosity, "on" intervals being longer than "off" intervals.

An example of type 2 variations is shown in Fig. 2. The times at which fade-outs occurred are marked by arrows. In intensity recordings of A and B, luminosity fluctuations show diffuse nonpulsating features until 1107: 40 UT. But at later times quasi-periodic fade-outs began at 1107: 40 UT, gradually tending to change the character into type 1 variations. This is a transient state of auroral forms. During the time interval 1108: 30–1111: 00 UT after changing the character in A and B, decreases in luminosity seen in C and D appear to correspond with switching-off of type 1 variations in A and B as indicated by dashed lines.

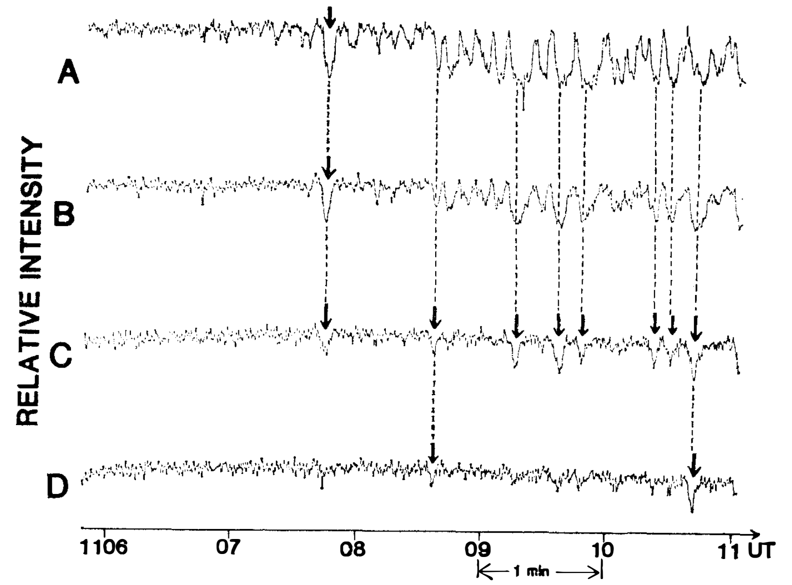

Fig 2. Same as for Fig. 1. Intensity recordings show partly decreases in luminosity as marked by arrows (Type 2 variations). During the time interval 1108: 30–1111: 00 UT, fade-outs seen in C and D appear to correspond with switching-off of type 1 variations in A and B.

Duration of continuous negative pulse train in type 2 variations is generally short in comparison with that in type 1 variations. Type 2 pulsations are observed just after an auroral breakup and just behind the poleward expansion front, or during the transformation of auroral forms from diffuse nonpulsating structures into pulsating displays.

Type 3 variations: Luminosity fluctuations show irregular burst-like pulsations, or complex mixture of the above two types (see the upper panel of Fig. 3). While each of

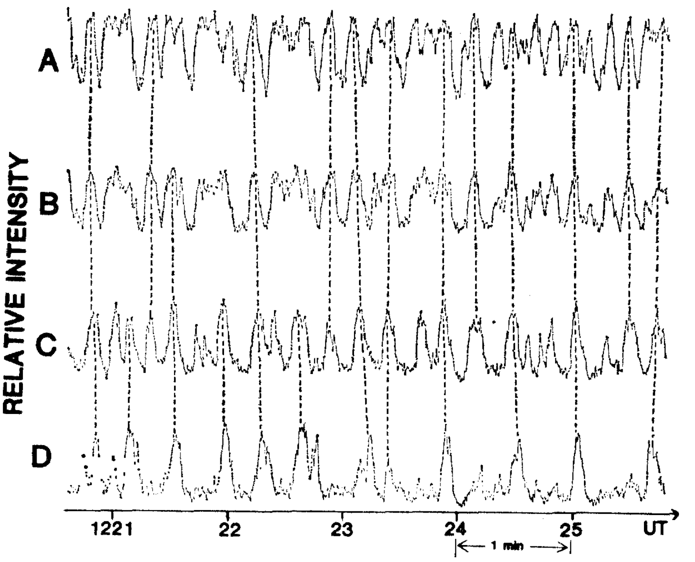

Fig. 3. Same as for Fig. 1. Intensity recordings of A show complex fluctuations in luminosity (Type 3 variations). Pulses of A partly correspond with those of B, C and D as indicated by dashed lines.

pulses in types 1 and 2 can be recognized as being isolated, type 3 variations are hardly found to show full luminosity changes and clear distinction of "on" and "off" intervals cannot be made. Type 3 pulsations are observed in the evening and the morning hours during magnetically active periods.

These three types of pulsations are sometimes related to each other. For example, even if auroral displays consist of individual fast pulsating moving forms, each of which can be categorized into type 1 variations, luminosity fluctuations look like type 3 variations when viewed at a single point, as a result of subsequent crossing of the auroral forms over the measuring point. This effect can be seen in Fig. 3.

In Fig. 3 the pulses at each measuring point correspond partly with those at adjacent points, meaning occasional crossings of auroral patches over parts of the measuring points. Luminosity fluctuations at point B are similar to those at point A which show a typical example of type 3 variations. However, intensity recordings of C tend to show full luminosity changes, and at point D they can be classified into type 1 variations. Average period in D is about three times as large as that in A. One serious problem arises, that is, the period of pulsating aurora.

Type 1 variations sometimes accompany type 2 variations. Examples are shown in Fig. 4, where pulsating patches and diffuse nonpulsating aurora are schematically drawn.

The left panels of Fig. 4 represent auroral structures deformed into a torch shape enveloped by a diffuse nonpulsating aurora. A pulsating patch, A, suddenly appears in the core of the torch in the upper panel. It propagates outward and along the structure (2nd panel), and touches the diffuse aurora (3rd panel). Then, patch A splits into two and at the same time the diffuse aurora fades out progressively from the south (4th panel). The split patches propagate away to the east and the west. Patches B_1 and

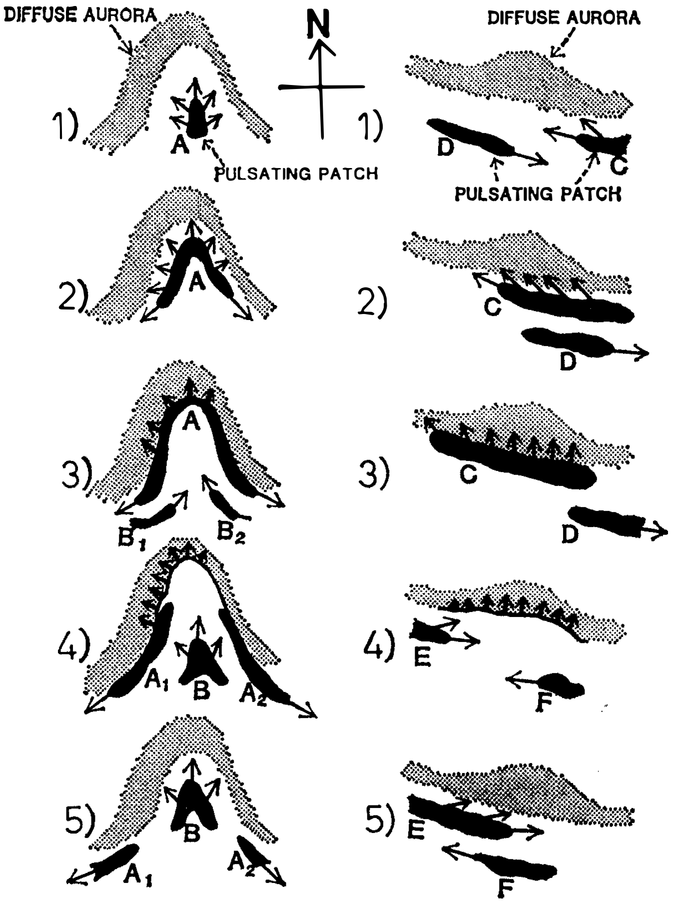

Fig. 4. Schematic illustrations of auroral forms, showing fade-outs of luminosity of diffuse aurora as a results of attachment of pulsating auroral moving forms. This effect is observed frequently in a torch structure (left panels) and in a zonal structure (right panels). The time begins on the top panel and reads vertically. The time interval between the panels is about 2–10 s.

B_2 approach from the east and the west (3rd panel), combining into one form (4th panel). Afterwards it goes on the same movements as patch A.

In the right panels, auroral displays take a form of a zonal structure which is aligned along the E-W direction and is bounded poleward by a diffuse aurora. Pulsating patches are moving almost parallel to the structure, but some of the patches also show a small poleward shifting motion. Occasionally they touch the diffuse aurora (patch C in the third panel) and are absorbed into it (4th panel). Then, the diffuse aurora fades out progressively from the equatorward boundary.

The physical processes causing this effect are not yet understood. Enhancing and depressing mechanisms may operate on the pulsating precipitation of energetic electrons.

It is also noted that maximum levels of amplitude of each pulse are fairly constant throughout the continuous train of pulses as seen in Figs. 1–3. This indicates stability of precipitation fluxes during a considerable interval, suggesting that background conditions with which instabilities causing enhanced precipitation are controlled are hardly changed through several cycles of pulsating precipitation of energetic electrons.

3. Results of Statistical Analyses

Figure 5 shows the histograms of "on" intervals (solid), "off" intervals (dashed and shaded), and periods (dashed). Pulsation periods were defined as the sum of "on" and subsequent "off" intervals. Here we examined type 1 and type 2 variations. As mentioned before, clear distinction of "on" and "off" intervals from type 3 variations is hardly made.

In a typical example of type 1 variation observed at La Ronge in the morning hours on February 15, 1980 ($Kp=2$), the maximum occurrence of periods appears around 16–25 s, scattering in a range from 5 to 40 s (Fig. 5a). While "on" intervals are confined within a smaller range of 4–8 s than periods, "off" intervals are scattered in a wide range, the standard deviation of "off" intervals (5.3 s) being approximately equal to that of periods (5.4 s). That is to say, the wide variation of periods is due to scattering feature in "off" intervals in this example.

Figure 5b shows another example of type 1 variations observed at Park Site in the early morning hours on February 16, 1980 ($Kp=6$). In this period the maximum in-

Fig. 5a.

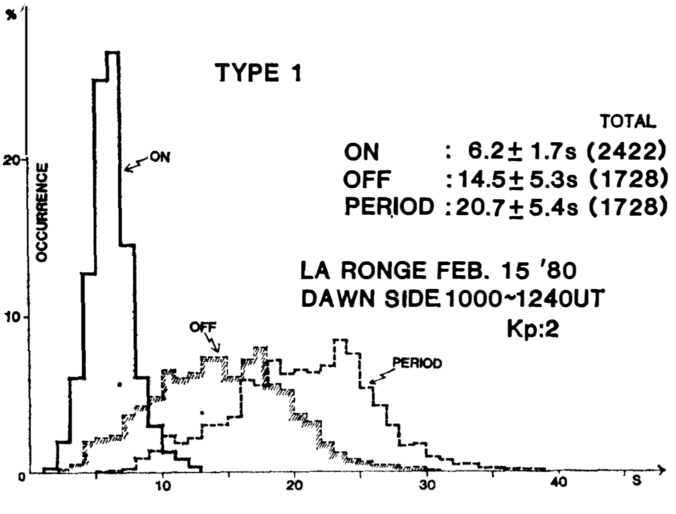

Fig. 5b.

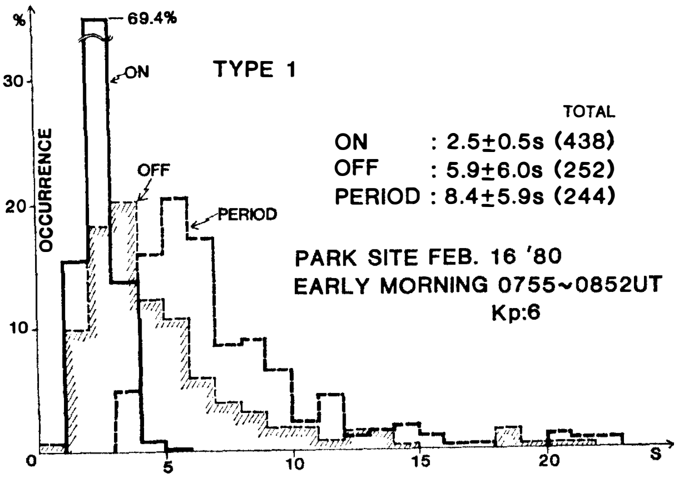

Fig. 5c.

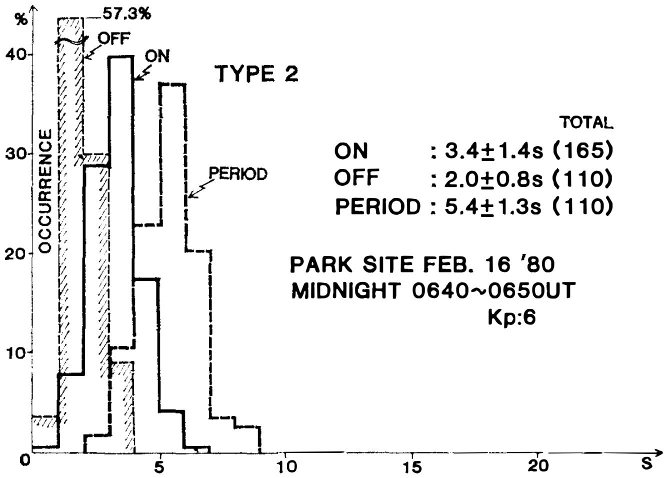

Fig. 5. Histograms of pulsation "on" interval (solid), "off" interval (dashed and shaded), and period (dashed). a) Type 1 variations observed at La Ronge in the morning, 1000–1240 UT, February 15, 1980. b) Type 1 variations observed at Park Site in the early morning, 0755–0852 UT, February 16, 1980. c) Type 2 variations observed at Park Site in the midnight, 0640–0650 UT (just after an auroral breakup), February 16, 1980. Total number of samples, mean value, and standard deviation are also shown in each panel. Note: In type 1 variations (Figs. 5a and 5b), "on" intervals reveal remarkable consistency in comparison with "off" intervals, and the standard deviation of "off" intervals is approximately equal to that of periods. In type 2 variations (Fig. 5c), the distribution of periods is similar to that of "on" intervals but with a bias of the mean value of "off" intervals.

tensity of 4278 Å emission exceeded 4 k*R*. Consistency in "on" intervals is more significant than the above example. The distribution of period is similar to that of "off" interval but with a bias of the mean value of "on" interval, again indicating that the wide variation of periods is due to "off" intervals. These two examples suggest that pulsation "on" interval is the most consistent and essential time constant of the

Fig. 6a.

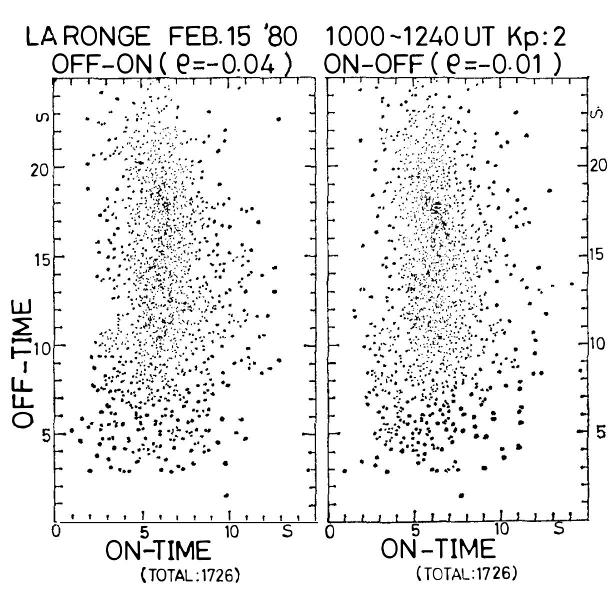

Fig. 6b.

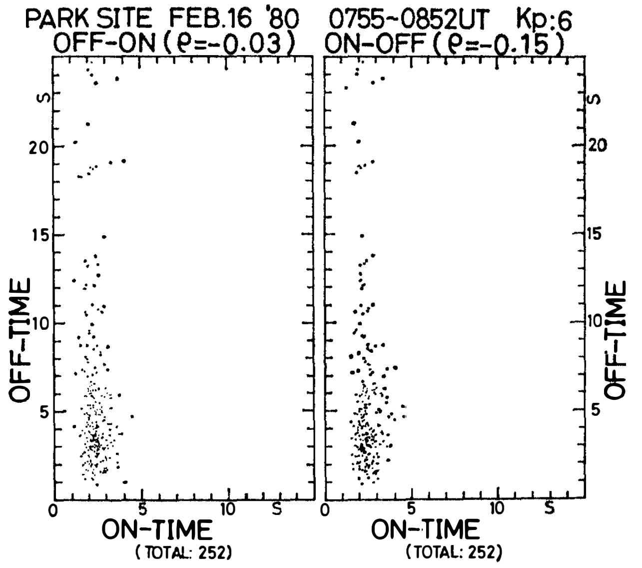

Fig. 6c.

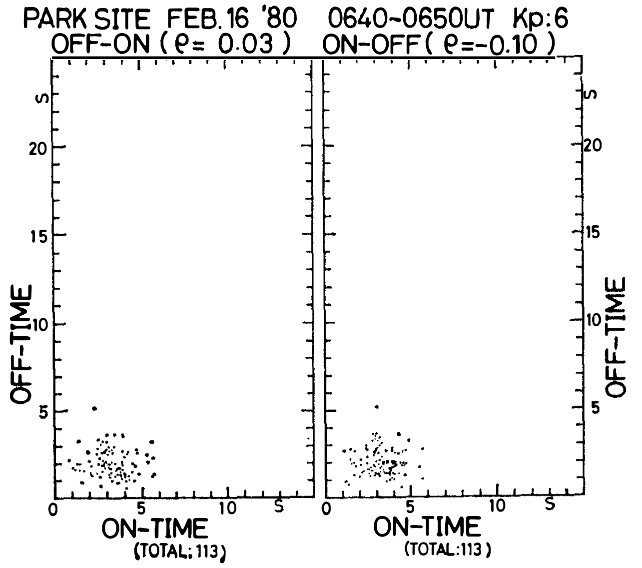

Fig. 6. Scatter plots of "off" versus subsequent "on" intervals (the left panels) and "on" versus subsequent "off" intervals (the right panels). a) Type 1 variations observed at La Ronge, 1000–1240 UT, February 15, 1980. b) Type 1 variations observed at Park Site, 0755–0852 UT, February 16, 1980. c) Type 2 variations observed at Park Site, 0640–0650 UT, February 16, 1980. Linear correlation coefficient, ρ, is shown on the upper right of each panel. Note: There are no relationships between "on" and "off" intervals.

pulsating auroral phenomena. A similar result was reported by SCOURFIELD and PARSONS (1969), using the data of sub-vidual pulsating auroras.

Type 2 variations appear to reveal different characteristics from type 1 variations. Figure 5c is made from an example obtained at Park Site in the midnight hours (just after an auroral breakup) on February 16, 1980 (Kp=6). This contains a transient state of auroral forms from diffuse nonpulsating to pulsating displays. "Off" intervals are confined within a smaller range than "on" intervals (0.8 s to 1.4 s of the standard deviations). Periods are sharply distributed in contrast with the wide variation of the previous examples. Whether type 2 variations are caused by the same mechanism as for type 1 variations or not is not yet understood. Differences of characters of precipitating electrons between these two types are also unknown. Type 2 variations probably occur in the critical state that separates the precipitation processes into nonpulsating and pulsating features.

It is interesting to investigate how "on" intervals are related to "off" intervals. A long "on" interval might be expected to follow a long "off" interval and *vice versa*. Figure 6 is a scatter plot of "on" versus "off" intervals. The left panels are drawn from "off" and subsequent "on" intervals and the right from "on" and subsequent "off". Linear correlation coefficient between "on" and "off", ρ, is also shown on the upper right of each panel. No relationships between "on" and "off" intervals are found in all the examples studied here. The maximum of absolute value of ρ is as small as 0.15, suggesting that luminosity fluctuations of pulsating aurora consist of individual isolated pulses.

4. Discussion

Pulsating auroral patches exhibit more or less spatial movements synchronized with luminosity changes. Since magnetic drift speed of energetic electrons near $L=5$ is about two orders of magnitude less than the velocity of patch motion projected along the field line onto the magnetospheric equatorial plane (order of Alfvén velocity), it is reasonable to discuss the phenomena on the assumption that energetic electrons persist in a particular flux tube for several pulsation cycles.

Pulsation sequence of auroral luminosity showing a train of pulses with abrupt on-off switchings like output from multivibrator of electronic circuit suggests that instabilities causing pulsating precipitation grow and decay nonlinearly. Pulsation "on" intervals are remarkably consistent, implying the existence of time constant for which wave-particle interactions are at a saturation level. Amplitude of pulses being fairly constant imposes stability of the saturation level during several pulsation cycles. There is also a significant feature in the pulsating auroral phenomena, that is, temporal variations in luminosity of different patches are incoherent in spite of sizes, shapes, or locations (SCOURFIELD *et al.*, 1972; OGUTI, 1976).

Several models have been given for explaining pulsating precipitation of energetic electrons into pulsating auroras (CORONITI and KENNEL, 1970; DAVIDSON, 1979; LUHMANN, 1979). If the temporal variations of precipitation fluxes are due to modulation caused by macroscopic waves such as the compressional mode HM waves (CORONITI and KENNEL, 1970) and the acoustic-gravity waves (LUHMANN, 1979), good coherency within a spatial scale greater than one wave length and movements of auroral patches with the velocity equal to the phase velocity of the macroscopic waves propagating perpendicular to the field line will be expected. Incoherency between adjacent patches (patch sizes are sometimes less than 10 km) and fast motions of patches of which speed is larger than acoustic speed (YAMAMOTO and OGUTI, 1982), however, indicates that macroscopic waves hardly account for all the pulsating auroras. It may be concluded that temporal variations of precipitation fluxes are basically caused by physical processes that act within a particular flux tube. Flux tube in the distant magnetosphere, where pulsating precipitations occur, is probably characterized by cold plasma irregularities, forming an auroral patch on the ionosphere (OGUTI, 1976).

DAVIDSON (1979) has suggested that pulsations are caused by self-modulated VLF wave-particle interactions. This mechanism invokes an injection source that replenishes the electrons and a temporary modification of the wave growth and loss parameter to allow repeated pulsations, being similar to a highly nonlinear relaxation oscillator with an irregular repetition rate. Time interval, for which the precipitation mechanism is acting, is surely dependent on the background cold plasma distributions and is expected to be fairly constant throughout several pulsation cycles. The background conditions are hardly modified during one precipitation pulse. The precipitation fluxes of energetic electrons are also expected to be constant during a considerable time interval. On the other hand, the recovery time for the mechanism must be strongly related to an injection rate of energetic electrons into flux tube. The injection rate probably fluctuates with time. The resulting electron precipitation pulses will basically agree with our observations of consistency in "on" intervals and of no relationships between "on" and "off" intervals.

The luminosity fluctuations of pulsating auroras consist of individual isolated pulses, and the time width of each pulse is probably dependent on the background conditions of the flux tube, especially upon cold plasma distributions along the field line as well as their radial and azimuthal distributions in the distant magnetosphere. However, there are many different types of pulsating auroras. Some types seem to be due to macroscopic wave propagations (OGUTI and WATANABE, 1976). Type 2 pulsations are probably caused by depression mechanisms. Previously proposed models hardly explain all. Different mechanisms may operate upon each type of pulsating auroras. Co-ordinated observations from ground, rocket, low-altitude-satellite, and synchronous-orbit-satellite, as well as quantitative analyses based on dynamical distinction of auroral forms, will give further information for discussing the pulsating auroral phenomena.

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