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Behavior of diffuse luminosity during the substorm growth phase

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Abstract. The behavior of diffuse luminosity equatorward of the southern boundary of the discrete auroral forms during the growth phase of a substorm has been investigated on the television (TV) auroral data. The method of TV images filtering was used. It was found out that diffuse luminosity brightness varies with the period of ∼15–20 min. Some auroral structures may appear inside diffuse luminosity. The interchange of homogeneous and structured diffuse luminosity occurs with the period of ∼10 min under the moderate magnetic activity and about 15 min under the weak one. Structures may be black bands or pulsating arc-like filaments motionless as well as drifting poleward or equatorward. During the growth phase, three types of auroral pulsations inside diffuse luminosity were observed: (A) – arc-like filaments inside diffuse luminosity pulsating with the period of ∼3–10 s, (B) – auroral pulsations of the southern boundary of diffuse luminosity with the period ∼30–40 s, (C) – auroral arc-like structures pulsating with the period of 30–50 s appearing with the period of 30–70 s at the south boundary of localized "resonator" region and spreading northward with the velocity of ∼0.2–0.8 km s^{-1} simultaneously with the same structures appearing at the north boundary and spreading southward. In the course of growth phase, one or two types of pulsations may be observed in diffuse luminosity at the same time. The substorm expansive phase represented by extension of bright diffuse region having internal structure as patches and arc fragments more often is preceded by the auroral pulsations of (A) type. Types (B) and (C) precede the explosive phase when poleward expansion looking like arcs jumps into more polar latitudes. Different pulsation types and their localization inside diffuse luminosity may be a result of plasma gradient existence (density, temperature, energy, and so on) and display the interaction of different magnetosphere regions, and thus should provide important information about magnetospheric structure.

1. Introduction

As known, diffuse luminosity is connected with unstructured precipitation of electrons and protons and it makes the main contribution to the energy balance of atmospheric radiation in the auroral zone [*Ponomarev*, 1985]. Diffuse luminosity dynamics and its relationship with electrojets and geomagnetic pulsations Pc1–2, IPDP, and Pi1 were in-

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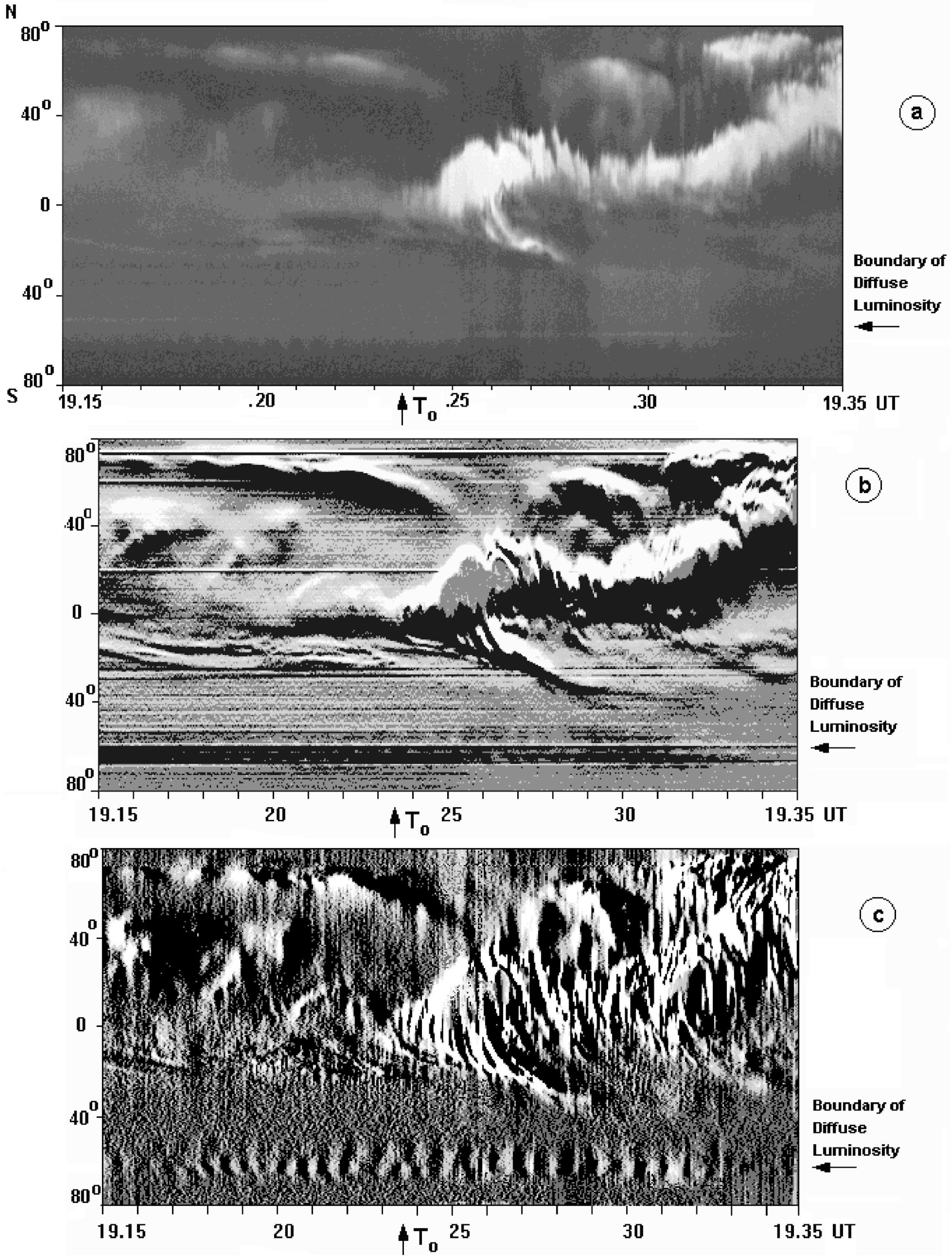

Figure 1. Examples of gradient keogram filtering. (a) Ordinary keogram, (b) space gradient, and (c) time gradient filters.

vestigated, for example, in *Solovjev* [1996] and references therein. Large scale undulations often appear at the equatorial edge of diffuse luminosity, and their relation with Kelvin-Helmholtz instability was considered in *Yamamoto et al.* [1991]. Auroral torch structures at the polar boundary of diffuse luminosity were studied in *Tagirov* [1993] and references therein. During the last decades, numerous measurements of characteristics of auroral energetic particle intrusions were carried out [*Galperin and Feldstein*, 1989; *Lui et al.,* 1977; *Valchuck et al.,* 1979; *Winningham et al.,* 1975]. It allowed us to find out the peculiarities of the structure in the global picture of electron and ions injections, their link with field aligned currents, and different manifestations of activity in the magnetosphere. A lot of papers were devoted to the problem of discrete and diffuse auroras mapping into the magnetosphere [*Galperin and Feldstein*, 1989; *Lui et al.,* 1977; *Valchuck et al.,* 1979; *Vorobjev et al.,* 2000; *Winningham et al.,* 1975; *Yahnin et al.,* 1997]. Nevertheless, this problem remains unsolved. Opinions differ as to the question in what regions of the magnetosphere are the polar aurora oval and diffuse luminosity projected? However, independently of the region where the diffuse luminosity is mapped, the processes occurring inside diffuse luminosity surely are connected with substorm development. Moreover, we suppose that they are different for various substorm onsets. In the present paper on TV auroral data, we investigate the behavior of diffuse luminosity during the growth phase of substorms and its relationship with explosive phase onset.

This paper is organized as follows. In section 2, we describe TV camera characteristics and method used for processing of TV data. In section 3, we present experimental data. The summary and conclusion are given in section 4.

2. Instrumentation and Data Processing

Auroral data have been recorded by SIT-vidicon TV cameras with Nicon all-sky lens. No aurora emissions filters were used, so camera spectral response was about 3500–7000Å, with a maximum near 5000Å. Computer framegrabber videocard and special software allowed us to digitize TV frames (up to 720 × 512 pixels) and arbitrary chosen frame fragments. Keograms along the stable profile of any width, shape, size, orientation or moving together with an auroral arc are also available with a time resolution up to 20 milliseconds. Data are always digitized with a maximum possible resolution (50 TV fields per second) and before they are recorded in computer memory they are summarized and averaged both cross keogram profile and in keogram time interval, which allows strongly expanded dynamic range of the data and enhances weak details of aurora luminosity afterwards [*Kornilov and Kornilov*, 1997]. Different image processing methods also can be used (gradient, convolution, filtering, warp image geometry, and TV tube field sensitivity corrections and so on) [*Kornilov,* 1999]. Filtering methods reveal a lot of details often invisible in initial data and use information obtained during the bad observational conditions (fog, clouds, twilight, city lights, etc).

TV data discussed in this paper have been processed by a very simple and efficient gradient filtering. Displayed keogram matrix is a result of subtraction of the initial matrix and matrix shifted in vertical or horizontal direction for the desired number of pixels. If, for example, an initial keogram profile was oriented from north to south, the resulting vertical gradient image amplifies weak details of auroral forms moving in a north–south direction, and horizontal gradient emphasizes temporal variations of auroral luminosity.

The advantage of the gradient filtering method can be seen in Figure 1, where (a) is an ordinary keogram, (b) and (c) are space and time gradient keograms respectively. Keograms demonstrate aurora development at Lovozero on 8 February 1997. Vertical scale is given in zenith angles. Arrow T_0 marks the breakup onset. Space gradient filtering allows us to reveal fine effects in the northern-southern aurora motion and to notice the stable south boundary of diffuse luminosity, which is hardly visible in an ordinary keogram. The time gradient keogram shows luminosity pulsations of auroral structures inside the discrete forms oval as well as in the diffuse luminosity. Auroral pulsations are clearly seen at the immovable southern boundary of diffuse luminosity (Figure 1c). Having two-dimensional keogram matrix, it is easy to calculate different sums along fragments of matrix rows or columns. For example, the so called "TV photometer" shows the sum of elements along some part of a keogram line in the chosen range of zenith angles and so represents an average brightness of aurora in that place.

3. Experimental Data and Analysis

The TV auroral data used in this study were obtained at Porojarvi (65.6°N, 105.9°E), Kalkkoaivi (65.6°N, 105.4°E), and Lovozero (64.07°N, 114.7°E) during Russian-Finnish experiments in 1993–1995, 1997 as well as during continuous observations in 1996–1998 at Loparskaya (64.7°N, 116.3°E) and Lovozero. (Coordinates of stations are corrected geomagnetic coordinates). Dynamics of auroral forms and diffuse luminosity behavior were analyzed for the growth and explosive phases of 18 substorms. The onset of explosive phase of substorm was defined by auroral data as brightening and poleward expansion of the equatorial arc. Magnetic disturbance was controlled by magnetic data of Loparskaya, Lovozero, and Scandinavian IMAGE Magnetometer Network. Also available, POLAR UVI data were attracted to control the ground observation of auroras and define their place in the global auroral picture.

The data analysis and special TV images processing described in section 2 allow us to reveal fine effects in the dynamics and structure of diffuse luminosity, and some common features have been found as well.

1. During the growth phase, the structure of diffuse luminosity situated equatorward of the southern boundary of discrete forms changes within a period of about 10 min at the moderate magnetic activity and 15 min at the weak one: an interchange of homogeneous and splitting diffuse luminosity is observed. Just 5 min before the breakup onset, the diffuse luminosity is split, and after the breakup it becomes ho-

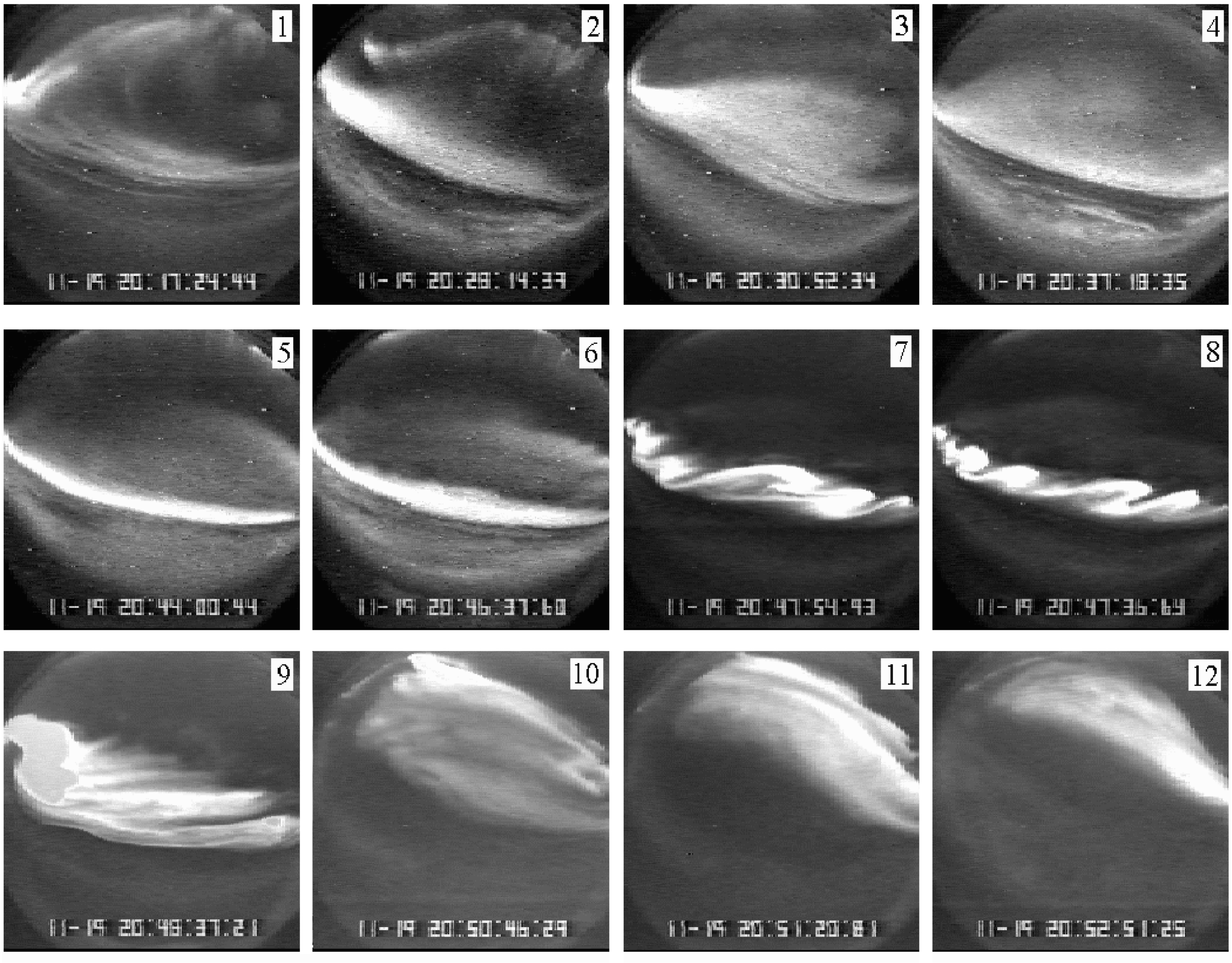

Figure 2. An example of interchange of homogeneous and splitting diffuse luminosity observed at Porojarvi on 19 November 1995.

mogeneous. An example of interchange of homogeneous and splitting diffuse luminosity is given in Figure 2. As seen from the Figure 2, southward of zenith there is an arc embedded in the diffuse luminosity. The southern part of the diffuse luminosity and the arc are separated by a black gap (Frames 2–4). Splitting — the appearance of structures in diffuse luminosity — is observed equatorward of the gap. Structures may look like stretched west-eastward black bands or thin, arc-like filaments brighter than the surrounding diffuse luminosity (Frames 2, 4, 6). Usually structures pulsate. Pulsating forms may be immovable or drifting to the north or south. At 2046:37 UT (Frame 6), homogeneous arc began to warp (this moment may be considered as breakup onset), and some folds appeared along it (Frames 7, 8). Frames 9–12 demonstrate aurora poleward expansion during which diffuse luminosity southward of warped arc is homogeneous.

2. The intensity of diffuse luminosity changes with a period of about 15–20 min. Usually, the diffuse luminosity region and that of discrete aurora are separated by a gap. The luminosity intensity inside the gap usually changes in the course of growth phase. If the gap is situated inside the diffuse luminosity, the latter changes nonsynchronously southward and northward of the gap. Figure 3a shows ordinary keogram from Porojarvi of 19 November 1995. Variations of diffuse luminosity intensity northward and southward of the gap detected by "TV photometers" described in section 2 are represented in Figure 3b. "TV photometers" positions are marked by vertical bars (Photometer N and Photometer S) to the right of the keogram in Figure 3a. Cross-correlation function showing the periodicity of luminosity variations is given in Figure 3c. The variations in the north lead those in the south by about 20 min.

3. An interesting feature of diffuse luminosity is pulsations. We have found three types of auroral pulsations occurring in diffuse luminosity in the course of the growth phase: (A) arc-like filaments pulsating with the period ~3–10 s, moving or motionless inside diffuse luminosity, (B) auroral pulsations of the southern boundary of diffuse luminosity with the period of ~30–40 s, (C) auroral arc-like filaments pulsating with the period 30–50 s inside a well localized re-

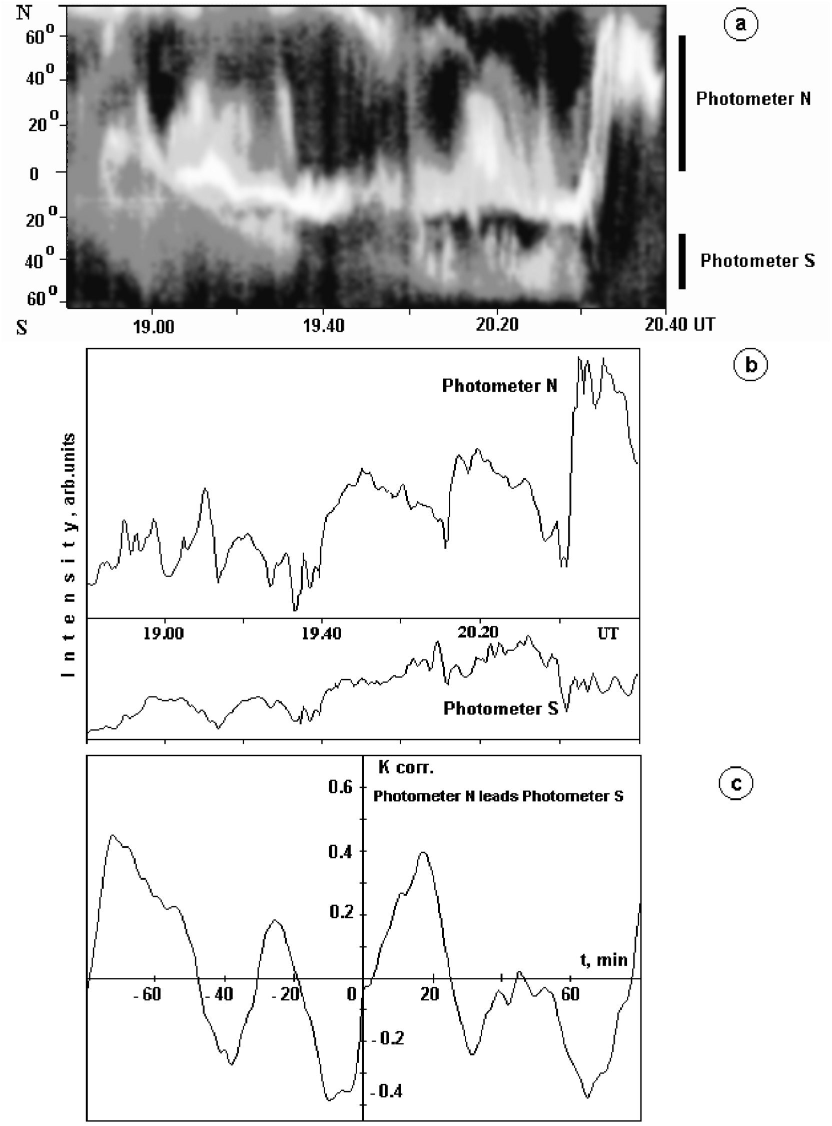

Figure 3. Aurora development at Porojarvi on 19 November 1995. (a) Keogram, (b) variations of diffuse luminosity intensity northward and southward of the gap, and (c) cross-correlation function showing the periodicity of variations registered by northern and southern "TV photometers."

gion, which we called "resonator." "Resonator," usually situated on the south boundary of diffuse luminosity, represents a band of width of 100–200 km stretched along geomagnetic latitude. Pulsating, arc-like filaments emerge every ~30–70 s at the southern boundary of "resonator" and move to its northern one with the velocity 0.2–0.8 km s^{-1}. Simultaneously, the same pulsating filaments appear at the northern boundary of "resonator" and move southward. As a result, an intricate interference picture arise that looks like waves moving behind the ship and reflecting from the walls of channel.

One can see pulsations of (A) and (B) types in Figure 4. Figure 4a shows an ordinary keogram longer than the interval of substorm development in Figure 1 registered on 8 February 1997 at Lovozero and three fragments (Figure 4b–4d) of this interval containing different types of pulsations. The interval of 1805–1810 UT belongs to the growth phase. During that time, the arc in the north pulsates within a period of ~6 s, and two overlapped chains pulsating with periods of ~3–9 s (pulsations of (A) type) are observed in diffuse luminosity near zenith. The interval of 1905–1910 UT also belongs to the growth phase. In this interval, only pulsations with the periods of ~30–40 s (pulsations of (B) type) were observed at the southern boundary, and no pulsations were revealed inside the diffuse luminosity. Arrow marked T_0 under ordinary keogram in Figure 4a signifies the breakup

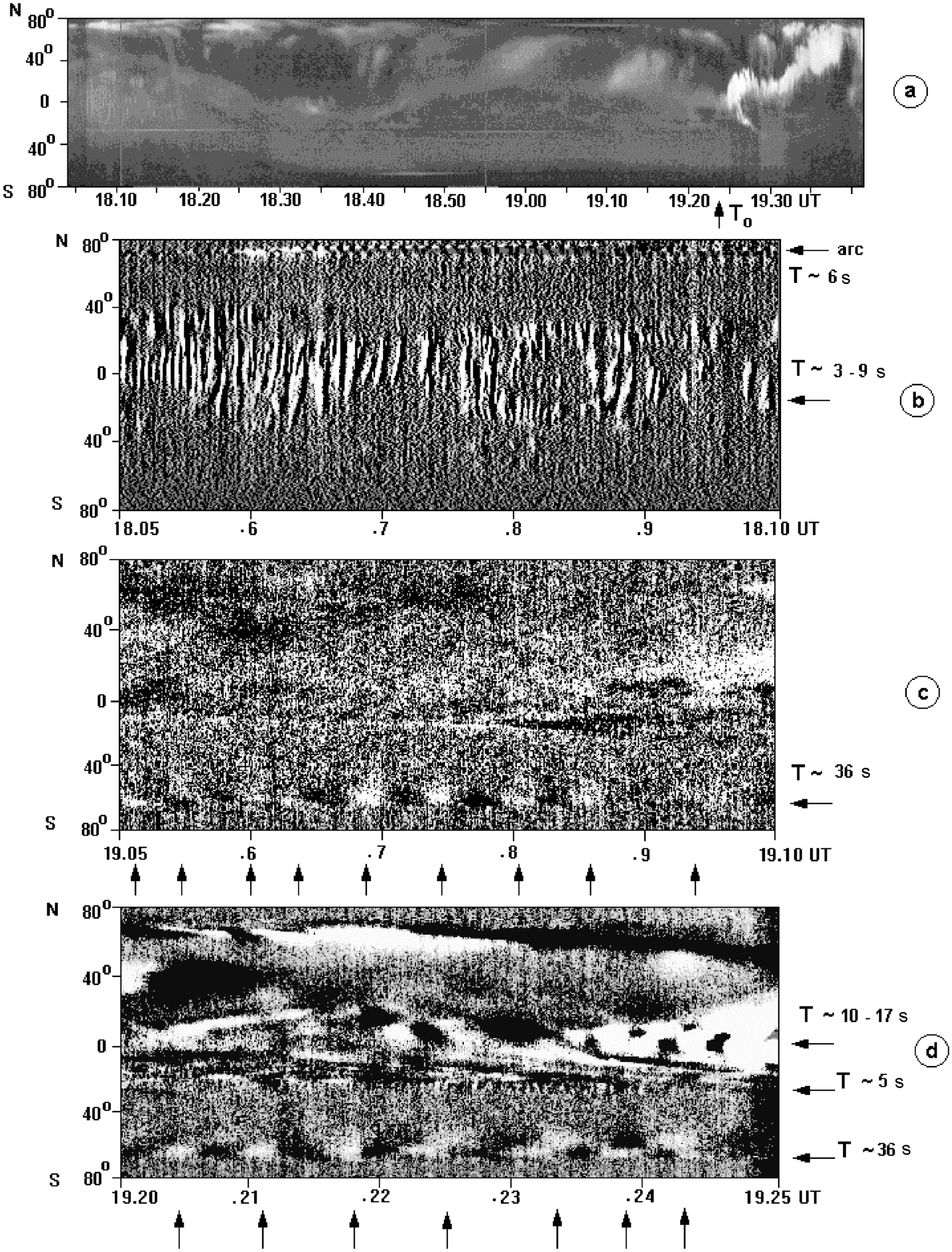

Figure 4. Auroral substorm development on 8 February 1997 at Lovozero. (a) Ordinary keogram; (b, c, d) time gradient keograms. Vertical arrows mark moments of brightening at the south boundary of diffuse luminosity.

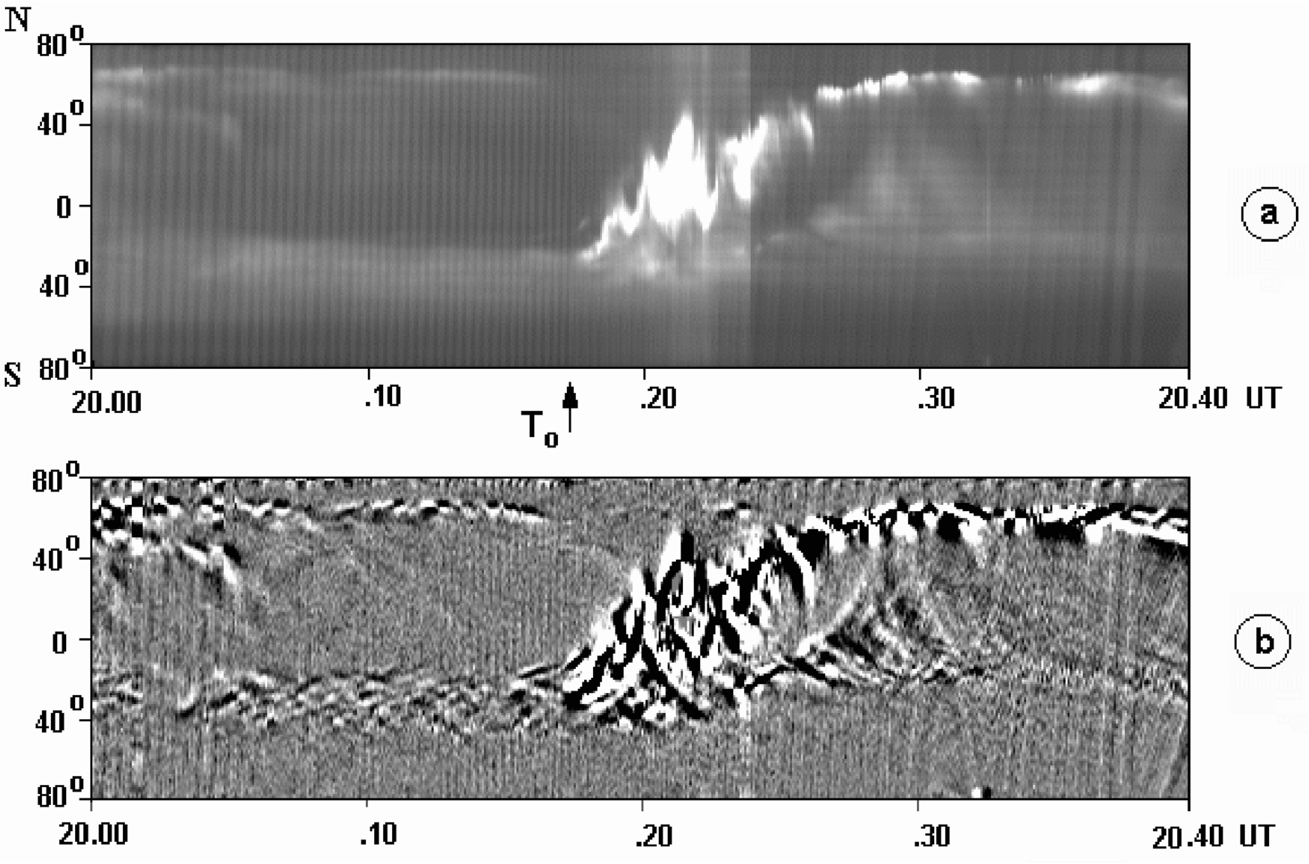

Figure 5. An example of pulsations spreading inside localized "resonator" region observed at Lovozero on 26 March 1998. (a) Ordinary keogram, and (b) time gradient keogram.

onset. Arrows under gradient keograms in Figure 4c, d mark the moments of the brightening of the south boundary of diffuse luminosity.

Figure 4d shows the interval of 1920–1925 UT just before the breakup onset (1923:48 UT) and ~2 min after it. From the moment of breakup onset, the arc in the zenith begins to move poleward, the curls drifting westward along the arc, and variations of luminosity intensity are manifested in the time gradient keogram as pulsations with the period of ~10–17 s. Inside the diffuse luminosity southward from the arc situated near zenith there are fast pulsations with the period of ~5 s. The southern boundary of diffuse luminosity pulsates with the average period of ~36 s.

An example of (C) type pulsations is given in Figure 5, showing substorm development on 26 March 1998 at Lovozero. Figure 5a is an ordinary keogram, and Figure 5b is a time gradient keogram. Vertical strips of different brightness in keograms are because of some TV camera defects. Arrow T_0 under ordinary keogram marks the breakup onset at 2017:40 UT. In the time interval 2000:00–2017:40 UT, the band of diffuse luminosity southward of zenith is seen in the ordinary keogram. Figure 5b shows pulsations occurring before the breakup onset in diffuse band situated at a distance of 17–47° southward of zenith. These pulsations look like waves simultaneously emerging in ~50 s at the northern and southern boundaries of the "resonator" and moving toward its contrary boundary. Velocities of the wave movement are of order of 0.2–0.8 km s^{-1}. Period of brightness luminosity changes in the waves is ~30 s. The width of "resonator" is ~100 km.

The study of a very weak diffuse background behavior during quiet conditions shows that even in such cases subvisual pulsations luminosity and their motion can be revealed using the TV image filtering method. Figure 6a represents a usual keogram showing an example of weak auroral development northward of Lovozero on 12 January 1997 in time interval 1800–1920 UT. Figure 6b–6e demonstrates four time gradient keograms for time intervals going one after another. As seen in Figure 6b, the development of auroral activity began at 1803 UT as a periodical brightening of the arc near the north horizon within the period of ~1 min. At 1822 UT (see Figure 6c), besides the pulsations of luminosity, recurrent southward shifting of this arc with the period of ~2 min is obvious. At the same time, a boundary of diffuse luminosity appeared and drifted southward till 1850 UT (Figure 6d), then moved poleward. The period of brightening luminosity changed while the boundary was moving. Southward motion accompanied by a shortening of the period from ~40 s to 30 s, during the northward drift period, increases to ~50–60 s. When the activity of the north arc ceased at 1913 UT

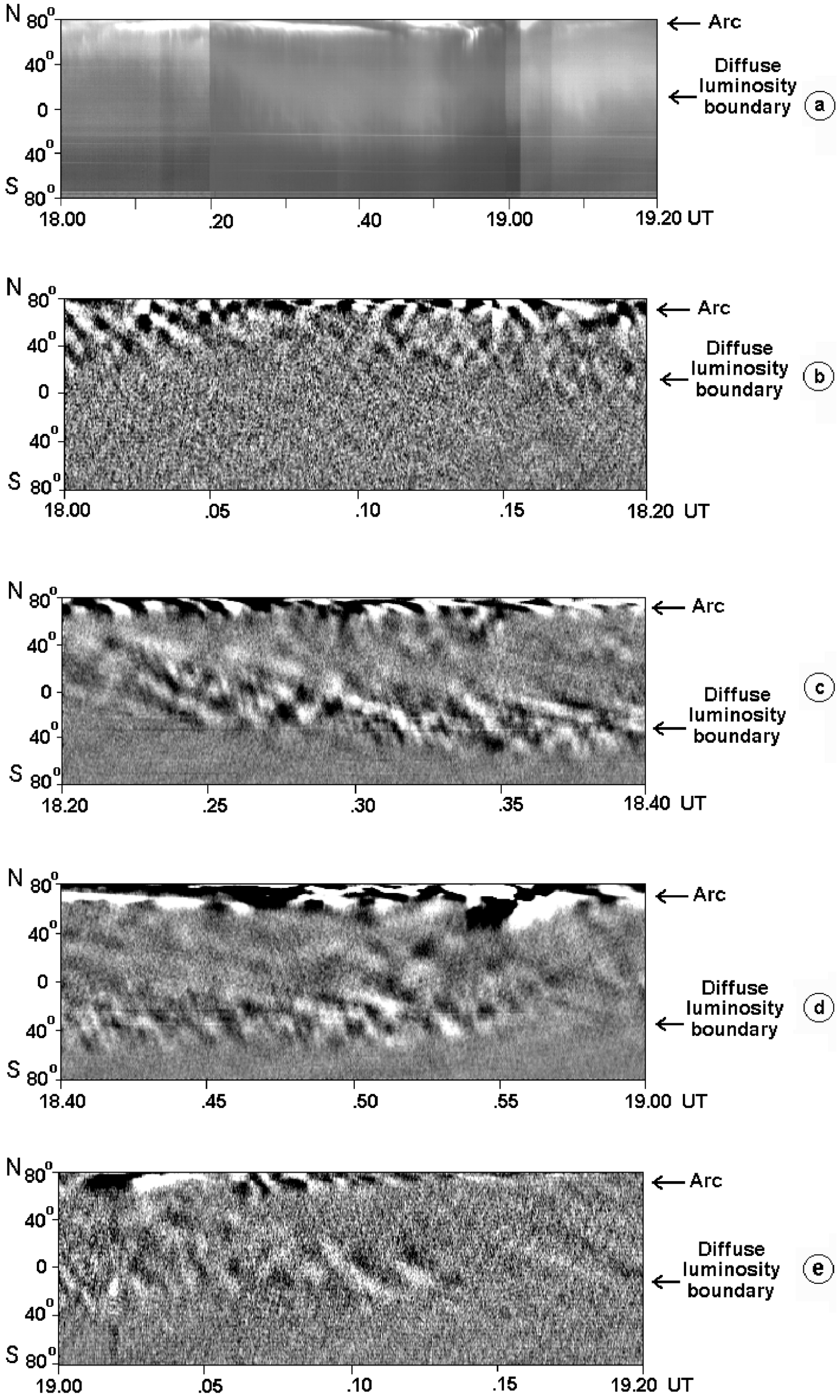

Figure 6. An example of pulsations observed in diffuse luminosity during weak auroral activity at Lovozero on 12 January 1997.

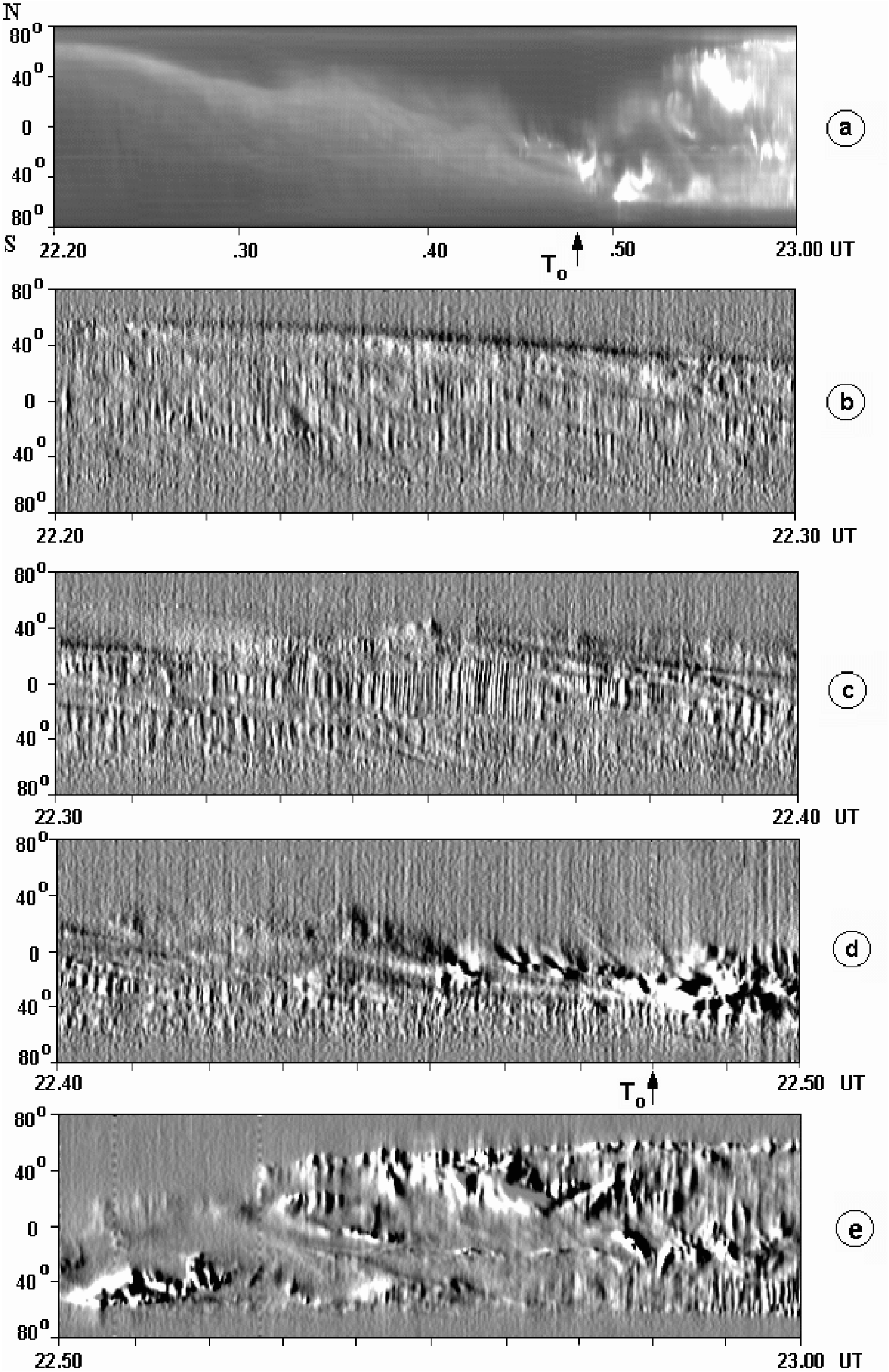

Figure 7. Aurora development at Loparskaya on 9 December 1996. (a) Ordinary keogram; (b, c, d, e) sequence of time gradient keograms.

(Figure 6e), pulsations of the southern boundary brightness disappeared.

The data analysis shows that in the course of growth phase in diffuse luminosity, one or two types of pulsations may be observed simultaneously. Some attempt was done to reveal a connection between auroral pulsation types during the growth phase and the poleward expansion types according to classification given in *Kornilova et al.* [2000]. As shown in *Kornilova et al.* [2000], the poleward expansion may be of two types. The first one is represented by leaped formation of new arcs into more polar latitudes. The poleward expansion during the second type looks like spreading of shining auroral region having irregular structure consisting of patches or arc fragments without a definite orientation. The patches and arc fragments are embedded within the diffuse luminosity region. Unfortunately, we do not have enough data for a decisive conclusion, but nevertheless, the analysis of available data has shown that before the first type of poleward expansion pulsations of (B) and (C) types, more often are observed. The pulsations of (A) type precede the second poleward expansion type.

An example of pulsations of (A) type before the second type of poleward expansion registered at Loparskaya on 9 December 1996 is shown in Figure 7, where ordinary keogram for time interval 2020–2300 UT (Figure 7a) and sequence of four time gradient keograms (Figure 7b–7e) for this interval are presented. As seen in Figure 7a, diffuse arc drifted equatorward since 2220 UT till 2232 UT. Southward of it, diffuse luminosity was observed. The breakup onset (2248:33 UT) is marked by arrow T_0. Figure 7b–7e shows that during time interval 2220–2248 UT, the whole region of diffuse luminosity was full only by auroral pulsations with the period of order of 3–10 s and no other pulsations were observed before the breakup onset.

4. Summary and Conclusions

The present work is, to our knowledge, the first where the fine structure of diffuse luminosity is studied using the methods of TV image filtering. This method allowed us to reveal unknown earlier fine affects in the dynamics and brightness variations of diffuse luminosity. Results from these studies can be summarized as follows:

1. During the substorm growth phase, variations of diffuse luminosity brightness with the period of ∼15–20 min are observed.

2. An interchange of homogenous diffuse luminosity and appearance of structures inside it with the period of ∼10 min for the moderate magnetic activity and about ∼15 min for the weak one take place.

3. During the growth phase, three types of pulsating structures are observed in diffuse luminosity: (A) arc-like filaments pulsating with the period ∼3–10 s inside diffuse luminosity, (B) auroral pulsations of the southern boundary of diffuse luminosity with the period ∼30–40 s, and (C) auroral arc-like structures pulsating with the period of 30–50 s and appearing with the period of 30–70 s at the south boundary of the localized "resonator" region and spreading northward simultaneously with the same structures appearing at the north boundary and spreading southward.

4. During the weak auroral activity, pulsations of brightness and their motion are observed in subvisual diffuse background.

5. Different types of poleward expansion during substorm explosive phases are preceded by different types of pulsations at the growth phase. Poleward expansion represented by leaps of arcs into higher latitudes is usually preceded by pulsations of (B) and (C) types; poleward expansion looking like spreading of bright diffuse region with internal structure is preceded by pulsations of (A) type.

We suppose that study of auroral pulsation types observed in diffuse luminosity during substorm growth phase allow investigation of wave processes in the plasma inhomogeneities regions and their connection with the explosive phase onsets. Different pulsation types and their localization inside diffuse luminosity can be a result of plasma gradients existence (density, temperature, energy, and so on). Probably, these pulsations manifest an interaction between different magnetosphere regions (for example, the inner boundary of the plasma sheet and the plasmapause) and so can give important information about magnetosphere structure.

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