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Optical observations of auroral forms at different zones in high latitudes (brief review)

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Abstract. The report is based on the results of TV observations of different auroral forms made by Polar Geophysical Institute in the auroral zone polar cap and cusp region. The auroral zone forms were pulsating aurora and torch (omega) like structures, observed from stations in Northern Scandinavia and Kola Peninsula. Clear connection of pulsating auroral patches with ELF-VLF emissions are shown. The results of mapping of auroral torches to magnetospheric equatorial plane are presented. We also present the results of observations of dayside auroral structures during strong northward IMF. TV observations were carried out in polar cap and cusp region on Franz-Joseph Land and covered the whole dayside sector. Auroral motion followed to "inverse" twin-cell convection pattern with sunward flow over the pole.

1 Auroral pulsations and accompanying VLF emissions

Quasiperiodic ELF and VLF emissions in the frequency range from 100 Hz to 10 kHz with periods in the range 520 s similar to pulsating aurora and spiketype intensity variations are reported e.g. in the catalogue (Helliwell, 1965). Chorus elements with periods of fractions of second are often seen. Similar temporal structure often occurs in pulsating aurora in the form intensity modulation (Oguti, 1976; Røyrvic and Davis 1977; Sandahl 1984). This is an indirect evidence of connection of VLF waves with auroral pulsations. But in experiments it was not always observed, mainly because of difficulties connected with high spatial and temporal variations of pulsating aurora.

Results of simultaneous observations during typical post-breakup period of VLF emissions and auroral pulsation in Sodankylä, Finland (L∼5) on February 15, 1991 were presented by Tagirov et al. (1999). Pulsating aurora was strong during the recovery phase of clear substorm onset, which commenced at about 2340 UT on February 14, 1991 and contained pulsating patches with characteristic periods of 5-10 s. VLF emissions occurred having trains of chorus elements in frequency range 1.5-2.5 kHz lasted 0.3-0.4 s. Both auroral and VLF activity existed 2 hours to the dawn.

The paper dealt with *pure or stable pulsations*, and *expanding or propagating pulsations*. These types of pulsation were described in details by Oguti (1976), Scourfield and Parsons (1971), and Kosch and Scourfield (1992).

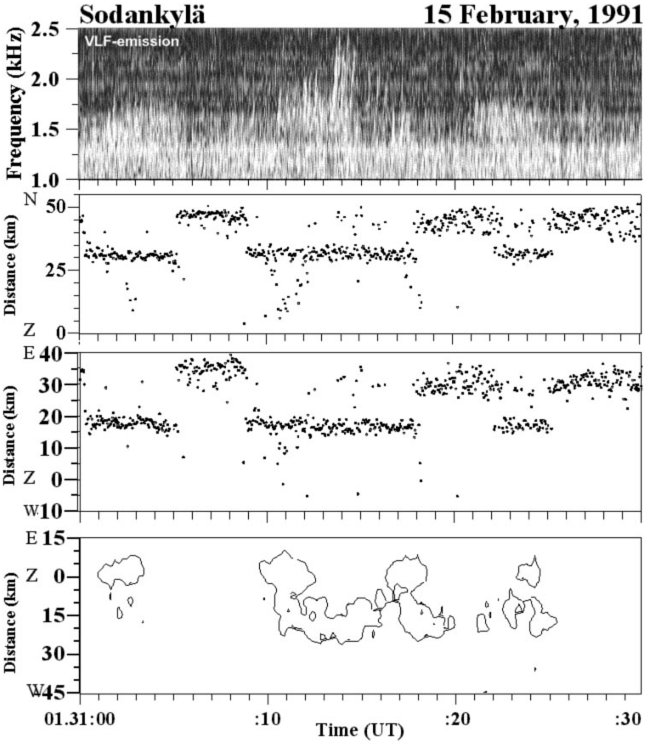

Fig. 1. The results of computer analysis of simultaneous ELFVLF emission and auroral pulsation data. The uppermost panel shows the dynamic spectrum of the lowfrequency emissions. The consequent locations of luminosity maximum for each TV frame in geomagnetic NS and EW directions are shown in the second and the third panels, correspondingly. The fourth panel shows the contour of keogram of pulsations

Auroral pulsations were observed by auroral low-light-level

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TV camera. ELF and VLF data were recorded on the same videotape with TV data. Each TV frame of 0.04 duration was digitized using 256×256 pixels corresponding to the field of view 84×84 degrees and 64 brightness levels. Two intervals of observations at 0131: 00–0131:30 UT and 0134:35–0135:35 UT were chosen for detailed analysis. Although only 90 s of auroral data were analyzed the total amount of individual frames was 2250. The data from these two selected intervals show strict mutual relation of VLF emissions and auroral pulsation. The pulsating phenomena were very dynamic and often had both spatial and temporal variations even during a single pulse.

The results of the analysis for the interval 0131:00–0131:30 UT are shown in Fig. 1. Dynamic spectrum of ELF-VLF emissions in the upper panel show quasi-periodic ELF narrow-band emission between 1.2-1.7 kHz and structured spikes of VLF chorus elements at frequencies around 1.5 to 2.5 kHz with 0.3-0.4 seconds periodicity from 0131:09 to 0131:18 UT. The maximum frequency of VLF chorus constantly rose during the first half of the interval up to 2.5 kHz at 0131:14 UT. After this it decreased roughly with the same rate to about 1.7 kHz at 0131:18 UT.

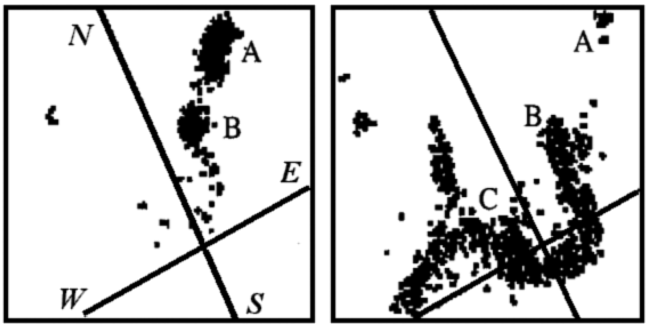

Fig. 2. The spatial distribution of luminosity maximum occurrences: for the first interval left panel); for the second interval (right panel)

Three lower panels show the behavior of auroral luminosity. The dots in the second and third panels in Fig. 1 present the location of the absolute maximum intensity for each TV frame. The luminosity maxima occur in two adjacent regions and the change from one to the other behaves like switching from one region to another. One region, named as "core A", is located at distances 40-50 km from the zenith in geomagnetic N-S and 25-40 km in E-W direction. Another region, named as "core B" was closer to the zenith at the distances 30-35 km in geomagnetic N-S direction and 15-20 km in E-W direction. Both cores have dimension of about 20 km in N-S and 25 km in E-W direction. There is an area between the cores where practically no luminosity maxima occur.

The ELF-VLF emissions appeared when the region of the luminosity maxima shifted closer to the zenith (0131:00, :09, :22 UT) into the core B region and disappeared when the luminosity maximum shifted to the core A region (0131:05, :18, :25 UT).

There were three occurrence of luminosity in the core B (0131:00-:05; 0131:09-:18; 0131:22-:25 UT). The first and the third ones differed by very localized position of the maximum appearance (see the second and the third panels in Fig. 1). Such situation when only the cores were illuminating was connected with occurrences of narrow-band ELF-emissions. The structured VLF emissions during these two intervals were quite weak or absent at all.

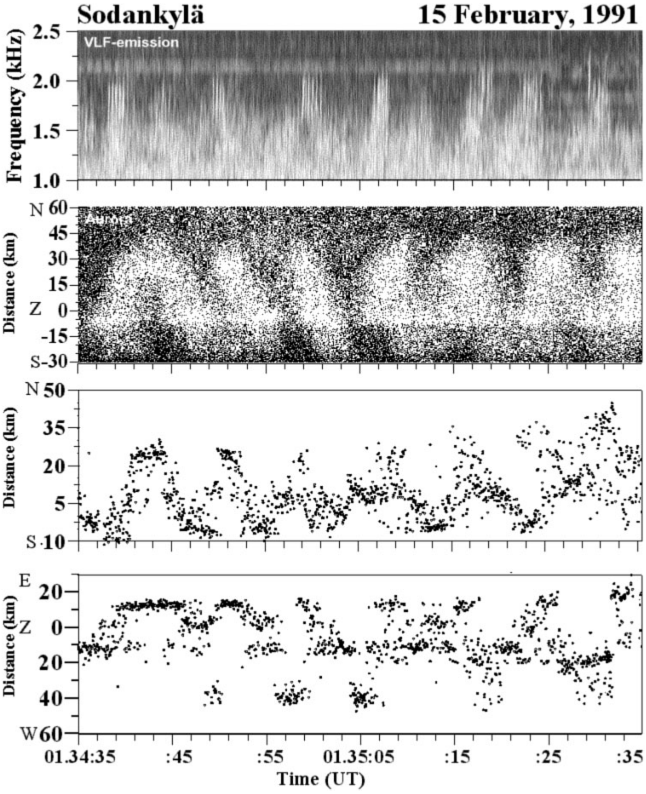

Fig. 3. The results of computer analysis of simultaneous ELFVLF emission and auroral pulsation data. The uppermost panel shows the dynamic spectrum of the lowfrequency emissions. The second panel shows the keogram of auroral pulsations. The consequent locations of luminosity maximum for each TV frame in NS and EW directions are shown in the third panel and the fourth panels, correspondingly.

The core B during the second intensification was also very stable and the most of dots indicating the intensity maxima were located at the same region as in the first and the third intensifications. But in comparison with these two latter ones there were much more occurrences of maxima outside the core B in the second intensification. It says that an envelope of the core B at this instant was not stable. At first the luminosity maxima appeared in south-west direction from the core. At the same time the first discrete VLF emissions appeared starting from the lower ELF range. Then the luminosity maxima moved to the opposite direction and in 2-3 seconds reached the extreme position in north-east sector. The velocity of luminosity expansion was always from 15 to 25 km/s. Simultaneously the frequency of the chorus elements steadily increased up to 0131:14 UT, when the frequency of chorus spike reached 2.5 kHz. VLF chorus elements appeared at intervals of fractions of a second. Then the upper frequency of chorus elements decreased. Simultaneously slight southwestward motion occurred in the location of luminosity maximum.

The fourth panel in Fig. 1 shows the keogram of auroral display made approximately in geographic W-E direction close to the zenith point. We present the keogram to show the behavior of the envelope of the core B, which rapidly propagated at first in geomagnetic westward direction and then back in eastward one, while the core itself, was stable.

The left rectangle in Fig. 2 shows that part of digitized area of TV frame where the maxima of luminosity occurred. The dots present the distribution of the locations of luminosity maximum occurrence for the whole interval. The distribution is divided into two clouds corresponding the cores A and core B. The cores are clearly separated and the boundary between them is located at distance of 35 km from the zenith.

The second analyzed interval is 3 min 35 s later than the first one described above. Phenomena were very variable but certain common and clearly different features can be recognized.

Dynamic spectrum of ELF-VLF emissions is presented in the upper panel of Fig. 3. The interval contained eight very distinct chorus trains in the frequency range 1.7-2.3 kHz. Each of them consisted of 3-6 chorus risers at 0.3-0.4 s intervals. The keogram in the second panel of Fig. 3 shows that the auroral pulsations rapidly propagated during a single luminosity burst. Fig. 3 shows without any doubt excellent relationship between the ELF and VLF waves and optical phenomena. There were eight auroral pulses and corresponding chorus trains within this interval. The cycle duration varies from 7 to 7.5 seconds. The third and fourth panels in Fig. 3 show the N-S and E-W components of auroral luminosity maxima propagation.

The same as in Fig. 2 (left), the dots in Fig. 2 (right) present the distribution of the locations of luminosity maximum occurrence for the whole interval. The core A almost disappeared during the second interval due to drift motion and other activity centers, appeared and became active. Figure 2 (right), shows that the propagation path of the luminosity maxima formed an arc-like pattern. The luminosity propagated along steep curved boundary. The motion of luminous maxima was more complicated than in the previous case and looked more like sweeping of brightness from one extreme position to another rather than switching on and off. One extreme position approximately coincides with core B location from the previous interval. Another extreme position can be considered as a new core C, which seems to be a little wider than the core B. The mean distance of propagation between the cores B and C was about 40-45 km in north-southward direction and about 30 km in east-westward direction. The propagating luminosity moved these distances in a few seconds having mean propagation velocity in the range from 10 to 12 km/s.

During this analyzed interval both cores were located in an area having about 30 km radius. VLF emissions do not coincide with the times when the luminosity is located at the extreme positions, but appear when the luminosity sweeps from the core B to core C. Also other cores appeared occasionally in the northwestward direction at distances more than 35 km, but they did not correlate with ELF-VLF activity.

The following main experimental facts could be emphasized from the data presented for the two intervals:

1) The analyzed period show that the pulsating aurora contained both stable and moving auroral patches with period 7.0-7.5 s and the velocity of the propagation was 10-12 km per second. The propagation took place in the limited region between the cores at about 50 km distance from each other.

2) Trains of structured VLF-risers appeared with the same periodicity as auroral pulsations fairly correlating with them. The propagation of luminosity was associated with VLF-chorus risers (1.7-2.5 kHz). Structured VLF-chorus emissions often started from lower frequency ELF-emissions below 1.7 kHz.

3) The radius of area where pulsations corresponding to the occurrences of VLF-chorus were observed was about 30 km slightly northward from zenith. The other auroral pulsations within the field of view didn't correlate with the VLF emissions.

4) The stable position of luminosity was connected with noise-like ELF-emissions whereas the expansion of luminosity from the cores was related to the appearance of VLF-chorus risers, which started from the ELF frequency range.

The analyzed data show that the pulsating aurora is very closely connected to low-frequency emissions supporting in general the existing theories of cyclotron wave-particle interaction in the magnetosphere as a cause of pulsating auroral phenomena. The most recent reviews of these theories were made by Davidson (1990) and Nemzek et al. (1995). The theory of so called “flowing cyclotron maser” proposed by Trakhtengerts et al. (1985, 1986), Tagirov et al. (1985, 1986), Demekhov and Trakhtengerts (1994) for explaining the quantitative experimental results is more advanced than the previous theories. Tagirov et al. (1999) proposed “feedback” mechanism based of relaxation properties of the ionosphere. It contains inherently assumptions, that the ionosphere is important in formation of auroral pulsations playing a role of external factor, which can modulate the existing precipitating electron flux. The relaxation time of the ionosphere is reflected in the pulsation periods and the slowly changing part of the auroral dynamics.

Most theories of pulsating auroras have so far dealt with the pulsation period and little attention has been given to motional features. These features are, however, closely related with the appearance of structured ELF-VLF emissions. This relation imposes strong restrictions on theoretical models for causing pulsations and can be used to test theories proposed so far.

2 Auroral torch (omega) structures: results of optical observations

Auroral torch structures represent large-scale undulations on the poleward boundary of the diffuse auroral zone in the morning sector. Their images on the all-sky camera pictures and on the DMSP-2 satellite photographs were presented by Akasofu (1974). Several torches may exist simultaneously. Dark holes between torches are usually called omega bands. Torches drift eastward with a velocity of several hundreds meters per second. During their motion they usually retain their shapes for several tens of minutes.

Gustafsson et al. (1981) proposed model explaining the connection between omega bands and Ps6 explaining them by eastward drifting ionospheric Hall current vortices associated with alternatively changing field-aligned currents. Andre and Baumjohann (1982), Opgenoorth et al. (1983), and Wild et al. (2000) showed that upward FACs were located in the torch structures and downward ones in the dark holes.

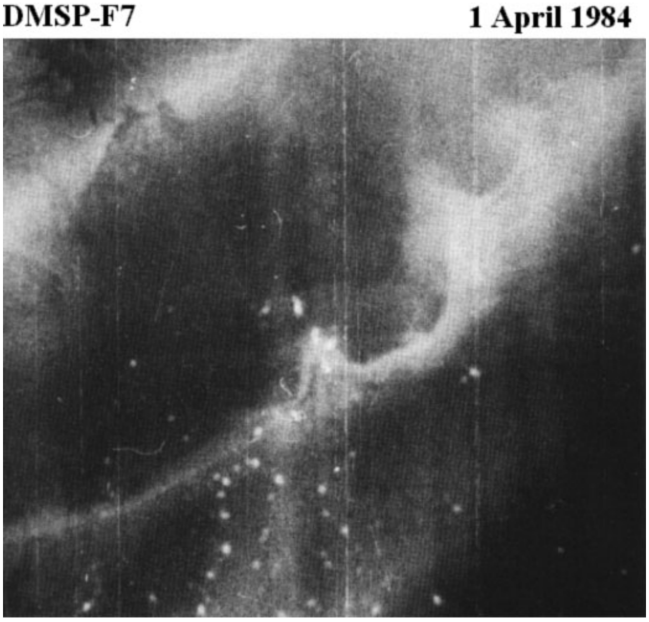

Fig. 4. Picture of the auroral display made from DMSP-F7 satellite on 1 April 1984. A train of torch structures is seen in the middle of the picture. The one in the center is located just above Apatity (Kola Peninsula). North is at the top of the picture.

The results of optical observations of a torch structure on 1-2 April 1984 are given in this section. It was one of the group, which consisted of at least four torches and which is shown in Fig. 4 where the DMSP-F7 picture of the whole auroral pattern is presented. The torch under consideration is in the center of the picture. The development of the torch took place long before its appearance in the zenith of Apatity. It moved from the west with a constant velocity of ∼350 m/s. All-sky images of the torch at the time when it was seen close to the meridians of Kiruna (68.8 °N, 20.4°E), Sodankylä (67.36°N, 26.63°E), Loparskaya (68.62 °N, 33.3°E) and Apatity (67.55°N, 33.34°E), are shown in Fig. 5, correspondingly. Hence one can propose that the whole auroral pattern moved in the same way with the same velocity.

The case of a group of torches, which appeared on 21-22 October 1979 above the Kola Peninsula, was chosen for study. In the sketches of all-sky films from Loparskaya (Fig. 6, upper panel) the passage of five torches is shown; they crossed the zenith one after another, appearing at the western horizon and disappearing behind the eastern one. The torches generally retained their shapes.

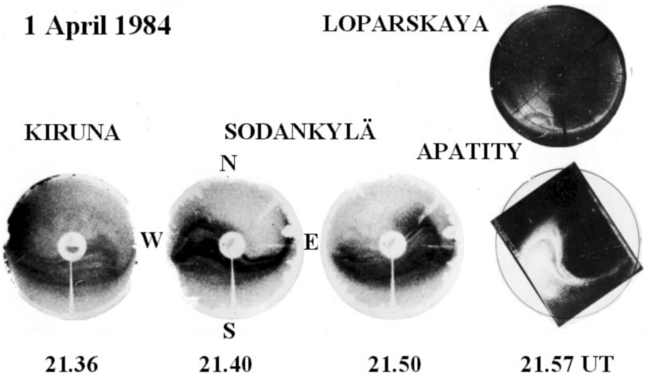

Fig. 5. All-sky images of the same torch drifting east-ward made at different meridians. The images from Loparskaya and Apatity were taken at approximately the same time as the picture in Fig.4.

Recordings of narrow angle photometers (with a 5 ° field of view) are shown under the all-sky films in Fig. 6. Each increase of intensity corresponds to the passage of the torch. It is seen that inside almost every one there are pulsations of luminosity with periods of 5-15 s. As it was shown by Oguti et al. (1981), Yamamoto (1988), and Tagirov (1988, 1993) it is quite usual for auroral torches. Using low-light level TV techniques they found that the torches might have a spatial structure consisting of non-pulsating periphery and a pulsating core. Patches inside the core represent striations of luminosity along the inner boundary of the stable diffuse band, never penetrating through it. The velocity of the luminosity propagation was several tens of kilometers per second.

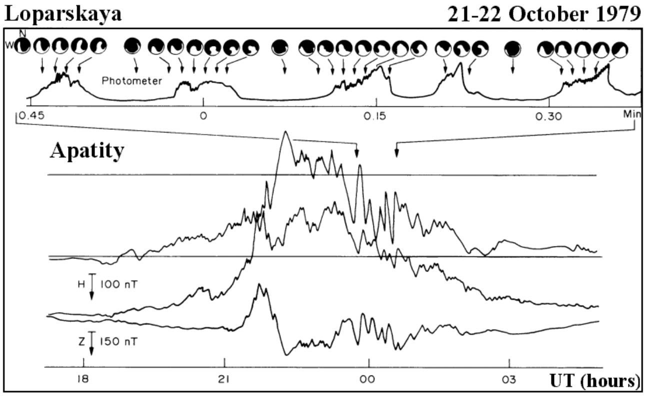

Fig. 6. Eastward drift of five torch structures above Loparskaya (upper panel), photomet-ric recordings in lower panel. Magnetograms with Ps6 pulsations are in the bottom panel (shown by arrows).

Standard magnetograms in the lower panel of Fig. 6 illustrate the well-known connection of the Ps6 geomagnetic pulsations with the torch structures (Baumjohann, 1979; Opgenoorth et al., 1983; Tagirov, 1988, 1993). The correspondence is very good in this case, showing a peak-to-peak correlation between the five torches and also five variations of the magnetic field; these are most intense in the D-component, a characteristic feature of Ps6 pulsations (Saito, 1978).

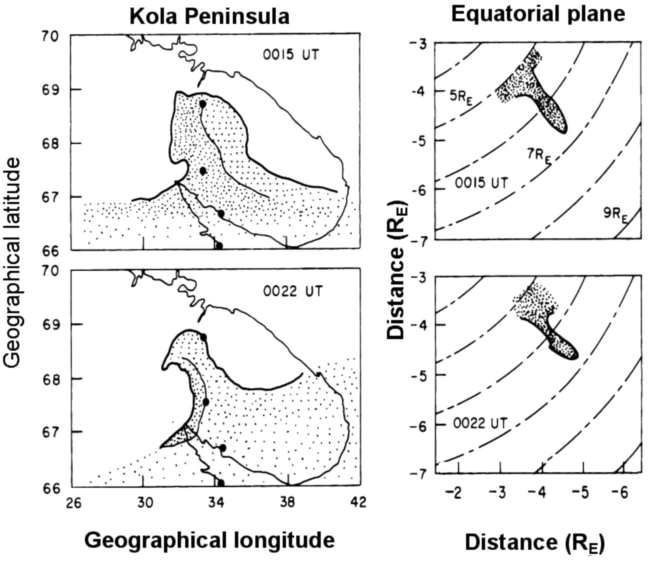

Fig. 7. The shapes of the torches on the map of Kola Peninsula (left side) and their projections into the equatorial plane of the magnetosphere made using the Tsyganenko (1989) model (right side).

Tagirov and Mal'kov (1991) have chosen this case for mapping into magnetospheric equatorial plane using Tsyganenko (1989) model. The shapes of the torches on the background of the Kola Peninsula coastline are shown on the left side of Fig. 7, and corresponding projections into the magnetosphere are shown on the right side. The figure shows that the foot of each torch was located at distance ∼5.5 R_E, while their lengths exceeded ∼1 R_E. This result was confirmed later by satellite measurements (Jorgensen et al., 1999).

1) The results of field-aligned mapping of the torch structures into the magnetospheric equatorial plane showed that the mechanism of torch generation was located quite close to the Earth at distances 5-10 R_E.

2) The spatial structure of torches often has a peculiarity consisting in a non-pulsating periphery band and a pulsating core.

3 Dayside aurora during strong northward IMF

There have been occasional reports of auroral events occurring during periods of strongly northward IMF orientation (Sandholt et al., 1996; Milan et al., 2000).

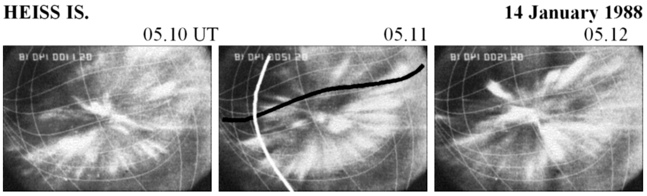

Fig. 8. The sequence of images of the auroral forms made at 1-min interval observed by TV camera located in Heiss Island (Franz-Joseph Land).

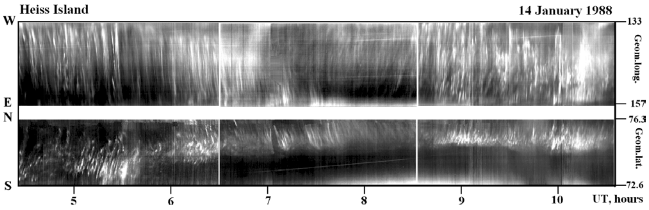

Fig. 9. The upper panel shows the dynamics and drift motion of auroral forms along geomagnetic parallel marked by black line in Fig. 8. The second panel shows the same but for geomagnetic meridian marked by white line.

Continuos high-time-resolution dayside auroral observations of more than 100 transient optical events were available throughout the interval from 0417 to 1030 UT (0922 to 1535 MLT) on January 14, 1988 from an all-sky TV camera with fish-eye lens located on Heiss Island in Franz-Joseph Land (Tagirov et al., 2000), located at 80.55 °N and 58.00°E, geographic (75.05° mag. lat. and 145.00° mag. long.).

IMP-8 observations indicated an exceptionally strong northward IMF Bz component (>18 nT) throughout this interval, Bx component was also positive, IMF By rotated from duskward to dawnward at 0830 UT which is by about 1.5 h after Heiss Island passed the local magnetic noon. The time interval of auroral observations at Heiss Island coincided with the initial phase of the interaction of the magnetic cloud with the magnetosphere, which encountered the magnetosphere at about 0450 UT 14 January 1988 (Farrugia et al., 1994).

The IMF in all components and solar wind data showed intense variations during the interval from 0504 to 0520 UT. The most dynamic corona-like auroral forms were observed several minutes later at about 0508-0527 UT. Figure 8 shows a sequence of auroral images extracted from the TV camera observations at 1-min intervals. The thin lines in the pictures show the calculated geomagnetic grid at an altitude of 140 km. In order to study temporal variations of value and direction of velocity of auroral forms motion the auroral dynamics was presented in the form of keograms. The lines on the images represent geomagnetic coordinate grid corresponding to the height level 140 km. Two keograms from the set of 12 keograms were chosen for demonstration as most representative (Fig. 9). The upper and lower panels in Fig. 9 show the keograms of auroral motion along geomagnetic parallel and meridian indicated by thick black and white lines in the second TV frame in Fig. 8.

Using the whole set of keograms the authors constructed a polar plot showing the directions of auroral forms motion as a function of geomagnetic latitude and magnetic local time. It is shown in Fig. 10. Velocity vectors of auroral forms are shown by lines in the direction of motion. The polar plot strongly suggests that the auroral motion followed a two-cell "reverse" convection pattern with sunward flow over the pole, as expected during periods of strongly northward IMF.

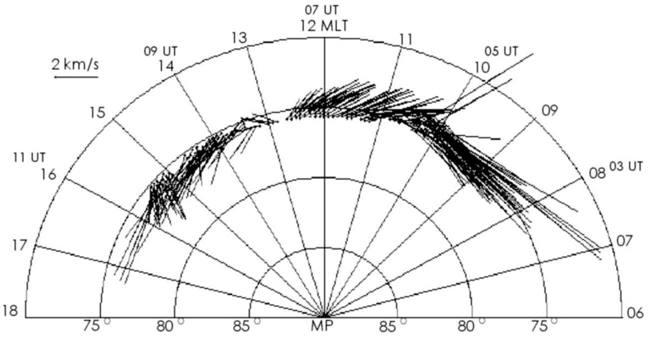

Fig. 10. Polar plot showing the directions of motion of auroral forms as a function of geomagnetic latitude and MLT.

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