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CONJUGACY OF ELECTRON AURORAS OBSERVED BY ALL-SKY CAMERAS AND SCANNING PHOTOMETERS

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Abstract: Simultaneous auroral observations were carried out at the Syowa–Husafell conjugate pair of stations ($L=6.1$) in the period of August 28–September 30, 1984. During the period of the campaign, conjugate auroral data were obtained on 4 nights of clear sky in the conjugate regions. In this paper, we show some initial results on the geomagnetic conjugacy of visible auroras observed by 5577 Å scanning photometers and all-sky cameras in the selected event study of September 26, 1984.

The characteristics of the conjugacy of visible auroras are as follows, 1) Auroral breakups occur almost simultaneously in the northern and southern hemispheres. However, the poleward expansion speed is much larger at Syowa than at Husafell, 2) The east-west (EW) aligned auroral arcs appear at almost the same geomagnetic latitude in the IGRF model in both hemispheres. However, the EW-aligned auroras observed at Husafell show a large longitudinal displacement (more than 300 km westward) relative to those observed at Syowa, 3) Isolated north-south aligned auroras show a good conjugacy in their shapes and locations, 4) The EW-aligned auroras generally show different movements and fine structures in both hemispheres.

1. Introduction

Ground foot points at each end of a geomagnetic field line in the northern and southern hemispheres are defined as geomagnetically conjugate points. Observations of conjugacy and non-conjugacy of auroral phenomena give us useful information on the acceleration mechanisms of auroral particles and the generation and propagation mechanisms of ULF, ELF and VLF waves. However, there are few conjugate pairs of observatories in the northern and the southern polar regions. Fortunately the conjugate point of Syowa Station is located near Husafell in Iceland. The National Institute of Polar Research (NIPR) carried out its first conjugate campaign at Husafell and Syowa under the International Magnetospheric Study (IMS) program in 1977 and 1978. Nevertheless, the period of this campaign was limited to the northern summer and autumn seasons from July to September. Observations throughout a year at conjugate regions are important for understanding the role of the ionosphere in the acceleration of auroral particles and in the generation and propagation of ULF-VLF waves since the electron density of the ionosphere varies greatly from summer to winter in both hemispheres. It is also important to observe auroras and related phenomena at multi-stations around conjugate points in order to study the motion of auroras and the propagation of waves. Therefore, a second conjugate campaign was planned by NIPR on an enlarged scale.

The campaign takes advantage of the geographical condition that the conjugate points of Syowa, Mizuho and Molodezhnaya Stations in Antarctica are located in the vicinity of Husafell, Isafjördur and Tjörnes in Iceland. From the data recorded at three pairs of conjugate stations, *i.e.*, Syowa–Husafell, Mizuho–Isafjördur and Molodezhnaya–Tjörnes, we aim at the understanding of temporal and spatial variations in the conjugacy of auroras and wave phenomena associated with auroral particle precipitation. We shall be studying auroral particle acceleration processes in the ionosphere-magnetosphere energy coupling system and also the generation and propagation mechanisms of ULF, ELF and VLF plasma waves.

In this paper we briefly report the geophysical context of the conjugate observatories and data acquisition systems, and then examine the conjugacy of visual auroras, using the data from all-sky cameras and scanning photometers at Syowa and Husafell on September 26, 1984.

2. Geophysical Values at the Observatories

Table 1 gives the geographic and geomagnetic coordinates of the stations calculated by the IGRF model dated January 1, 1985. Magnetic local time is found by adding universal time (UT) to the time listed in the column. It is evident that the conjugate points of Syowa, Mizuho and Molodezhnaya Stations in Antarctica are located in the vicinity of Husafell, Isafjördur and Tjörnes in Iceland, respectively. Details of the method of calculating the geomagnetic coordinates are reported by ONO (1987, in this issue). In this paper, we mostly discuss auroras using data from the Syowa–Husafell conjugate-pair of stations. Table 2 gives the geophysical context of both stations calculated by the IGRF model dated September 26, 1984. By a "conjugate point" in Table 2 we mean the calculated geographic coordinates of the point where a field line, starting from an altitude of 110 km directly above the station, reaches the same level in the opposite hemisphere. The position is derived from the IGRF

Table 1. Geographic and geomagnetic coordinates of the stations, calculated by the IGRF model for January 1, 1985. Magnetic local time (MLT) is given by adding universal time (UT) to the time listed in the column.

Station	Geographic		Magnetic dipole		Invariant (geomagnetic)			
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	MLT (HH:MM)	*L*-value
Antarctica								
Syowa Station	69.00S	39.58E	−70.0	80.81	66.22	71.42	00:10	6.15
Mizuho Station	70.70S	44.43E	−72.34	82.27	68.09	71.68	00:11	7.18
Molodezhnaya	67.67S	45.85E	−70.04	88.66	66.61	77.61	00:35	6.35
Iceland								
Leirvogur	64.18N	21.70W	69.58	71.78	65.50	68.44	23:58	5.82
Husafell	64.67N	21.03W	69.90	73.17	65.88	69.39	00:02	5.99
Isafjördur	66.08N	23.13W	71.56	72.64	67.66	68.83	00:00	6.92
Tjörnes	66.20N	17.12W	70.50	79.52	66.81	73.79	00:20	6.45

Table 2. Geographic and geomagnetic values at the conjugate-pair stations of Syowa, Antarctica and Husafell, Iceland at 2100 UT on September 26, 1984.

	Syowa Station	Husafell
Geographic latitude	−69.00°	64.67°
Geographic longitude	39.58°	338.97°
Geomagnetic latitude (Invariant)	−66.21°	65.88°
Geomagnetic longitude	71.42°	69.39°
L-value	6.15	5.99
MLT (HH:MM)	21:11	21:03
Total magnetic field	44392 nT	52152 nT
Inclination	−64.72°	75.93°
Declination	313.52°	337.95°
H component	18959 nT	12677 nT
Z component	−40139 nT	50587 nT
*Conjugate point	65.39°, 340.89°	−69.18°, 36.67°

* Conjugate point at 110 km altitude from the zenith.

model for 2100 UT on September 26, 1984. From this model, the conjugate points of Syowa at 110 km altitude deviates approximately 77 km to the north and 88 km to the east from Husafell. The appreciable differences of total intensity and dip angles of the geomagnetic field at each station may have some affect on particle precipitation and wave propagation (STENBAEK-NIELSEN *et al.*, 1973; SATO *et al.*, 1980; SUZUKI and SATO, 1987). The geomagnetic local time (MLT) at both stations is almost equal to universal time (UT) (within 10 min), while the geographic local time at Syowa (UT+3 h) is about 4 h ahead of that at Husafell (UT−1 h). This difference in geographic local time may also control some conjugate phenomena (SATO *et al.*, 1987; SUZUKI and SATO, 1987).

3. Data Acquisition System

At Syowa Station a monitoring system for the systematic measurement of upper atmosphere phenomena and for digital recording on computer tapes in real time has been in operation continuously since 1981 (SATO *et al.*, 1984a). The system installed in Iceland was designed to be compatible to the one at Syowa in regard to the recording format of the data. A part of the system was installed at Husafell in the summer of 1983. The remainder of the system comprising three stations in Iceland was constructed in the summer of 1984. All of the facilities except for auroral equipment have been operated throughout a year by the Icelandic research partners. The observation equipment at the three stations are fluxgate magnetometers, search coil magnetometers, cosmic noise absorption detectors, ELF-VLF natural wave receivers, and fixed-direction photometers. Extra instruments such as scanning photometers, all-sky cameras and auroral TV cameras were installed at Husafell. The data are recorded on analog recorders and digital tapes with a sampling frequency of 0.5 Hz. A block diagram of the observation system at Husafell is shown in Fig. 1. Details of the specifications and facilities have been described by SATO *et al.* (1984b). In the conjugate auroral campaign period at Syowa Station in Antarctica and Husafell in Iceland starting from 1984, all-sky auroral TV cameras, all-sky cameras, fixed three-

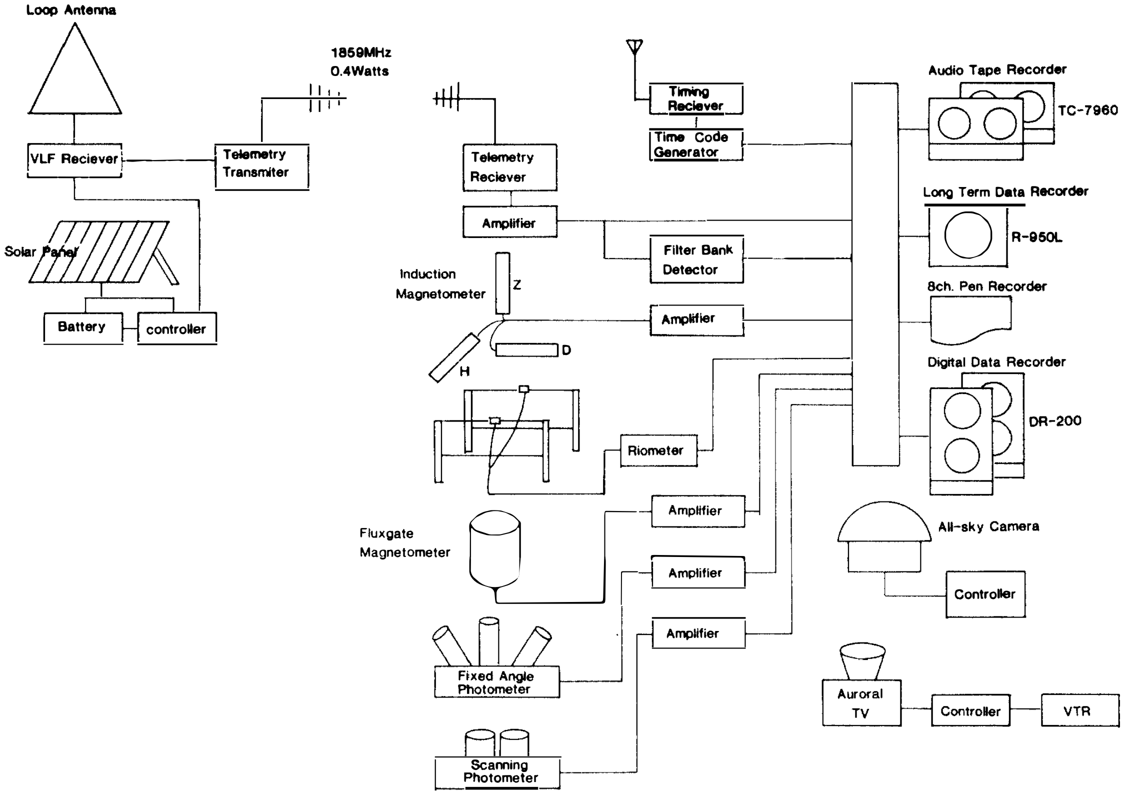

Fig. 1. A block diagram of the observation system at Husafell. The all-sky TV cameras, scanning and fixed direction photometers were set up in 1984; other equipment had been constructed in 1983.

direction photometers and meridian scanning photometers (5577 Å and Hβ) were installed at both stations. The aperture ratio of the fish-eye lenses of the all-sky cameras installed at Syowa and Husafell are F/1.4 and F/2.8, respectively. The all-sky cameras were operating with exposure times of 7 and 15 s at Syowa and Husafell, respectively, throughout the conjugate campaign period. The signals of meridian scanning photometers which scan in the geomagnetically north-south meridian were recorded on digital magnetic tapes at the two stations. The digital data from the scanning photometers are processed and plotted to give iso-intensity contour lines or gray scales of auroral luminosity along a geomagnetic meridian as a function of time using a HITAC M-180 computer system installed at the National Institute of Polar Research.

4. Conjugacy of Visual Auroras

It has long been accepted that auroral particles precipitate along a geomagnetic field line. As early as the last century, auroral researchers speculated about simultaneous occurrences of identical auroras at geomagnetically conjugate stations as reported by WESCOTT (1966). On the basis of the IGY all-sky camera data in conjugate areas, DEWITT (1962) found that auroras show striking similarities in form and motion in both hemispheres. After this study, BELON *et al.* (1969), DAVIS *et al.* (1971), STEN-

BAEK-NIELSEN *et al.* (1972), and MAKITA *et al.* (1981) found that the conjugate auroras appeared at different positions from the conjugate point calculated from a geomagnetic field model. They also noted that the characteristics of auroras such as shapes and motions are not always the same in the conjugate regions. STENBAEK-NIELSEN *et al.* (1973) found differences of auroral intensities in the two hemispheres, and they explained them as a result of differences of mirror heights along an L shell. In this paper we examine the conjugacy of visual auroras as observed by the all-sky cameras and scanning photometers at Syowa and Husafell.

Case study of the September 26, 1984 event

In the 1984 conjugate campaign, simultaneous observations of auroras were carried out at Syowa and Husafell in the period of August 28–September 30, 1984. Throughout the whole observation period, the September 26 event was the best one with regard to meteorological and moonlight conditions. Some initial results for the September 26 event on the conjugacy of visual auroras and related phenomena are discussed in this paper.

Figure 2 shows magnetic variations of the H and D components, magnetic pulsations of the H component, cosmic noise absorption at 30 MHz (downward direction corresponds to an increase of the absorption intensity), and VLF emission intensities at 4 kHz observed simultaneously at Syowa in Antarctica, Husafell, Isafjördur and Tjörnes in Iceland during the period 2100–2400 UT on September 26, 1984. The bottom panel of Fig. 2 shows scanning photometer data of 5577 Å auroras along a geomagnetic meridian as a function of time. The ordinate in this figure does not refer to geomagnetic latitude, but refers instead to the view angle from the zenith at the observatory. The gray scales are proportional to the emission intensity. The scanning period from the poleward horizon to the equatorward horizon is 30 s at both stations. The auroral luminosity increased at 2205 UT and the activity continued till the dawn of September 27. After 2310 UT pulsating auroras were observed at both stations (FUJII *et al.*, 1987a). In the following discussion of the location of auroras using the conjugate data of scanning photometers and all-sky cameras, the emission altitudes of auroras are assumed to be 110 km. The Kp index during the period was 3. The conjugacy of proton auroras during this period was reported by SATO *et al.* (1986).

Figure 3 shows a time expanded display from the scanning photometers of 5577 Å auroras observed at Syowa and Husafell during the period 2200–2300 UT on September 26. In this figure we can easily compare the dynamics of auroral activity in space and time. A small auroral breakup occurred at 2205 UT and 2213 UT at the two stations. It is noticeable that the auroras observed at Syowa appeared further towards the equator than those observed at Husafell during 2205–2218 UT in these auroral diagrams. This displacement of auroras between the two stations is approximately 60–100 km in the geomagnetic meridian plane. In comparison to the expected location of conjugate points at Syowa and Husafell as listed in Table 2, this apparent displacement of auroras corresponds to the latitudinal difference of the conjugate points, because the auroral behavior during 2205–2218 UT shows good similarity in the geomagnetically north-south direction. It is worth noting that the auroras ob-

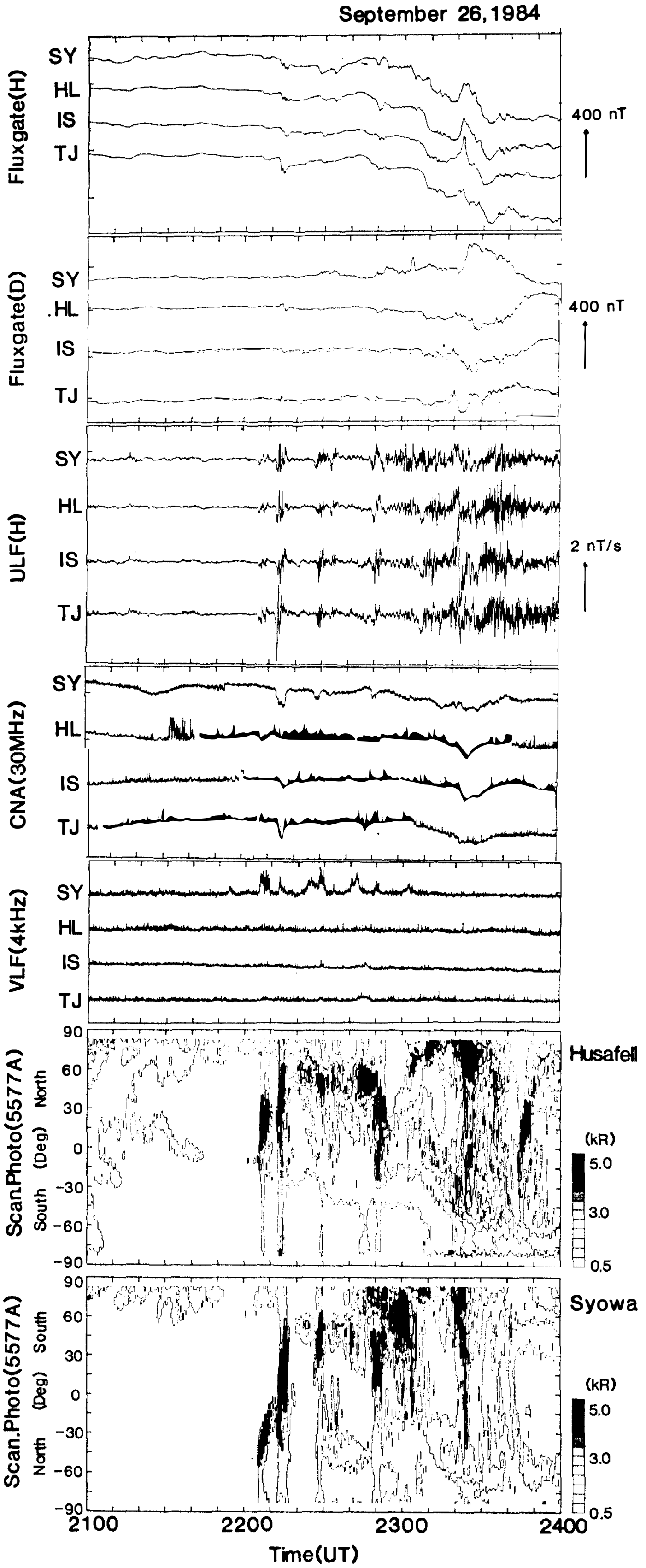

Fig. 2. Magnetic variations of the H and D components, magnetic pulsations of the H component, cosmic noise absorption at 30 MHz, and VLF emission intensities at 4 kHz observed simultaneously at Syowa, Husafell, Isafjördur and Tjörnes in the period 2100–2400 UT on September 26, 1984. Scanning photometer data of 5577 Å aurora observed at Husafell and Syowa are also shown in the bottom panel.

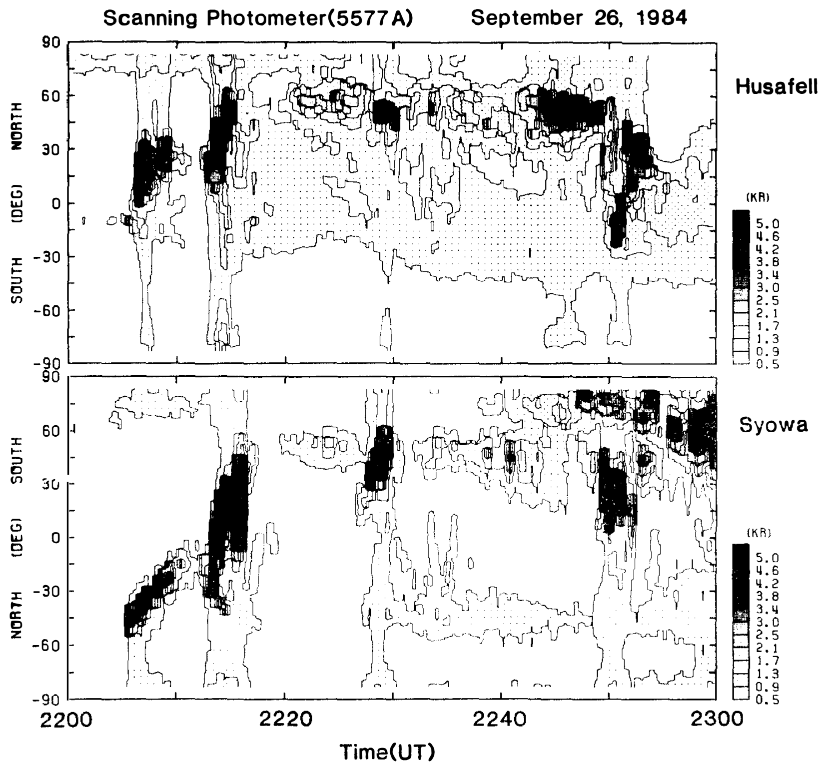

Fig. 3. The time-expanded scanning photometer display for 5577 Å emission observed during the period of 2200–2300 UT on September 26, 1984.

served at Syowa expanded poleward with time from 50° north to 15° north of the zenith during the period 2205–2210 UT, while such a movement is small at Husafell in this figure. The difference in poleward expansion speed at conjugate stations is also confirmed by the data from the all-sky cameras (*cf.* Fig. 4) and the TV cameras (FUJII *et al.*, 1987b, in this issue).

While the scanning photometer data may be good for providing an overall picture of the average auroral activity and brightness, it is the all-sky data from which conjugacy of auroral forms is derived. Figure 4 shows the all-sky camera data obtained at both stations during 2205–2210 UT. The exposure time in these pictures is 7 s at Syowa and 15 s at Husafell. At a first glance at these pictures, it is difficult to find a one-to-one correspondence in the shapes of auroras observed in the two hemispheres. The auroral pictures from the two stations will now be compared in detail. A faint aurora an east-west (EW) direction appeared at both stations at 2205 UT. It is clear in the small-scale structures within the arcs that rayed-structure aurora appeared only at Syowa (details are reported by FUJII *et al.*, 1987b). At 2206 UT, the EW arc expanded in length to extend all the way from the eastern horizon to the western horizon at Syowa. However, at Husafell the arc did not expand in an eastward direction. It is noticeable that the geomagnetic conjugate point of Syowa deviates approximately 88 km to the east from Husafell as shown in Table 2. Hence, the conjugate auroras show a large longitudinal displacement (more than 300 km) relative to the IGRF magnetic field model. Detailed descriptions of the longitudinal displacement observed by TV cameras are reported by FUJII *et al.* (1987b). The enhanced region of the au-

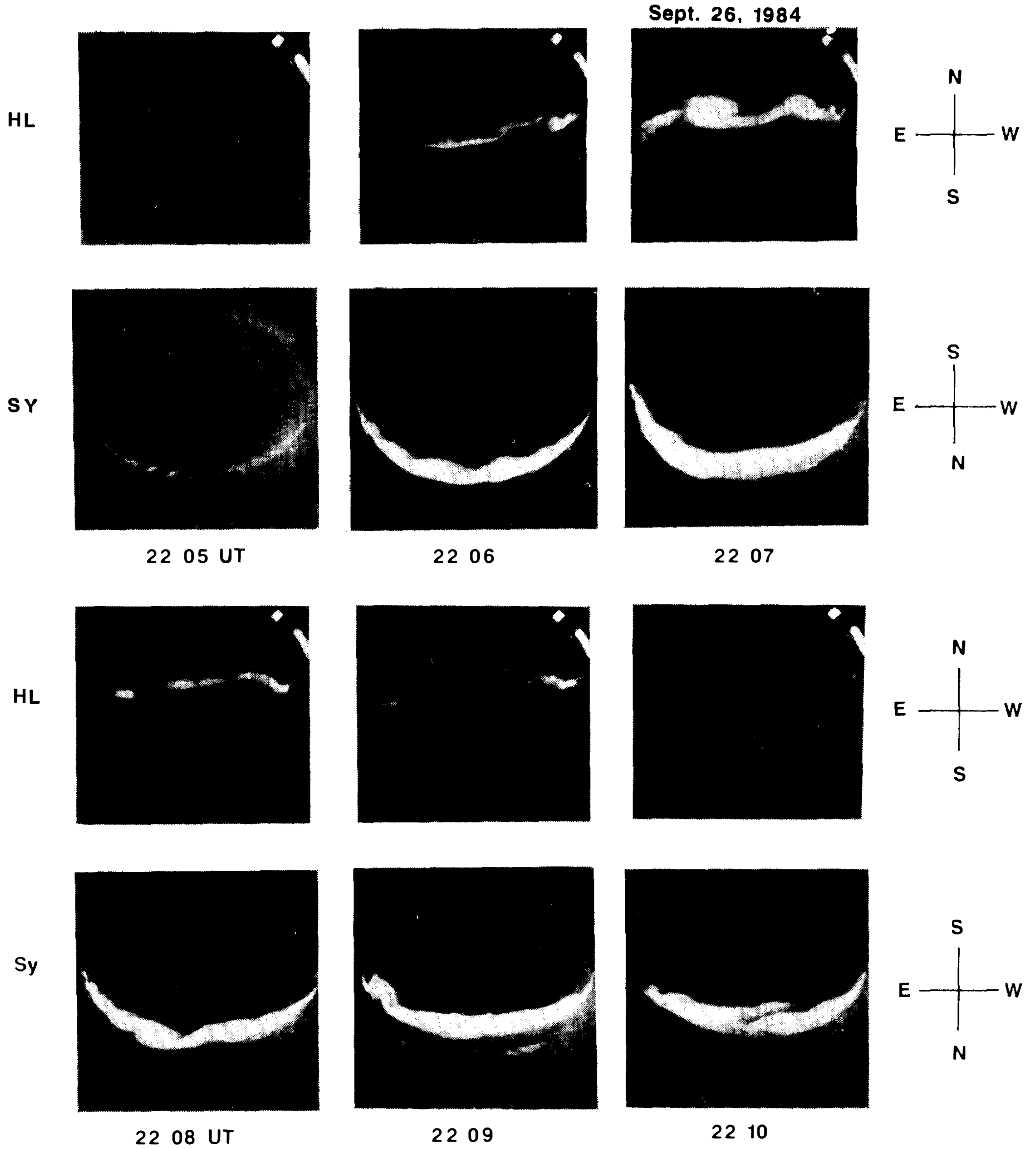

Fig. 4. All-sky camera data at Syowa Station and at Husafell on September 26, 1984. The exposure time and aperture ratio of the fish-eye lens are 7 s and F/1.4 at Syowa and 15 s and F/2.8 at Husafell, respectively.

rora at Husafell reached the eastern horizon at 2207 UT. The small-scale structure of auroras still failed to show conjugacy, in that a vortex-structure appeared only at Husafell. The brightness of auroras became weak from 2208 to 2210 UT at Husafell, though the decrease in brightness was not so steep at Syowa. Furthermore, rayed-structure auroras were observed only at Syowa. Details of the rapid movements of the auroral breakup event (2205–2207 UT) observed by TV cameras are reported by FUJII *et al.* (1987b).

The second auroral breakup occurred at 2213 UT as shown in Figs. 2 and 3. In order to study the auroral structure at both stations, all-sky camera pictures taken at 2212–2214 UT are shown in Fig. 5. At 2212 UT, the brightness of auroras started to increase at the eastern and western edge as seen from Syowa, though there were no auroras at Husafell. The auroras suddenly intensified all over the sky at 2213 UT at both stations. At 2214 UT, multiple arcs were observed at both stations, though the brightness of the auroras were different at the two stations.

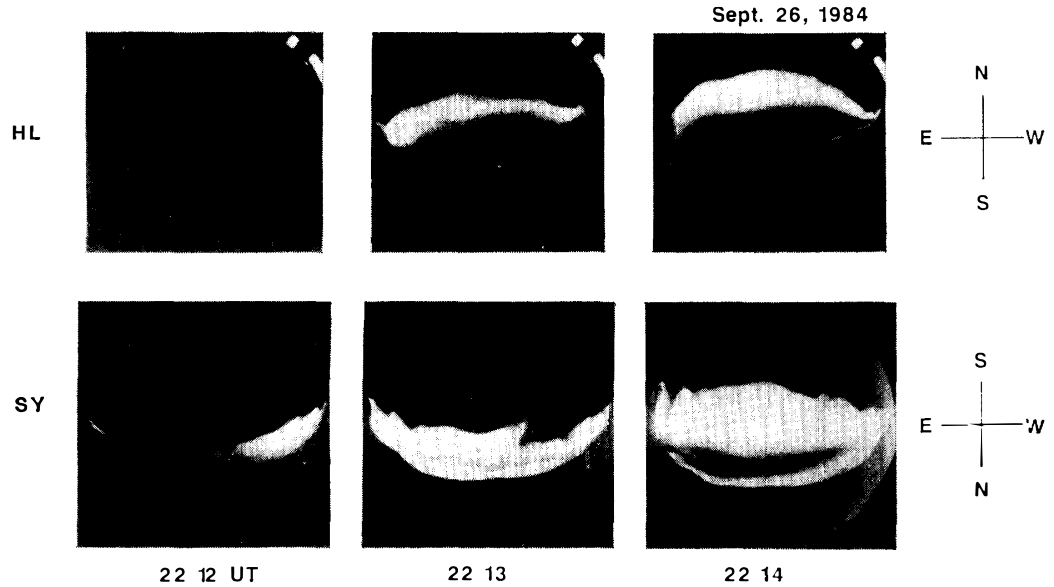

Fig. 5. The same as Fig. 4 except for the period of 2212–2214 UT on September 26, 1984.

It is worth noting the relation between cosmic noise absorption and visible auroras in the two hemispheres. During the time interval 2213–2214 UT, the active auroras were observed in the zenith at Syowa and on the poleward side of Husafell, *i.e.*, near the zenith of the Isafjördur and Tjörnes stations. Corresponding to the location of bright auroras, cosmic noise absorption was observed at Syowa, Isafjördur and Tjörnes, but was very weak at Husafell during the time interval 2210–2217 UT as shown in Fig. 2. The strong asymmetry of auroral enhancements in the two hemispheres is seen during the period 2245–2300 UT in Fig. 3. An enhancement of auroral luminosity in a direction of 45°–60° towards the pole was observed only at Husafell during 2245–2249 UT, while such asymmetric enhancements were observed only at Syowa during 2255–2304 UT (*cf.* Fig. 8). Figures 6 and 7 show examples of all-sky camera data from 2227 to 2232 UT and 2245–2252 UT. It is also difficult to point out a one-to-one correspondence in the conjugacy of auroral shapes.

Figure 8 shows time-expanded displays for the period 2300–2400 UT. Enhancements of auroral luminosity occurred at both stations during 2320–2323 UT. After the enhancements, auroras of the pulsating type were observed continuously till dawn. Details of the conjugacy of pulsating aurora observed by TV cameras in the interval 2338–2347 UT are reported by FUJII *et al.* (1987a). It is noticeable that the boundary of auroral luminosity nearish to the equator shifted towards the quator in both hemispheres from 2305 UT. The boundary observed at Syowa is located at a lower latitude than that observed at Husafell. However, the difference of location of the auroral boundary corresponds to the difference in conjugacy of the two stations as calculated by IGRF model.

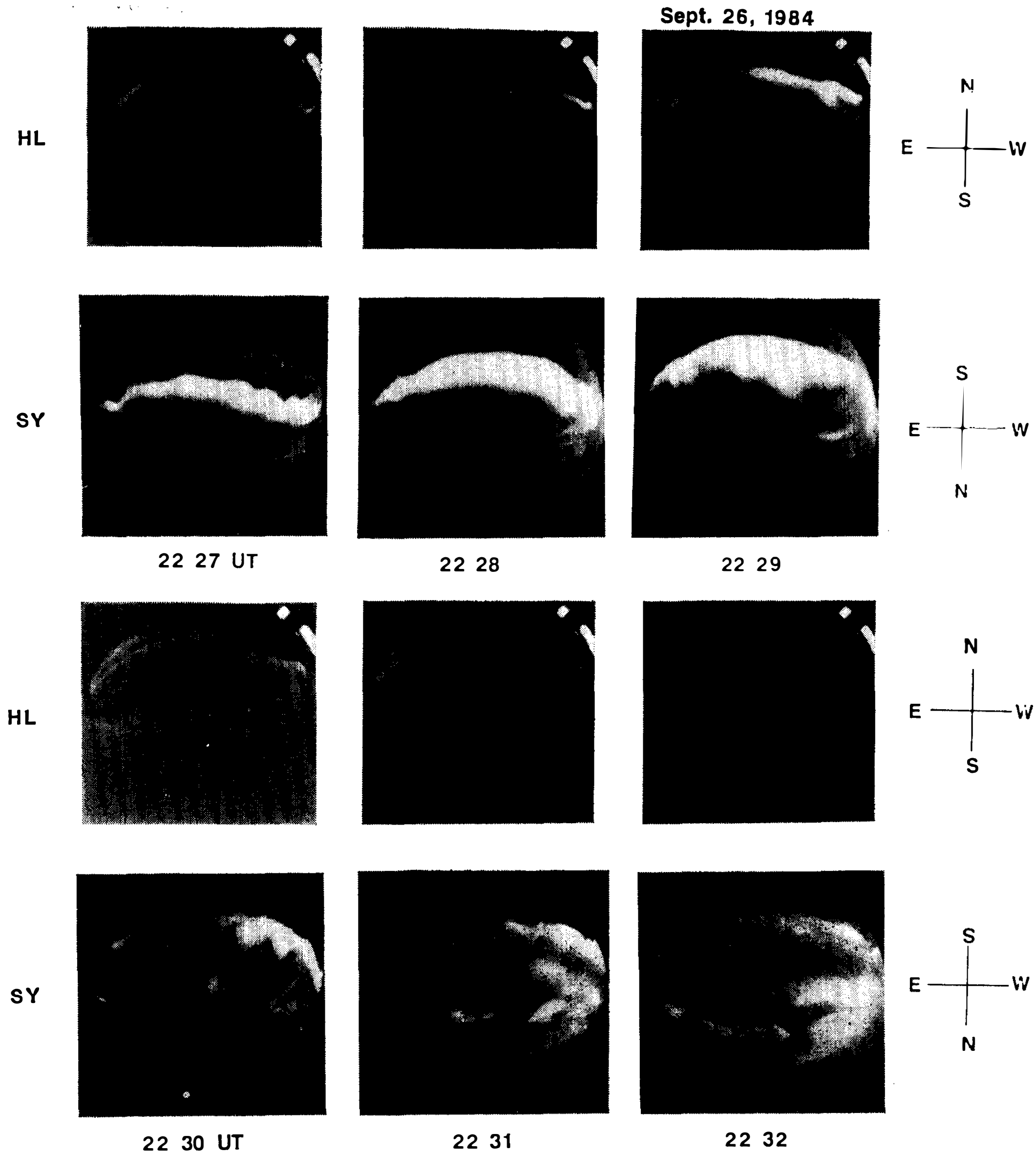

Fig. 6. The same as Fig. 4 except for the period of 2227–2232 UT on September 26, 1984.

A large asymmetry of auroral enhancements at the conjugate stations appeared in the scanning photometer data from 2345 to 2350 UT. Figure 9 shows all-sky camera data from 2343 to 2345 UT. It is noticeable that the auroras were enhanced along the geomagnetic meridian (NS-aligned auroral arcs) near the zenith of the two stations and showed a good similarity in shape. The arcs moved westward with time. The reason for the strong asymmetry in the meridian scanning photometer data is that the NS-aligned arc first appeared towards the east and then moved westward, crossing the zenith at Husafell. At Syowa on the other hand, the arc appeared to the west of the zenith and moved westward. So the arc did not cross over the zenith at Syowa. In this event it is found from all-sky camera data that the NS-aligned arc had almost the same shape at the two conjugate stations. The relative displacement of the NS-aligned arcs in the two hemispheres is such that the auroras at Husafell deviate ap-

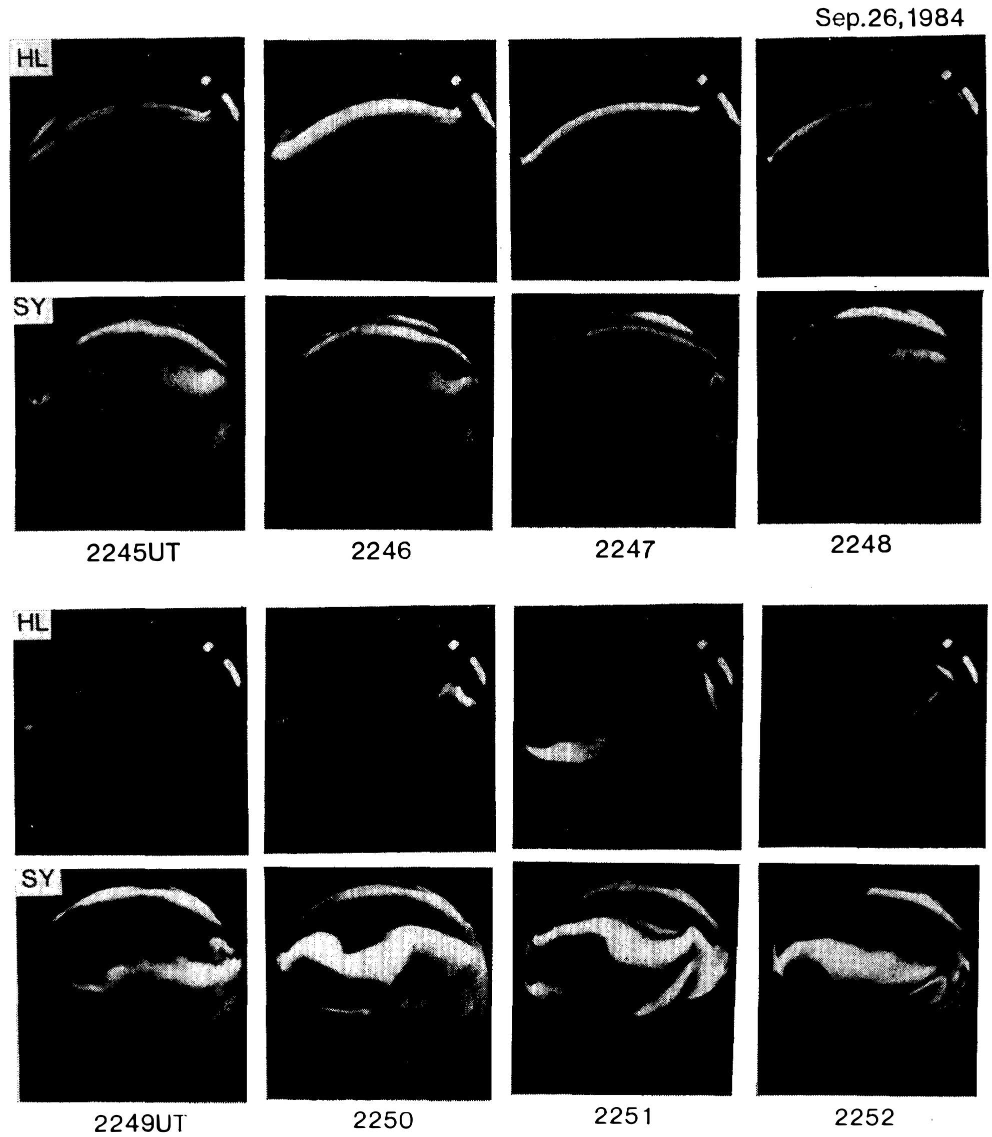

Fig. 7. The same as Fig. 4 except for the period of 2245–2252 UT on September 26, 1984.

proximately 40–60 km to the north and 50–70 km to the east from those observed at Syowa. This displacement of the conjugate aurora corresponds rather closely to the deviation of the conjugate points of Syowa and Husafell as calculated by the IGRF model. In other words, the NS-aligned aurora actually shows good geomagnetic conjugacy.

5. Summary and Discussion

From the scanning photometer and all-sky camera data obtained simultaneously at the two geomagnetically conjugate stations on September 26, 1984, the following characteristics are found.

(1) Auroral breakups occurred almost simultaneously in both hemispheres. The east-west (EW) aligned auroral arcs in the two hemispheres appeared close to the geomagnetic latitudes predicted by the IGRF model is referred.

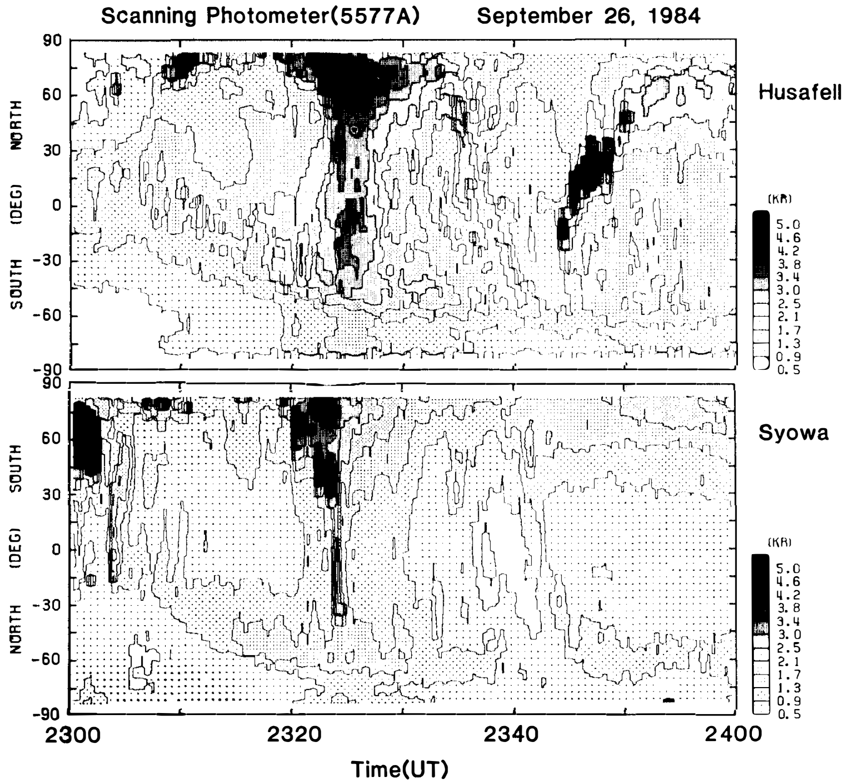

Fig. 8. The same as Fig. 3 except for the period of 2300–2400 UT on September 26, 1984.

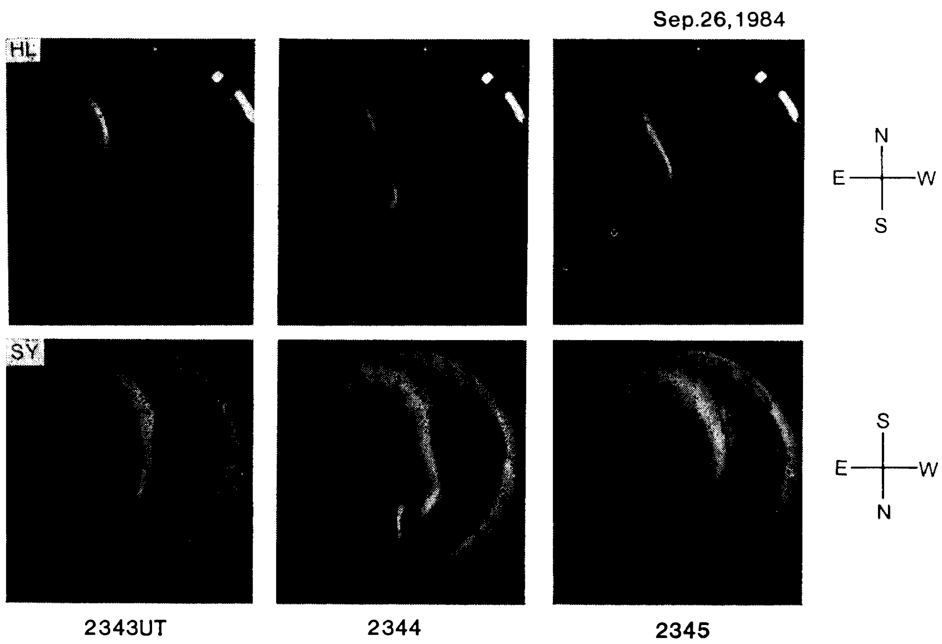

Fig. 9. The same as Fig. 4 except for the period of 2343–2345 UT on September 26, 1984.

(2) Isolated north-south (NS) aligned auroras appeared with very similar structure in both hemispheres, and showed good conjugacy according to the IGRF model in both the latitudinal and longitudinal direction.

(3) The poleward expansion speed of auroral breakups was much larger at Syowa than at Husafell. The EW-aligned auroras observed at Husafell showed a large longitudinal displacement (more than 300 km westward) in comparison to that observed at Syowa.

(4) The EW-aligned auroras generally showed different shapes and movements in the two hemispheres.

(5) Cosmic noise absorption (CNA) phenomena were closely related to appearances of auroras, *i.e.*, CNA at Syowa were more similar to those at Isafjördur and Tjörnes than to those at Husafell.

The isolated auroras such as NS-aligned arcs and pulsating auroras are more comparable when we study the one-to-one correspondence of auroras between conjugate stations. From the results (2) and studies of the pulsating aurora (FUJII *et al.*, 1987a), the isolated auroras observed during the recovery phase of an auroral substorm showed good conjugacy, suggesting that the source region of these auroras exists near the equatorial plane in the magnetosphere and that the auroral particles precipitate along the geomagnetic field line. The results (1) also suggest that the source of triggering of auroral breakups and the source of auroral particles exist near the equatorial plane in the magnetosphere.

However, the poor conjugacy results (3) and (4), the difference of shapes, movements, and large longitudinal displacement in the two hemispheres, could be caused by the difference of geophysical environment such as the electric field, magnetic field, and plasma density in the conjugate regions. These dissimilarities in the conjugate region suggest that the local acceleration process by the ionosphere-magnetosphere coupling may play a important role in enhancing the dissimilar auroras in both hemispheres. It is difficult to conclude here whether the large longitudinal displacement of auroras in the two hemisphere is caused by the movement of the conjugate point or by the local acceleration process, because we have been unable to establish a one-to-one correspondence in the fine structures and shapes appearing simultaneously in both hemispheres. A more detailed analysis and discussion will be carried out in the near future.

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