Mem. Natl Inst. Polar Res., Spec. Issue, **48**, 72–80, 1987

CONJUGACY OF RAPID MOTIONS AND SMALL-SCALE DEFORMATIONS OF DISCRETE AURORAS BY ALL-SKY TV OBSERVATIONS

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Abstract: Simultaneous observations of discrete auroras were made on 26 September 1984 by means of all-sky TV cameras at a geomagnetically conjugate pair of sites: Syowa Station in Antarctica and Husafell in Iceland. A comparison of the data obtained at the two places gives the following characteristics regarding the conjugacy of discrete auroras under a geomagnetically weakly disturbed condition ($\Delta H = -50$ nT): Before the onset of a small substorm conjugate faint discrete auroras were identified in both conjugate areas despite a small displacement (0.5°) in invariant latitude (the southern aurora is 0.5° higher than the northern one). A striking dissimilarity of the conjugate auroras is noted in small-scale structures within the auroras. That is, the northern discrete aurora was rather homogeneous, whereas the southern one was a rayed aurora. During the substorm the east-west movement and/or extension of discrete auroras was quite conjugate and simultaneous. However, the vortex-like structures such as folds on the discrete auroras were not always simultaneously observed at the both places. Even if they appeared simultaneously, their sizes seemed to be different between the conjugate regions. These results would suggest that the large-scale structures and their movements are mainly controlled by some conditions in the magnetosphere, perhaps near the equatorial region, but the small-scale structures such as vortices are greatly due to local acceleration processes between the magnetosphere and the ionosphere.

1. Introduction

Since 1983 simultaneous observations have been carried out at a geomagnetically conjugate pair of sites: Syowa Station in Antarctica and Husafell in Iceland. As is described in some previous papers (*e.g.*, SATO *et al.*, 1985; SATO and SAEMUNDSSON, 1987; FUJII *et al.*, 1987), several kinds of observations have been made at the two places, including the optical measurements of auroras such as observations of auroral images and luminosities by all-sky TV cameras and photometers. The purpose of this article is to report on the similarities and differences of discrete auroras between the conjugate areas under a weakly disturbed condition.

A discrete aurora, which include arc- and band-type auroras, is one of the fundamental forms of auroras. It shows a variety of deformations and motions in association with geomagnetic activities. Duing quiescent geomagnetic conditions, a discrete aurora (arc) with an east-west extension appears with very little deformations and motions. On the other hand it becomes active and frequently shows deformations such as spirals, folds and curls during disturbed geomagnetic conditions, especially in the expansion and early recovery phases of a substorm. Each of those deformations has a characteristic size, life time and rotational sense (HALLINAN and DAVIS, 1970). A curl configuration corresponds to a ray structure (HALLINAN and DAVIS, 1970) and a spiral is almost equivalent to a surge (DAVIS and HALLINAN, 1976). The discrete aurora shows motions and/or extensions in either eastward-westward or poleward-equatorward.

Several theoretical works suggested possible mechanisms for the vortex-like deformations and their movements. The production mechanism of the small-scale deformations such as curls and folds would be due to an electric field shear driven instability where the electric field is induced by an unshielded charge sheet (MIURA and SATO, 1978; WAGNER *et al.*, 1983). On the other hand the spirals could be produced by a magnetic shear due to field-aligned currents associated with the discrete aurora (HALLINAN, 1976). Mechanisms of the movement of the spirals (surges) had been also proposed (KAN and SUN, 1985; ROTHWELL *et al.*, 1984).

Conjugate studies of auroras provide important information on generation mechanisms of the auroral particle injection, acceleration processes of auroral particles and mechanisms of auroral deformations. DEWITT (1962) first investigated the similarity of auroras in the conjugate areas using all-sky camera data. From the conjugate observations by using aircraft, BELON *et al.* (1967, 1968, 1969) found that there are two arc systems. The conjugate auroral display exhibits a demarcation line across which the degree of conjugacy changes. They reported that the auroral conjugacy becomes poor on the high-latitude side of the demarcation line. Also reported were relative motions of auroral conjugate points and differences in auroral luminosity at conjugate points (STENBAEK-NIELSEN *et al.*, 1972, 1973). These previous works were, however, mainly concerned with the conjugacies of auroral forms and displacements in the conjugate regions. Hence significant characteristics of the auroral conjugacies, such as the conjugacies of the auroral movements and deformations have been still remained unclear.

The present paper demonstrates especially the conjugacies of auroral vortex (folds and spirals) and of temporal variations using high time-resolution data obtained by sensitive TV cameras in the conjugate regions.

2. Observations

A sensitive all-sky TV camera was installed in 1984 at both sites of geomagnetic conjugate pair; Syowa Station (geomagnetic latitude=66.12°, geomagnetic longitude=70.81°) in Antarctica and Husafell (65.99°, 70.09°) in Iceland. The digital TV system at Syowa yields monochromatic images with the sampling time of about 0.5 s, using filters (5577Å, 4278Å, 6300Å, H_β). In the present analysis we use 5577Å data. The TV system at Husafell supplied panchromatic images with the sampling time of 33 ms. More detailed information on the TV system at the two places is described by FUJII *et al.* (1987). The original images with distortions from a fish-eye lens were converted into images in the coordinates of invariant latitude (63°–69°) and magnetic longitude (63°–77°), assuming the lower border of the auroral altitude of 110 km. It should be noted that only auroral forms and relative auroral intensities will be discussed in this paper, because the inter-calibration of the luminosity has not yet been made.

During the period of the Syowa–Iceland conjugate campaign in 1984, the sky was clear enough at both stations to permit a detailed study of conjugate aurora on only two nights (September 3 and 26). We analyzed the data obtained on September 26. On this day the overlapped period of the optical observations was from 2100 to 2350 UT, when the sky was dark at both stations.

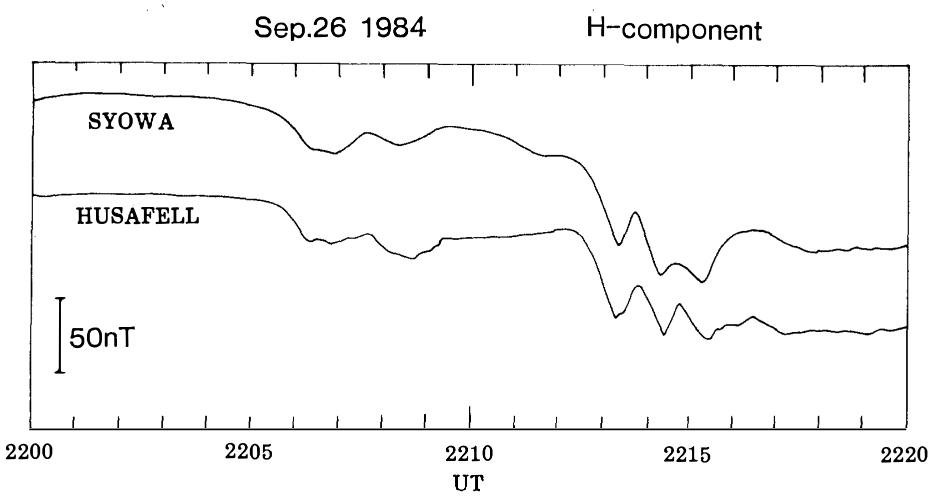

Fig. 1. Magnetograms obtain at Syowa Station in Antarctica and Husafell in Iceland at 2200–2220 UT on September 26, 1984. Husafell is an approximately geomagnetic conjugate point of Syowa Station.

As is shown in Fig. 1, the first geomagnetic perturbation occurred at 2205 UT with very small negative H-component variations of about 50 nT. Several negative perturbations followed it until 2330 UT and pulsating aurora appeared afterward. The present article discusses the conjugacy of auroras observed during the first small negative geomagnetic perturbations.

Before 2205:20 UT the geomagnetic activity was very low, and quite faint and stable discrete auroras were visible in both conjugate areas. Figure 2 shows conjugate auroras observed at 2204:24 UT (about 22 MLT) in the area of invariant latitude (63°–69°) and geomagnetic longitude (63°–77°). A discrete aurora is clearly identified around 66° invariant latitude in both conjugate regions with a decrease of latitude toward the nightside region. At higher latitude of this aurora a more intense rayed aurora appeared at Syowa, whereas a corresponding aurora was not observed within

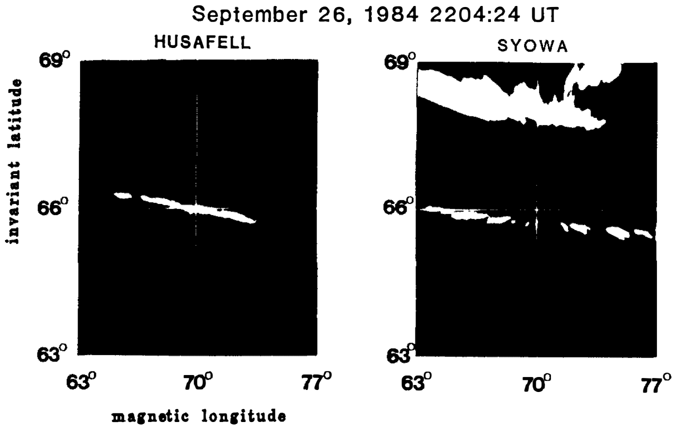

Fig. 2. Conjugate faint discrete auroras observed by sensitive TV cameras at 2204:24 UT on 26 September 1984, at the geomagnetically conjugate pair of observation sites: Husafell (left) and Syowa Station (right). A small substorm was started about one minute later. The discrete aurora around 66° invariant latitude was observed in the two region but small-scale structures inside the auroras show a clear dissimilarity in both regions, that is, the discrete aurora was homogeneous in the northern hemisphere, whereas it had a rayed structure in the southern hemisphere. Rather intense aurora around 68° invariant latitude observed at Syowa Station has no corresponding one in the field of view of the TV camera at Husafell.

the all-sky field of view at Husafell. The present data does not provide any evidence whether this rayed aurora did not have a conjugate counterpart in the northern hemisphere or the conjugate aurora was beyond the all-sky field of view from Husafell. Concerning the discrete aurora around 66°, its form in the northern hemisphere was similar to that in the southern hemisphere, whereas the northern discrete aurora was located at 0.5° higher latitude than the southern one. The fine structure of the conjugate aurora was, however, dissimilar to each other. The northern discrete aurora was rather homogeneous and truncated at both eastern and western edges. The southern aurora had, on the contrary, apparently rayed structures and was extending from the eastern horizon to the western horizon. This example shows that the fine structure is not always conjugate even under a very quiet geomagnetic condition.

Figure 3 shows the temporal development of the auroras in the conjugate areas before and after the negative perturbation started at 2205:20 UT. The upper and lower panels show the auroras observed at Husafell and Syowa Station, respectively. At 2205:10 UT the auroral forms were very similar to those at 2204:24 UT in Fig. 2. The auroras were located more wastward than those at 2204:24 UT. We note here that the aurora around 68° invariant latitude still remained in the southern hemisphere. Between 2205:10 and 2205:19 UT the discrete auroras around 66° became intense in the both regions, while the higher latitude aurora at Syowa Station became weaker and then disappeared. Between 2205:19 and 2205:35 UT the discrete auroras in both hemispheres simultaneously moved and/or extended eastward. Afterward the auroras moved and/or extended reversely westward until 2205:45 UT. Between 2205:19 and 2205:35 UT when the auroras moved eastward, the auroral forms did not change so much in comparison with those after 2205:35 UT. Small vortices (~50 km) were seen in the southern hemisphere at 2205:26 UT, but not clearly identified

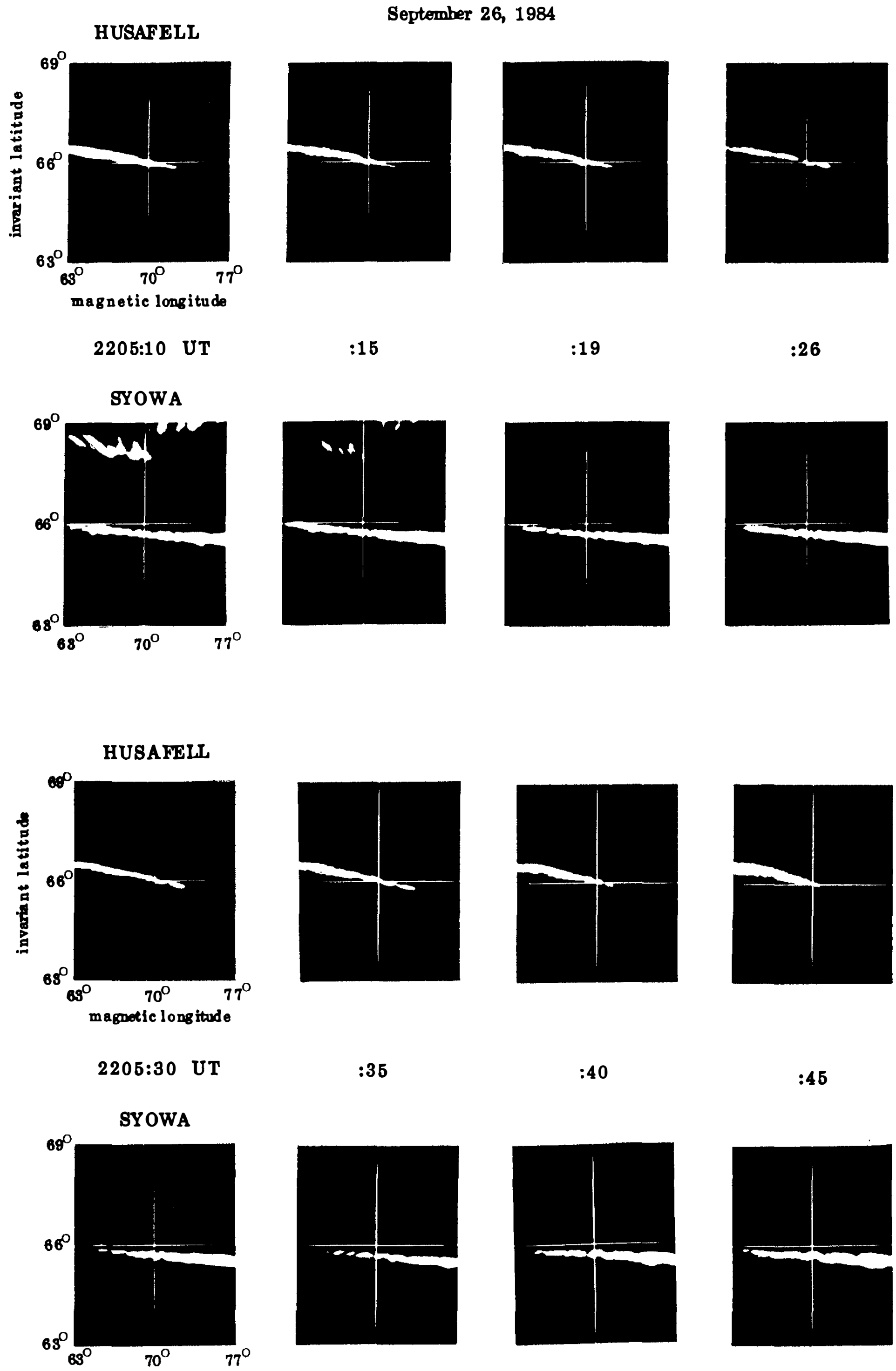

Fig. 3. Temporal development of the auroras in the conjugate areas before and after negative perturbations started at 2205:20 UT. The upper panels show the auroras observed at Husafell and the lower one at Syowa Station. Simultaneous movement toward the same direction was observed in the conjugate areas, that is, an eastward motion between 2205:19 and 2205:35 UT and a westward motion between 2205:35 and 2205:50 UT. The difference in the small-scale vortex structures can be seen in both places after 2205:45 UT. Also seen is the east-west displacement between both the places.

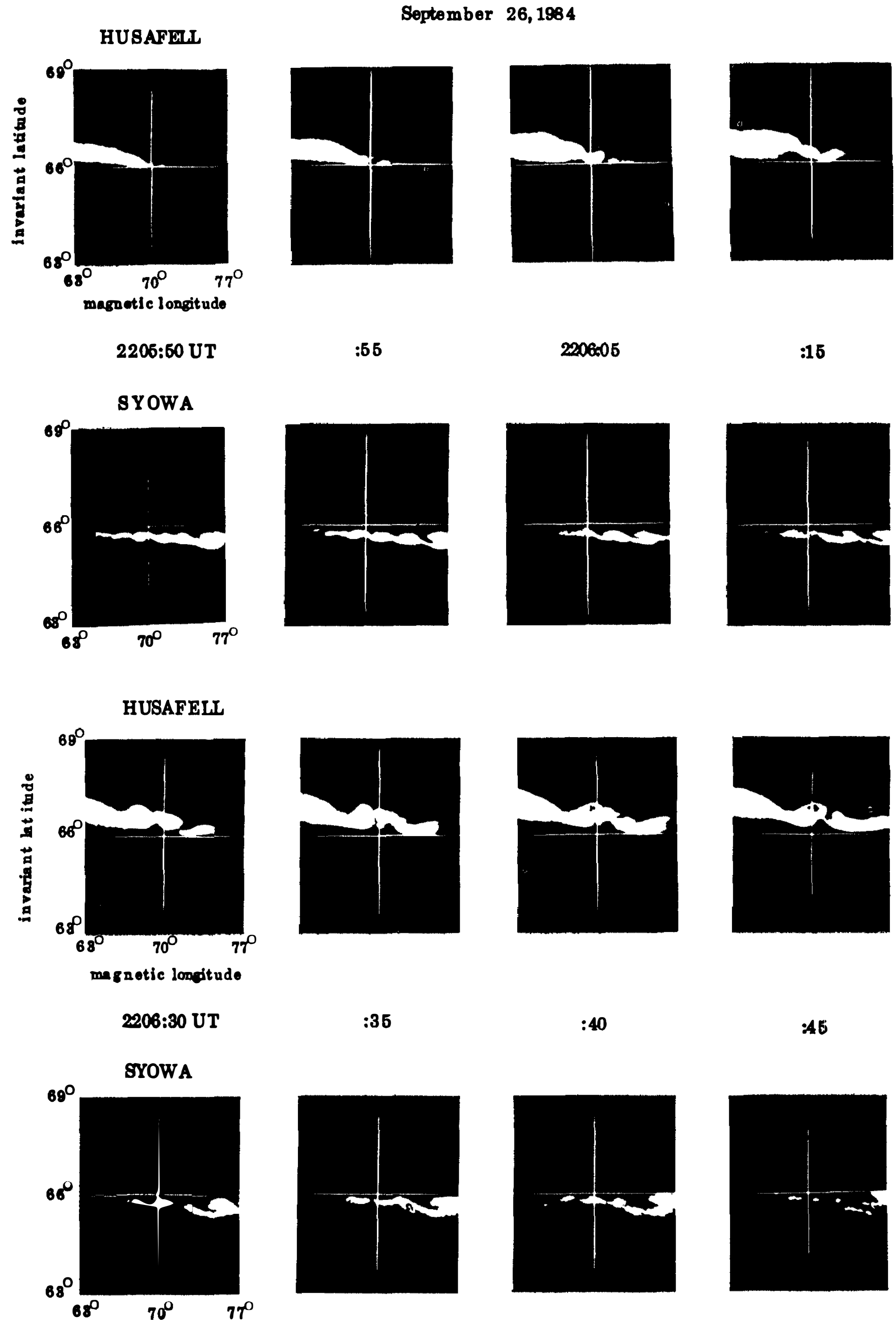

Fig. 4. Continuation of Fig. 3 after 2205:50 UT. Eastward motion is simultaneously observed in the conjugate region. A noticeable difference in vortex structures can be seen between both regions.

in the northern hemisphere. After 2205:35 UT when the discrete auroras moved and/or extened westward, the width of the auroras became thicker in both conjugate regions, and vortex structures developed at the western portion of the aurora in the southern hemisphere.

Figure 4 illustrates the temporal variations of auroral forms after 2205:50 UT. At 2205:50 UT the conjugate discrete auroras started to move and/or extend eastward simultaneously. The latitude range of the auroras became much wider. The vortex structures in the southern hemisphere became greater in scale, and a vortex appeared at the eastern edge of the northern conjugate aurora. After 2206:30 UT the vortex structure in the northern hemisphere became more distinguishable, whereas a part of the southern vortices moved and/or extended at 2206:45 UT beyond the eastern edge of the field of view. Concerning the western edge of the discrete auroras, it was located around 68° in magnetic longitude at Husafell and below 63° at Syowa Station. This implies that the longitudinal displacement of the conjugate arcs was at least greater than 5° which is equal to about 210 km. The latitudinal displacement of the conjugate arcs was 0.5° which is the same as that before the substorm onset.

3. Conclusions and Discussions

We examined conjugacies of the descrete auroras observed around 22 UT on 26 September 1984, at the geomagnetically conjugate-pair observatories; Syowa Station in Antarctica and Husafell in Iceland, during a weak geomagnetic disturbance.

Before the onset of a small substorm, the conjugate faint discrete auroras were identified at the two places. The large-scale form and the location of the aurora in the northern hemisphere were almost the same as those in the southern hemisphere. This result is consistent with the previous result by BELON *et al.* (1969). It suggests that the form of the discrete aurora is controlled by a certain process in the equatorial region in the magnetosphere. The dissimilarity of the conjugate auroras is found in the small-scale structure; the northern discrete aurora is rather homogeneous, whereas the southern one has rayed structures (curls). This striking dissimilarity would be associated with a local acceleration process between the magnetosphere and the ionosphere, or within the ionosphere. As was suggested by a theoretical simulation (WAGNER *et al.*, 1983), the poor conjugacy could be caused either by a difference in electric fields in the conjugate region or by some difference in the ionospheric conditions, such as a development of an ion sheath around the arcs. This dissimilarity suggests that the local acceleration process does not always occur simultaneously at the northern and southern feet of a certain magnetic field line across the geomagnetic equatorial plane.

During the substorm, the conjugate discrete auroras with small-scale structures simultaneously moved and/or extended either westward or eastward in the same direction. This shows that the movement and/or extension of the auroras is controlled by a force common to the both conjugate auroras. An intensification of the auroral luminosity and a broadening of the discrete auroras also occurred simultaneously in the both regions. On the other hand, small-scale vortices (50–100 km) were not always observed at both of the conjugate places simultaneously. They were observed in the southern hemisphere, but not in the northern hemisphere before 2205:50 UT. Afterwards the auroral vortices were observed at both stations. The spatial scale of vortices was, however, different from each other, that is, about 100 km in the southern hemisphere and more than 200 km in the northern hemisphere. One of the possible explanations for this dissimilarity is that the form of the vortices does not directly subjected to a gross magnetospheric structure but rather to a local process on the field line between the magnetosphere and the ionosphere, which is not necessarily symmetric with respect to the magnetospheric equatorial plane. Another it must be remarked here that a large longitudinal displacement (more than 210 km) of the conjugate auroras prevents us from observing of conjugate vortices.

Acknowledgments

We wish to express our thanks to T. NAGATA and T. MATSUDA (National Institude of Polar Research (NIPR), Japan) for their effort to initiate and organize this project. We acknowledge to the Wintering Party of the 25th Japanese Antarctic Research Expedition for data acquisition at Syowa Station. We are grateful to M. EJIRI (NIPR) and T. OGUTI (University of Tokyo) for their valuable discussion. We also thank K. UCHIDA and H. SAKURAI (NIPR) for data processing. This research was done using M-180 computer facilities at NIPR. The project in Iceland was supported by Grant-in-Aid for Overseas Scientific Survey (60041085) and for Scientific Research B (61460051), Ministry of Education, Science and Culture, Japan.

References

BELON, A. E., MATHER, K. B. and GLASS, N. W. (1967): The conjugacy of visual aurorae. Antarct. J. U. S., **2**, 124–127.

BELON, A. E., DAVIS, T. N. and GLASS, N. W. (1968): Conjugacy of visual auroras during magnetically disturbed periods. Antarct. J. U. S., **3**, 117–119.

BELON, A. E., MAGGS, J. E., DAVIS, T. N., MATHER, K. B., GLASS, N. W. and HUGHES, G. F. (1969): Conjugacy of visual auroras during magnetically quiet periods. J. Geophys. Res., **74**, 1–28.

DAVIS, T. N. and HALLINAN, T. J. (1976): Auroral spirals 1. Observations. J. Geophys. Res., **81**, 3953–3958.

DEWITT, R. N. (1962): The occurrence of aurora in geomagnetically conjugate areas. J. Geophys. Res., **67**, 1347–1352.

FUJII, R., SATO, N., ONO, T., HIRASAWA, T., FUKUNISHI, H., KOKUBUN, S., ARAKI, T. and SAEMUNDSSON, Th. (1987): Conjugacies of pulsating auroras by all-sky TV observations. Geophys. Res. Lett., **14**, 115–118.

HALLINAN, T. J. (1976): Auroral spirals, 2. Theory. J. Geophys. Res., **81**, 3959-3965.

HALLINAN, T. J. and DAVIS, T. N. (1970): Small scale auroral arc distortions. Planet. Space Sci., **18**, 1735–1744.

KAN, J. R. and SUN, W. (1985): Simulation of the westward traveling surge and Pi 2 pulsations during substorms. J. Geophys. Res., **90**, 10911–10922.

MIURA, A. and SATO, T. (1978): Shear instability; Auroral arc deformations and anomalous momentum transport. J. Geophys. Res., **83**, 2109–2117.

ROTHWELL, P., SILEVITCH, M. B. and BLOCK, L. P. (1984): A model for the propagation of the westward traveling surge. J. Geophys. Res., **89**, 8941–8948.

SATO, N. and SAEMUNDSSON, Th. (1987): Conjugacy of electron auroras observed by all-sky cameras and scanning photometers. Mem. Natl Inst. Polar Res., Spec. Issue, **48**, 58–71.

SATO, N., FUJII, R., KOKUBUN, S., ARAKI, T. and SAEMUNDSSON, Th. (1985): 1984-nen Aisulando ni okeru ôrora genshô no kyôyakuten kansoku hôkoku (Report of the 1984 conjugate campaign in Iceland). Nankyoku Shiryô (Antarct. Rec.), **87**, 78–95.

STENBAEK-NIELSEN, H. C., DAVIS, T. N. and GLASS, N. W. (1972): Relative motion of auroral conjugate points during substorms. J. Geophys. Res., **77**, 1844–1858.

STENBAEK-NIELSEN, H. C., WESCOTT, E. M., DAVIS, T. N. and PETERSON, R. W. (1973): Differences in auroral intensity at conjugate points. J. Geophys. Res., **78**, 659–671.

WAGNER, J. S., SYDORA, R. D., TAJIMA, T., HALLINAN, T. J., LEE, L. C. and AKASOFU, S.-I. (1983): Small-scale auroral arc deformations. J. Geophys. Res., **88**, 8013–8019.

(Received March 25, 1987; Revised manuscript received May 14, 1987)