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COEXISTENCE OF POLAR ARCS WITH PATCHES —RESULTS FROM THE SIMULTANEOUS OBSERVATIONS BY AKEBONO SATELLITE AND ALL-SKY IMAGER AT QAANAAQ—

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Abstract: To understand the processes of formation of polar arcs together with patches, an investigation has been made based on the simultaneous observations with an all-sky imager at Qaanaaq in Greenland and Akebono (EXOS-D) satellite. On some occasions, we have identified coexistence of polar arcs with patches. Specifically, polar arcs were replaced by patches or *vise versa*. These phenomena have been seen in the transient periods of IMF polarity change. Growth and decay of polar arcs with respect to the IMF polarity change has also been investigated with a particular interest in a delay time. The delay time was in a range from 30 min to 1 hour. Since a life time of patches seems to be longer than 1 hour, the coexistence was noticed by the all-sky imager at Qaanaaq.

1. Introduction

All-sky imaging has revealed that the polar cap *F*-layer is active for both $Bz<0$ and $Bz>0$ of the interplanetary magnetic field (IMF). BUCHAU *et al.* (1983) demonstrated that during quiet periods, polar arcs are predominant. Polar arcs disappear during magnetically active periods, and large patches of enhanced ionization drift in the antisunward direction. To investigate polar arcs and patches in more detail, OBARA *et al.* (1996) compared all-sky image data taken at Qaanaaq in Greenland with Akebono (EXOS-D) observations. They have clarified an electrodynamical feature of polar arcs and inferred a source region of precipitating electrons causing polar arcs. OBARA *et al.* (1996) concluded that velocity shear is essential to produce polar arcs, but it is still uncertain why these velocity shears are produced in the polar cap region during northward IMF conditions. They also speculated that velocity shear whould be identical to the discontinuities in the magnetospheric convection electric field, and such mesoscale structure might be generated by a disturbance at the magnetopause boundary at high latitude. When the IMF is directed southward, a mesoscale (100 to 1000 km) density enhancement, named polar patch, drifts across the polar cap. The direction of the drifting was confirmed by the Akebono satellite (OBARA *et al.*, 1996), suggesting the movement of patches is due to the polar cap convection.

In order to have a further clue in terms of the formation of polar arcs, we have examined the transient periods in which polar arcs were replaced by patches or vice versa. Among the cases (38 cases) when simultaneous observations were made by the all-sky imager at Qaanaaq and the Akebono satellite, there were three cases showing a coexistence of polar arcs with patches (OBARA *et al.*, 1996). Specifically, polar arcs were replaced by patches in two cases and vice versa in one case. In this paper, we present the simultaneous observation data and will investigate the formation of polar arcs. We will also comment on a time delay of appearance or disappearance of polar arcs with respect to the IMF polarity change.

2. Data Description

The Akebono (EXOS-D) satellite, which was launched on February 22 in 1989, has an inclination of 75° and passed over Qaanaaq (77.5°N, 69.2°W) once per day. OBARA *et al.* (1996) surveyed simultaneous observation periods and found 38 passes during winter months of 1989, 1991 and 1992. Since the all-sky imager at Qaanaaq has a very high sensitivity; *i.e.* it can detect down to tens of R, it always observed patches or polar arcs. In three cases, patches were observed together with polar arcs. In the following, we will describe two cases for different situations.

2.1. A case from arc to patch (February 15, 1993)

In order to demonstrate the structure more clearly, we used sketches in the present paper. On February 15, 1993, Akebono approached to the Qaanaaq station; actually it passed over the station at 0729 UT. Consecutive sketches from all-sky image data are given in Fig. 1, where a sun-aligned arc as marked "A" changed its location as time progressed and finally disappeared at 0741:04 UT. We can also see a polar patch as marked "B". It first appeared on a noonside and then drifted deep into the

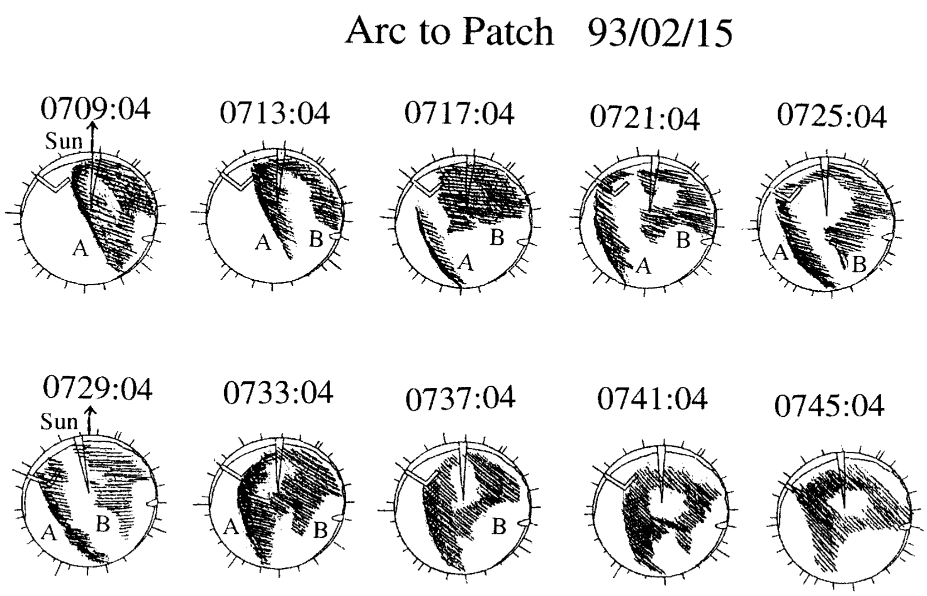

Fig. 1. Sketches from all-sky images taken at Qaanaaq station during the night of February 15, 1993. Top of each sketch directs to the sun. A bright polar arc, marked "A", was replaced by the patch, marked "B".

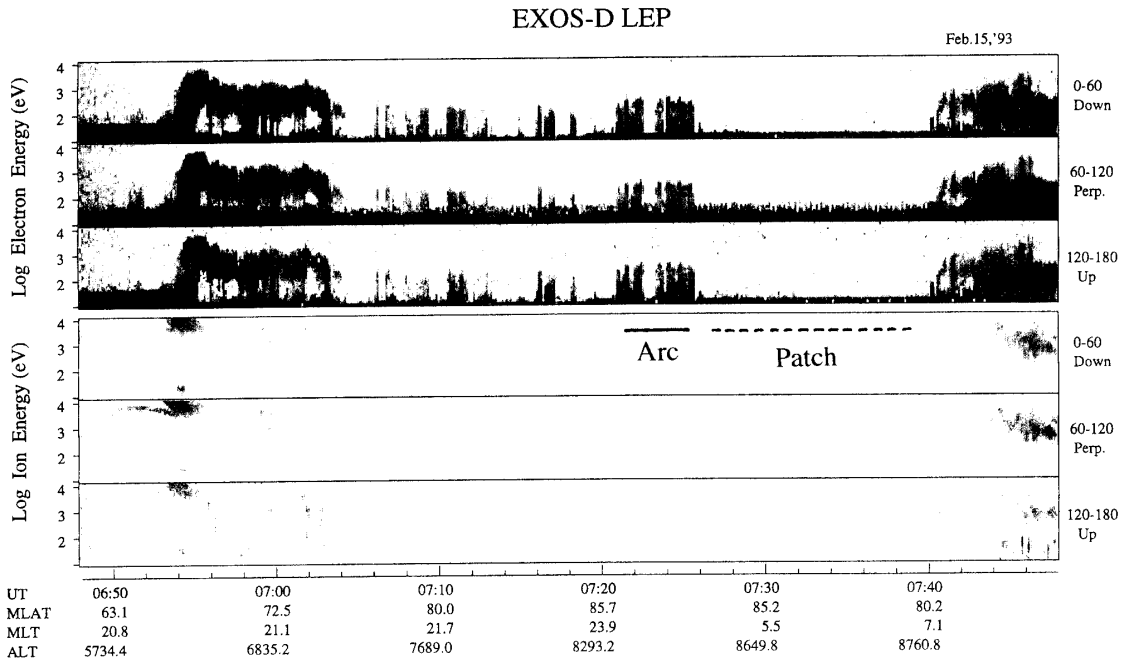

Fig. 2. Akebono E-t diagram for electrons (top three) and ions (bottom three), sorted by the pitch angle. Energy range is logarithmically scaled in the ordinate, ranging from 10 eV to 16 keV for each species. The Akebono satellite entered the polar cap region at 0703 UT and stayed till 0740 UT, observing intense electron precipitations at around 0721–0724 UT. After the encounter with arcs, the Akebono satellite entered the 'patch' region.

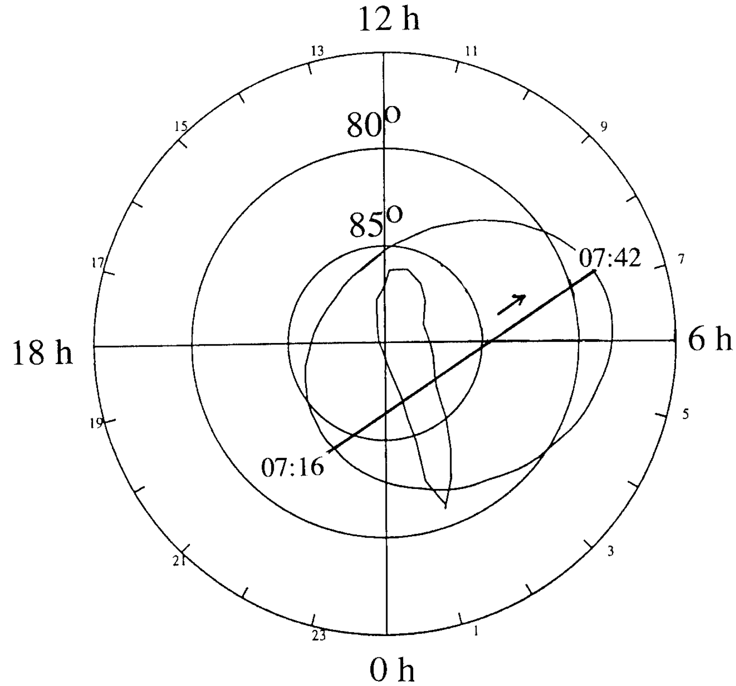

Fig. 3. Projection of polar arc at 0725 UT into the polar map together with the trajectory of the satellite (solid line). An ellipse demonstrates the field of the view of Qaanaaq all-sky camera.

polar cap (see sketches from 0709:04 UT to 0729:04 UT). The LEP (Low Energy Particle) instrument on board Akebono satellite made comprehensive observations of low energy electrons with sufficient information on pitch angle (MUKAI *et al.*, 1990). Figure 2 demonstrates *E-t* diagrams for electrons (top three) and ions (bottom three) sorted by pitch angle. At around 0724 UT, the Akebono satellite was in the post midnight polar cap region and detected localized electron precipitations. Projection of the polar arc at 0725 UT together with Akebono trajectory is given in Fig. 3, where the satellite encountered with the polar arc in the post midnight region. After the encounter with polar arc, Akebono entered patch regions and observed no significant electron precipitations. This observation is consistent with the nature of the patch; *i.e.* the patch is an illumination emitted from a high density region in the *F*-layer, being transported from the dayside into the polar cap rather than being formed locally by the precipitation (WEBER *et al.*, 1984). Though there was no IMF observation in this interval, this replacement must have been taking place in a very transient condition in terms of IMF polarity change (from northward IMF to southward IMF, in this case).

2.2. A case from patch to arc (February 11, 1993)

On February11, 1993, we have observed an opposite situation; *i.e.* a patch was replaced by a polar arc. In Fig. 4, consecutive sketches from all-sky image data demonstrate that polar patches drifted from the noonside to the center of polar cap. At 0937:23 UT, a very intense sun-aligned polar arc, as marked "C", appeared. The arc became brighter with time. In this case, Akebono satellite traversed polar cap region from 0913 to 0933 UT, observing no significant electron precipitation. Akebono, also, observed a clear antisunward convection, consistent with the movement of patches. In this case, we have no information on IMF, but a sudden growth of polar arc must be due to a northward turning of IMF.

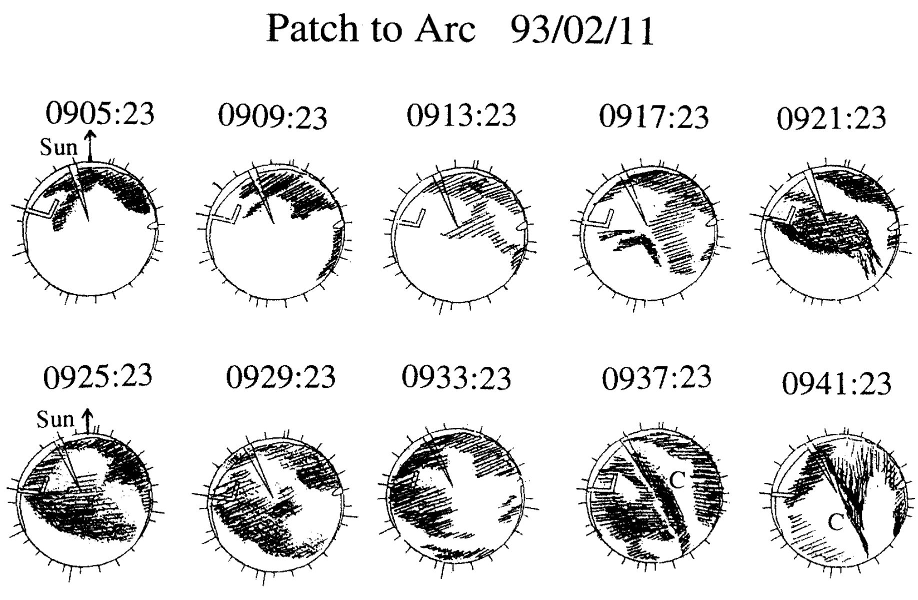

Fig. 4. Sketches from all-sky images taken from Qaanaaq station during the night of February 11, 1993. A bright polar arc appeared at 0937:23 UT.

2.3. DMSP observations

In order to get information on the IMF polarity, we used polar cap convection deduced from a drift meter instrument on board DMSP satellite. The DMSP satellite observed polar cap convection in a period from 0648 to 0708 UT on February 15, just before all-sky image data were taken (see top panel in Fig. 5). Polar cap convection in that interval was quite irregular, showing an existence of multiple convection cells. This very irregular pattern was thought to be a manifestation of the northward IMF condition. On the contrary, the polar cap convection obtained during a period from 0736 to 0756 UT (see bottom panel in Fig. 5) is not irregular, showing a coherent antisunward convection in a morning side polar cap region. From this data, we would say that IMF has already turned to southward by that time. Decay of the polar cap convection at around 0737 UT is likely due to the southward turning of the IMF.

Figure 6 demonstrates the DMSP observations on February 11. The polar cap

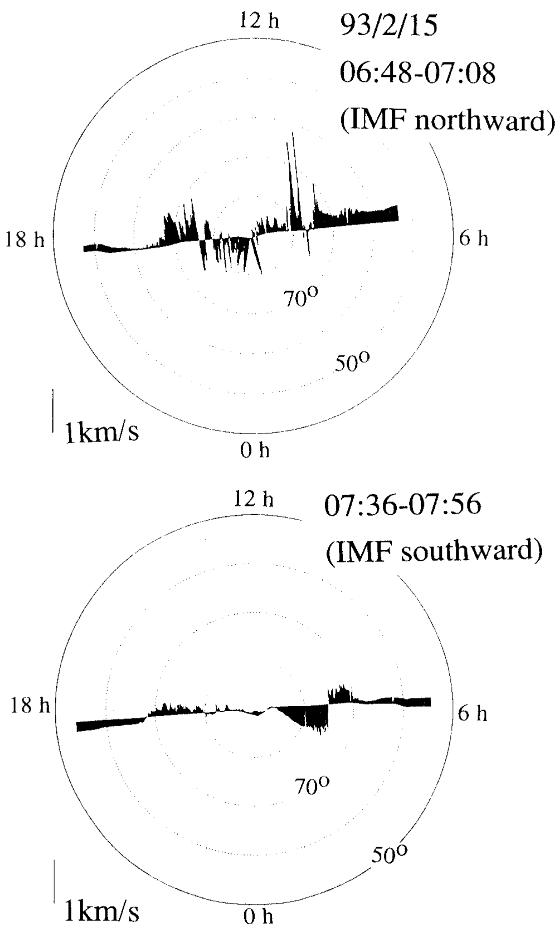

Fig. 5. Polar cap convection obtained from DMSP drift meter instrument. Observation was made on February 15, 1993.

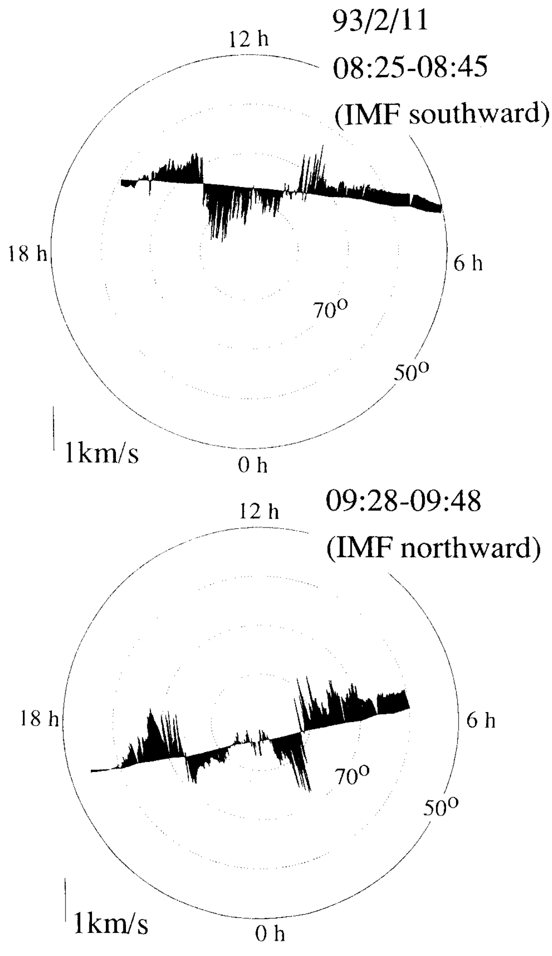

Fig. 6. Same as Fig. 5. Observation was made on February 11, 1993.

convection during a period from 0825 to 0845 UT (see top panel in Fig. 6) was anti-sunward, suggesting a southward IMF condition. On the contrary, the polar cap convection from 0928 to 0948 UT (see bottom panel in Fig. 6) demonstrates the existence of multiple convection cells, suggesting a northward IMF condition. We can see several velocity shears in the polar cap region; one of which caused the polar arc seen from Qaanaaq at around 0937 UT in Fig. 4.

3. Discussion

Investigation of growth and decay of polar arcs in response to IMF is quite important to understand the actual interaction between the solar wind and the magnetosphere. Right now, we have rather limited knowledge on a configuration of the magnetosphere for the northward IMF condition, and we must collect more information. In this paper, we particularly studied the transient processes with coexisting polar arcs and patches, and we found that the coexistence can be seen in a highly transient state in terms of IMF north-south polarity change.

More direct information can be obtained by a continuous all-sky camera observation together with IMF. Efforts to investigate the response of the polar cap ionosphere to a sudden IMF change have been made by the Geophysical Directorate of Phillips Laboratory. They evaluate an exact time delay of appearance and disappearance of polar arcs, resulting in a range from 30 min to 1 hour. OBARA *et al.* (1996) did a case study on that issue, yielding the same results.

One of the recent results obtained from the all-sky imager at Qaanaaq together with IMF is given in Fig. 7, where the time variation of the IMF *Bz* was plotted. We can identify a sudden polarity change at 0542 UT. After that time, IMF *Bz* took rather large value (~15 nT) for more than two hours, except for short southward turnings at 0630 and 0720 UT. All-sky image data taken from Qaanaaq on that day (December 3, 1992) have been given in Fig. 8. We can recognize several patches drifting anti-sunward during a period from 0541:53 to 0613:53 UT (see arrows in the figure). After 0617:53 UT, patches ceased their movement, showing the stagnant features. At 0633:53 UT, a bright polar arc appeared from the dayside portion, extending to the nightside

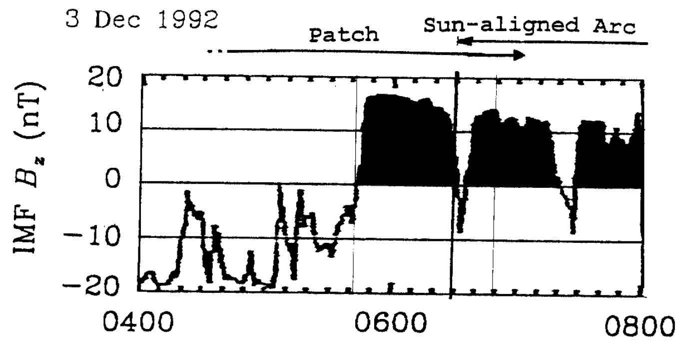

Fig. 7. Time variation of IMF Bz on December 3, 1992. Intervals with Bz>0 are marked in black. Polar arc appeared at 0630 UT and patches disappeared at 0700 UT, yielding 30 min of coexistence.

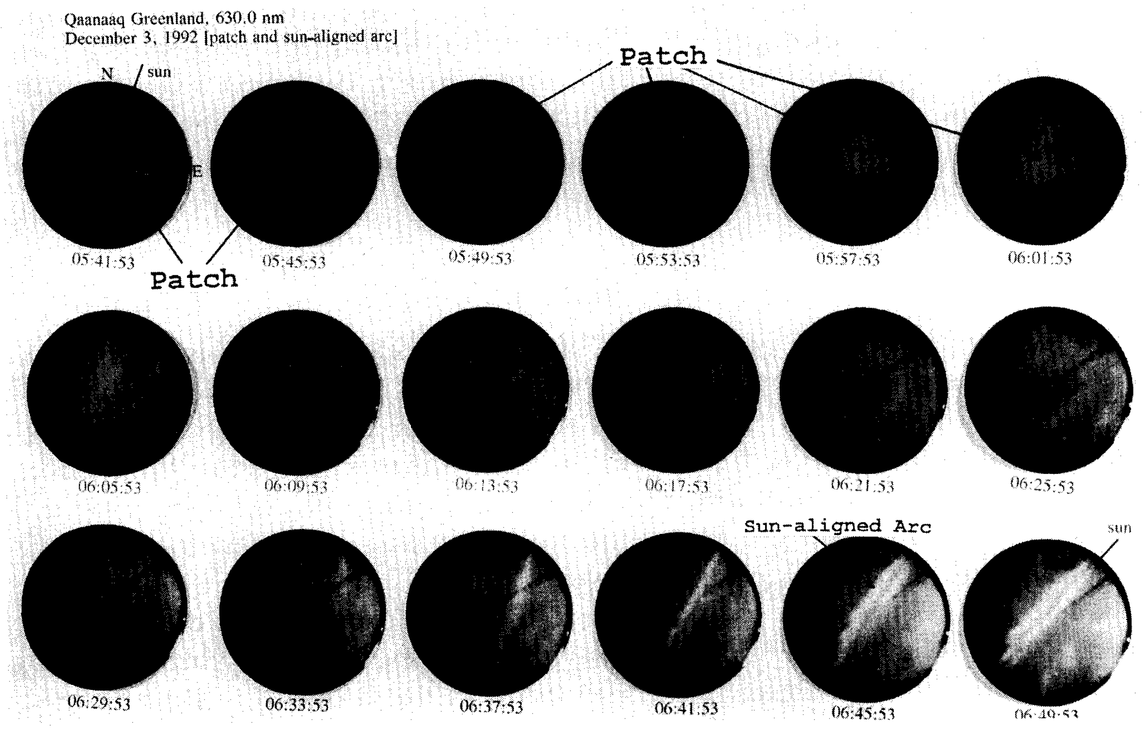

Fig. 8. All-sky image data taken from Qaanaaq station. Observation has been made on December 3, 1992. Top of each sketch directs to the sun.

as time went on. We could see very bright sun-aligned arc at 0641:53 UT. The polar arc appeared with a time delay of ~50 min after the northward turning, being consistent with previous work such as OBARA *et al.* (1996). It was so bright arc that a fine structure was made at 0645:53 UT, showing a double arc structure.

From the present results, we will be able to infer a possible life time of patches. We could see the patches till 0700 UT on December 3, 1992. The patches which were seen from Qaanaaq station seems to be transported from the dayside cusp region. Though it depends on the convection speed, it likely took about 30 min to shift to the center of the polar cap (near the magnetic pole). The patches, which could be seen above Qaanaaq at 0621 UT, were alive till 0700 UT. From all-sky image data, we can suggest a life time of patches is about one hour or more, yielding the possible coexistence of patches with polar arcs. Actually in the present case (December 3, 1992), we could see the coexistence for ~30 min.

On February 15, 1993, we could see patches drifting into the deep polar cap at 0709:04 UT (see Fig. 1). Supposing that the decay of polar arcs had a significant long time lag and the drift speed of patches was fast, a coexistence in this case can be understood easily. We speculate that the IMF might have turned to southward at around 0700 UT or a little bit earlier.

The time lag may be determined (in part) by the convection velocity across the polar cap. A piece of evidence supporting this idea is that the polar arc decays from the dayside (Rodriguez, private communication). The Qaanaaq image data, as shown in Fig. 8, seems to be suggestive, too; the polar arc grows from the dayside. The growth and decay of polar arcs are closely related to the growth and decay of velocity shear. More experimental work on the coherence of the dynamics over its length is to be performed in near future.

Acknowledgments

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