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Short Communication

Polar cap arcs: Sun-aligned or cusp-aligned?

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ABSTRACT

Polar cap arcs are often called sun-aligned arcs. Satellite observations reveal that polar cap arcs join together at the cusp and are actually cusp aligned. Strong ionospheric plasma velocity shears, thus field aligned currents, were associated with polar arcs and they were likely caused by Kelvin–Helmholtz waves around the low-latitude magnetopause under a northward IMF B_z. The magnetic field lines around the magnetopause join together in the cusp region so are the field aligned currents and particle precipitation. This explains why polar arcs are cusp aligned.

1. Introduction

Early ground observations revealed that the auroral arcs in the polar cap tend to align parallel to the noon-midnight meridian (Mawson, 1925; Denholm 1961; Davis, 1962; Lassen, 1969). The polar cap arcs are often called sun-aligned arcs (Berkey et al., 1976; Valladares and Carlson, 1991; Crain et al., 1994; Kornilov et al., 2008). Fig. 1a, adapted from Fig. 1 of Akasofu (1964), shows a sketch of polar cap arcs before an auroral substorm. The sketch indicates that the polar arcs above magnetic latitude (Mlat) of 80° are essentially parallel to each other. However, the arcs are not fully sun-aligned. Due to lack of dayside ground imaging observations under a sunlit condition, it is not clear whether the arcs join together on the dayside or simply connect to the dayside auroral oval as straight lines. The sketch in Fig. 1b, (adapted from Fig. 1 of Ismail, et al., (1977)), demonstrates that the arcs above 80°Mlat are mixed with sun-aligned and non-sun-aligned arcs. The dayside ends of these arcs on the dusk side of the magnetic pole tend to tilt dawn-ward and vice versa for the dawn side arcs. Using satellite based visible auroral images, Akasofu (1976) summarized the features of auroral emissions (Fig. 1c). Despite that there are no auroral arcs above 80° Mlat in the sketch (Fig. 1c), the dayside (local time between 0600 and 1800) arcs below 80° Mlat are roughly oval aligned and tend to join together around noon and ~75 °Mlat where cusp is located. Fear et al. (2015) reported a case where a transpolar arc intersected a cusp auroral spot during part of the arc lifetime. These studies raise a question: Are the polar arcs above 80 °Mlat also joined together at cusp region?

2. Satellite FUV observations of polar arcs

Far Ultraviolet (FUV) imagers on satellites, such as Viking, Polar, IMAGE, TIMED and DMSP provide global view of the auroral oval and are able to observe dayside auroral emissions under a sunlit condition. The FUV imagers, such as TIMED/GUVI (Paxton et al., 1999, Christensen et al., 2003) and DMSP/SSUSI (Paxton et al., 2002) offer auroral images with high spatial resolutions and are capable to detect thin auroral arcs. Fig. 2 (left panel) shows the F16 DMSP SSUSI auroral image at N_2 LBHS (150–165 nm) band mapped in the magnetic coordinates around 17:38UT on May 15, 2005. It is clear that the polar cap was filled with auroral arcs and these arcs joined together on the dayside region around Mlat slightly above 75° at a pre-noon local time (~11:20) (see the red circle). Most of the arcs are not sun-aligned and orientate about 20° away from the sun-aligned direction. The simultaneous proton auroral image (right panel in Fig. 2) indicates that the dayside region (also marked by a red circle) was associated with an isolated spot of proton aurora. The associated interplanetary magnetic field (IMF) B_z from ACE satellite was 4.2 nT (northward). This proton auroral spot is similar to the cusp proton aurora under a northward IMF condition (Frey et al., 2003), suggesting the dayside region is the cusp. Therefore, the polar cap arcs joined together in the cusp.

Fig. 3 (left panel) shows another example of cusp aurora

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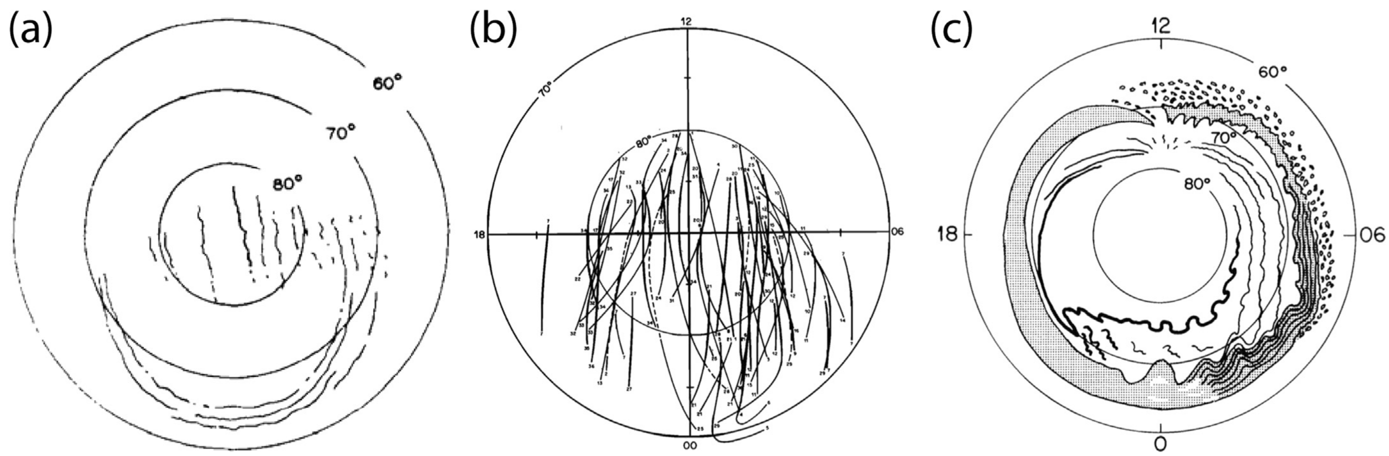

Fig. 1. (a) A sketch of polar cap arcs based on ground observation (adapted from Fig. 1 of Akasofu (1964)). (b) A sketch of polar arc location and orientation from ground observation (adapted from Fig. 1 of Ismail et al. (1977)). (c) A sketch of auroral oval and arcs below 80° Mlat based on visible auroral images from DMSP satellite (adapted from Fig. 13 of Akasofu (1976)).

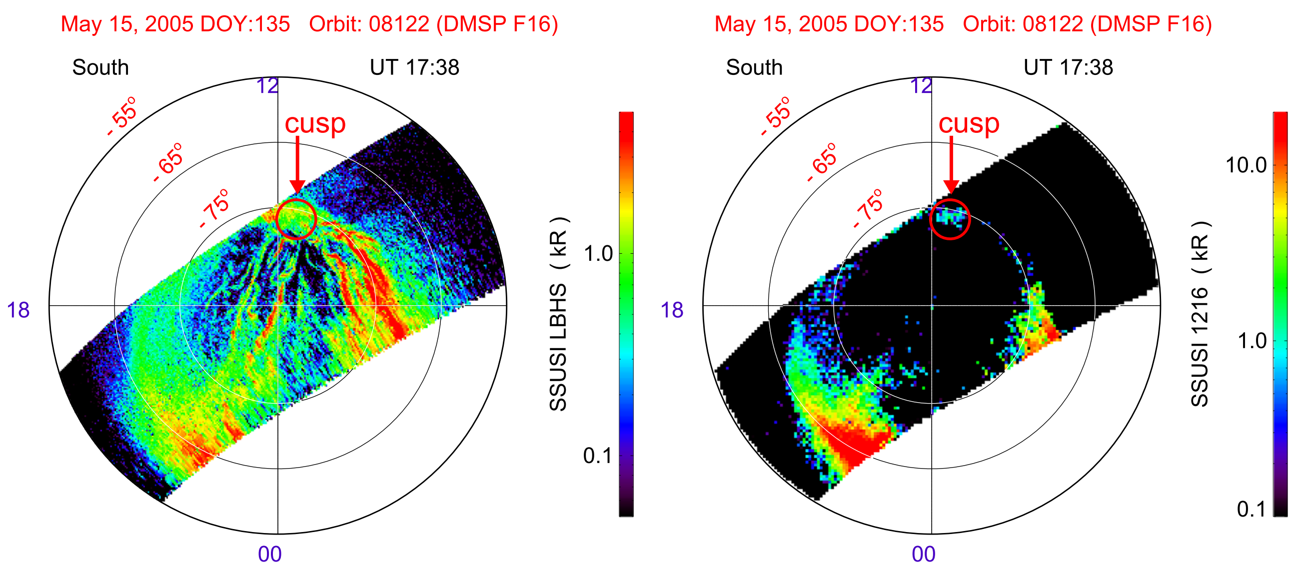

Fig. 2. F16 DMSP SSUSI auroral images around 17:38 UT, May 15, 2005: N_2 LBHS (150–165 nm) (left panel) and proton aurora around 121.6 nm (right panel). The IMF (B_x, B_y, and B_z) condition from ACE satellite around 17:38 UT were −32.2, −10.1, 4.2 nT, respectively (the propagation effect from ACE to the dayside magnetopause has been corrected). The red circle indicates the cusp location. The left panel is adapted from Fig. 2 of Zhang et al. (2009). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(dayside isolated proton auroral spot around noon and 80° Mlat, marked by a red circle) from F19 DMSP SSUSI at 12:19 UT, March 16, 2015. The associated IMF B_z from ACE satellite was 9.9 nT (strongly northward). The simultaneous N_2 LBHS auroral image (right panel in Fig. 3) also shows a bright auroral spot at the cusp region. There are a few parallel polar cap arcs (above 80° Mlat) join together in the cusp region. The orientation of the arcs (the dayside ends) are tilted toward the dusk side, similar to those in the sketch of Fig. 1b.

There are cases where the polar cap arcs in the dawn and dusk sectors tilted differently, as revealed by the auroral image in the left panel of Fig. 4. This can be explained by the cusp location (around noon) and the location of the nightside end of the arc where they connected to the auroral oval. There is an extreme case that one polar cap arc is about 45° away from the sun-aligned direction (see the right panel of Fig. 4). The two cases in Fig. 4 were observed under a strongly northward IMF (B_z~9.6 nT) and slightly northward (B_z~2.2 nT) conditions, respectively.

3. Discussion

Auroral signature in the cusp location has been studied under a southward IMF (Zhang et al., 2005 and references therein) and northward IMF (Frey et al., 2003). Under a southward IMF, cusp aurora covers a large magnetic local time (MLT) range (e.g. 9:00 – 15:00 MLT), moves to a low Mlat and covers a narrow latitude range (Zhang et al., 2005). This is due to a strong magnetic field reconnection between IMF and the earth's magnetic field at the low latitude magnetopause. During a northward IMF, the cusp aurora move to high latitudes and become a localized spot with a limited MLT and Mlat coverage (Frey et al., 2003). The northward IMF cusp is created by high-latitude magnetic field reconnection (Frey et al., 2003; Zhang et al., 2009). The FUV auroral images shown in Figs. 2–4 were all associated with a northward IMF. The FUV observations also indicate that polar cap arcs are connected to the cusp region. They appear to be cusp aligned. This concept indicates that the orientation of polar cap arcs is determined by the cusp location and the location of the nightside end of the arcs. This explains why polar cap arcs are sun-aligned sometimes and they are often not sun-aligned.