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OCCURRENCE CONDITIONS FOR TWO DIFFERENT KINDS OF TRANSPOLAR ARCS

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Abstract: On the basis of DMSP auroral image and particle data, the occurrence conditions of sun-aligned arcs and theta auroras are examined for various solar wind conditions. Sun-aligned arcs appear during geomagnetically quiet period and also the period of northward IMF associated with high solar wind velocity. Theta auroras appear during the period of moderate geomagnetic activity and also extremely high solar wind velocity. However, IMF B_z is not always positive when theta auroras appear. These results may suggest that the source of sun-aligned arc and theta aurora are quite different.

1. Introduction

Auroral activity in the polar cap is not so high in general. Several researchers studied high latitude auroral phenomena in the polar cap (*e.g.*, DAVIS, 1963; STARKOV, 1968; EATHER and AKASOFU, 1969). Among them, LASSEN and DANIELSEN (1978) showed that discrete auroral arcs are observed along the sun-earth direction in the polar cap. These transpolar arcs in the polar cap is called the sun-aligned arcs, and they demonstrated the statistical distribution of sun-aligned arcs for various IMF condition. They showed that sun-aligned arcs appear during the period of northward IMF.

Recently, attention has been paid to very fascinating auroral phenomena in the polar cap. Especially, FRANK *et al.* (1986) showed bright transpolar arcs in the polar cap using DE-1 satellite auroral image data. This bright transpolar arc is called theta aurora and its characteristics is quite different from sun-aligned arc. For example, sun-aligned arc is very weak in luminosity and its width is very narrow. On the contrary, theta aurora is very bright and its width is very wide.

MAKITA (1985) examined the characteristics of particle precipitation associated with sun-aligned arc and also theta aurora. He showed that the energy spectrum of precipitating particles associated with sun-aligned arc has a clear peak electron flux at about a few hundred eV. On the other hand, the electron spectrum associated with theta aurora shows a clear peak at energy between 1 to 10 keV. PETERSON and SHELLY (1984) also showed that there is no difference between ion precipitation in the transpolar aurora and that in the auroral oval.

Although several researchers examined the polar cap aurora and obtained various new results, it is still not well understood what kind of conditions are essential to excite sun-aligned arc and/or theta aurora. In this paper, the occurrence conditions of these two types of polar cap auroras are examined for various solar wind conditions using DMSP auroral image and particle data.

2. Occurrence Condition for Sun-Aligned Arcs

DMSP/F2 electron precipitation data from August 1978 to December 1979 were examined in order to clarify the occurrence conditions for sun-aligned arc.

The sun-aligned arcs are observed during quiet geomagnetic activity and northward IMF period, so that we selected the particle data during the period when IMF B_Z is positive and AE index is less than 100 nT at least over 6 hours. Since we analyzed limited particle data obtained during the polar passes traversing latitudes higher than 80°, only 23 events were selected from our data set.

We identified distinct sun-aligned arc precipitation events using the criteria that (1) electron precipitation is seen above 80° latitude, (2) its number flux is larger than 10^8 (eI/cm^2. sr, s) and (3) its average energy is higher than 500 eV. If the electron flux and average energy are lower than the above threshold values, we classified these events as low energy electron precipitation events without accompanying sun-aligned arcs. The relationship between occurrences of visual sun-aligned arcs and the critical levels of electron flux and average energy was confirmed through the comparison between auroral image data and electron precipitation data.

We examined the relationship between solar wind velocity and IMF B_Z value for these two different particle precipitation phenomena. Our statistical result is illustrated in Fig. 1. It shows that sun-aligned arcs are mainly observed during the period of high solar wind velocity. There is no clear relationship between positive B_Z values and occurrences of sun-aligned arcs. On the other hand, the low energy (<500 eV) electron precipitation events are often observed in the polar cap during the low solar wind velocity period.

We also examined the relationship between AE index and these two different types of precipitation events. It is found that the value of AE index during the appearance of sun-aligned arc is slightly larger than that during the period of low energy electron precipitation events.

3. Occurrence Condition of Theta Auroras

On the basis of the DMSP auroral image data obtained during January, October, November, December 1983 and January 1984, seven typical transpolar auroras (theta auroras) are found in our data. Here, we defined theta aurora as a very bright and discrete aurora extending from the midnight auroral oval to the center of the polar cap. Among the above seven events, IMF data are available for only four events. We examined the occurrence conditions of these four events for solar wind velocity and geomagnetic activity.

The scatter plot of the occurrence conditions of theta aurora is illustrated in Fig. 2. We also selected several typical sun-aligned arc events as well as low energy electron precipitation events without sun-aligned arc. These results are also plotted

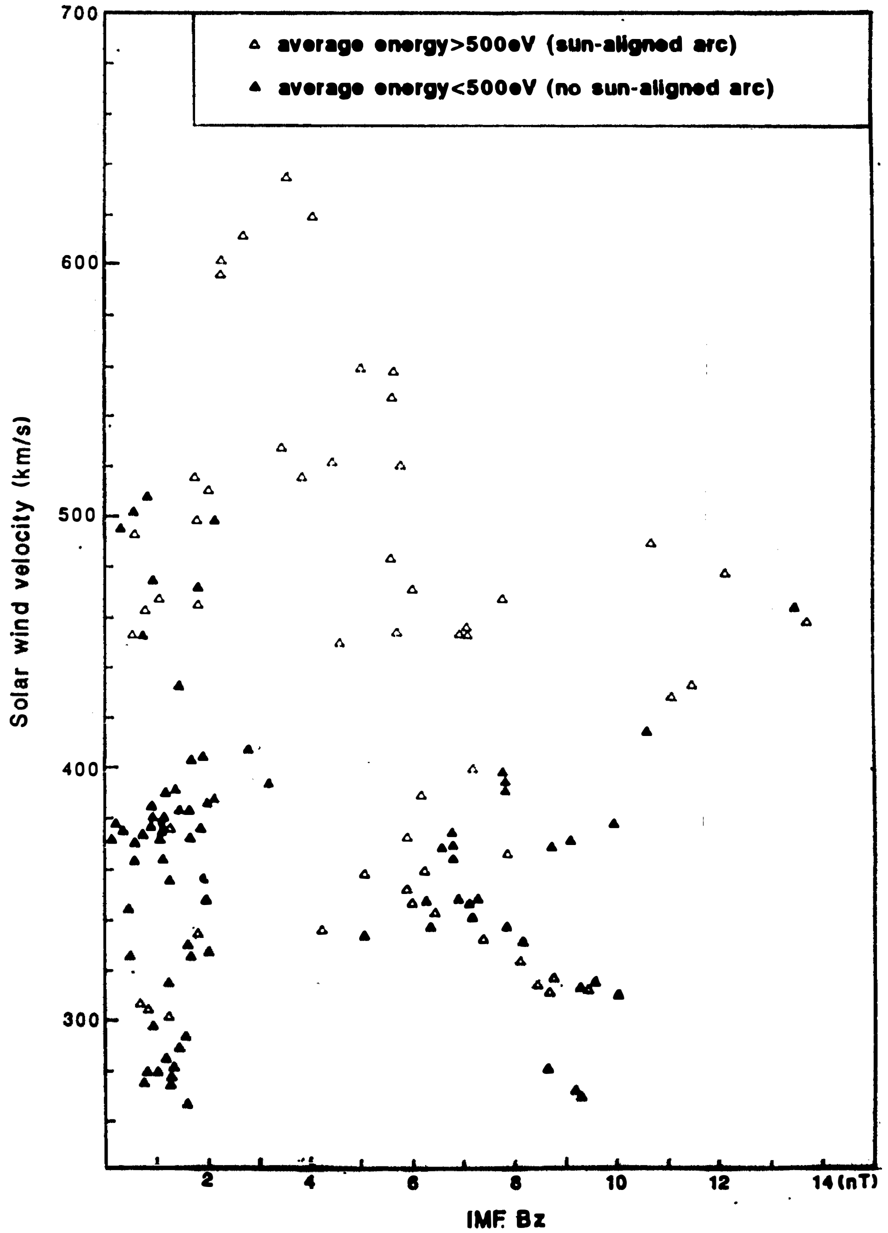

Fig. 1. The relationship between solar wind velocity and IMF Bz value during sun-aligned arc (E>500 eV) precipitation events and low energy electron (E<500 eV) precipitation. The sun-aligned arc precipitation occurs more frequently during high solar wind velocity period.

in Fig. 2. It indicates that theta auroras occur during the period of large AE index (>100 nT) and also high solar wind velocity (>400 km/s). On the contrary, sun-aligned arcs occur when AE index (<100 nT) is small and solar wind velocity is high (>400 km/s). Furthermore, low energy electron precipitation events occur during the period of low AE index and low solar wind velocity.

The occurrence conditions of bright transpolar arcs (theta aurora), sun-aligned arcs and also low energy electron precipitation events without sun-aligned arcs in

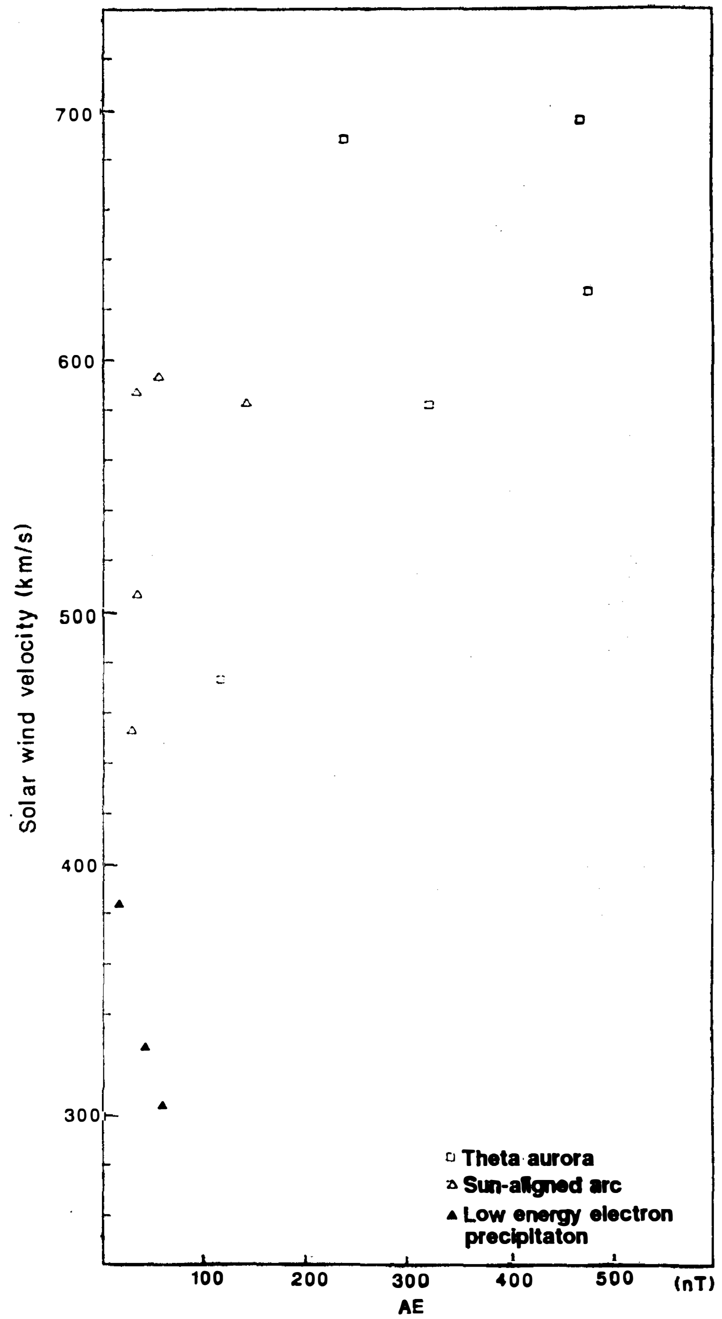

Fig. 2. The occurrence conditions of theta aurora, sun-aligned arc precipitation and no sun-aligned arc precipitation are shown for solar wind velocity and hourly average AE index. Theta auroras are seen during the period of large AE index and also high solar wind velocity.

Fig. 2 are summarized for various parameters in Table 1. Although the occurrence conditions of these events must be different case by case, however, low energy electron precipitation events tend to occur during the period of northward IMF (B_Z=4.7 nT), small AE index (AE 56 nT) and low solar wind velocity (V=347 km/s).

Sun-aligned arcs occur during the period of the northward IMF (B_Z=4.6 nT),

Table 1. The magnitude of IMF (B), the Z component of IMF (Bz), solar wind velocity and AE index are summarized for low energy electron precipitation events, sun-aligned arc precipitation events and also theta auroras, respectively.

Low energy electron precipitation	IMF B	IMF B_Z	Velocity (km/s)	AE index
1983, Mar. 9, 15h–16h	10.1	2.6	306	48
1983, Oct. 28, 16h–17h	12.7	10.1	351	92
1983, Nov. 23, 12h–13h	3.5	1.5	385	28
(average)	8.8	4.7	347	56
Sun-aligned arc				
1983, Jan 1, 15h–16h	10.4	10.0	509	75
1983, Oct. 8, 14h–15h	4.8	1.3	584	142
1983, Nov. 11, 06h–07h	10.8	5.4	596	59
1983, Nov. 17, 14h–15h	8.0	1.5	737	316
(average)	8.5	4.6	606	148
Theta aurora				
1983, Jan. 15, 12h–13h	18.0	6.4	473	163
1983, Nov. 15, 15h–16h	10.9	−0.9	627*	480
1983, Nov. 29, 16h–17h	10.3	6.2	689	242
1984, Jan. 30, 15h–16h	7.0	0.2	751	422
(average)	11.6	3.0	635	327

* one hour after value

moderate AE index (AE=148 nT) and large solar wind velocity (V=606 km/s). On the other hand, theta auroras are observed during the period of northward IMF (B_Z=3.0 nT), large AE index (AE=327 nT) and large solar wind velocity (V=635 km/s). Furthermore, the theta auroras are mostly observed during the period of large IMF magnitude associated with rapidly increasing solar wind velocity. Among four events in Table 1, two events (Nov. 29, Jan. 30) are seen after the onset of SSC and during the recovery phase of substorms.

4. Discussion

There are two different kinds of transpolar arcs in the polar cap. They are sun-aligned arcs and theta auroras. It was shown that the occurrence conditions of these two types of transpolar arcs are quite different each other. Sun-aligned arcs appear during northward IMF, and thus during the period of low geomagnetic activity. The solar wind velocity is high in such intervals. On the other hand, the occurrence condition of theta auroras is quite different from that of sun-aligned arcs. It seems that theta auroras appear when IMF is not always strongly northward and thus the geomagnetic activity is relatively low. It is also found that the solar wind velocity is very high when theta auroras appear.

From these results, it may be said that particles from the sun causing sun-aligned arcs and theta auroras are quite different. We consider that the particle sources of sun-aligned arcs seem to be accelerated magnetosheath electrons and/or plasma mantle electrons. The sun-aligned arc precipitation has energy spectra with a clear peak at a few hundred eV (MAKITA, 1985). On the contrary, the particle sources of theta auroras appear to be precipitating plasma sheet electrons during disturbed geomagnetic activity period. In fact, the electron precipitation associated with the transpolar branch of theta aurora shows a clear peak at energy between 1 and 7 keV. The energy spectrum of precipitating electrons associated with theta aurora in the polar cap is basically the same as that associated with bright discrete arcs along the auroral oval (MAKITA, 1985). Our results are consistent with ion precipitation observations examined by PETERSON and SHELLY (1986), who claimed that no difference exists in the case of transpolar and oval auroras.

It is our new finding that two different kinds of transpolar auroras appear in the polar cap during the period of high solar wind velocity. These results suggest that the auroral activity in the polar cap is more directly controlled by solar wind velocity as well as B_Z polarity. In the future, we will examine much more events to clarify the relationship between solar wind-magnetosphere interaction processes and transpolar auroral arcs.

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