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POLAR CUSP, PLASMA MANTLE PARTICLES AND THEIR RELATIONSHIPS TO POLAR RAIN

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Abstract: On the basis of low altitude DMSP satellite particle data, characteristics of polar rain, cusp and plasma mantle are examined during the asymmetric polar rain enhancement period. Obtained results are summarized as follows; (1) From the comparison between number flux of cusp and polar rain precipitations, the cusp flux does not increase correlatively with the increasing of polar rain flux. This result suggests that sources of precipitating particles are quite different from each other. (2) Low energy pulsive electrons (plasma mantle) are occasionally observed in the polar rain region. These plasma mantle particles are observed in both hemispheres and the polar rain enhancement shows hemispheric asymmetry. The mixing of polar rain and plasma mantle may be occurred due to the movement of plasma mantle by electric field drift.

1. Introduction

Asymmetric polar rain precipitations in the northern and southern hemispheres are controlled by the interplanetary magnetic field sector structure (YEAGER and FRANK, 1976; MENG and KROEHL, 1977; MAKITA and MENG, 1987; Gussenhoven *et al.*, 1984; BAKER *et al.*, 1987). Many researchers reported that during the toward sector ($B_x>0$ and $B_y<0$), the polar rain flux in the southern hemisphere is larger than that in the northern hemisphere and during the away sector ($B_x<0$ and $B_y>0$), the polar rain flux in the northern hemisphere is larger than that in the southern hemisphere. The enhancement of polar rain seems to be occurred due to the interaction of the interplanetary magnetic field (IMF) and magnetospheric tail field line. However, since this phenomena does not always occur even if IMF and tail field line satisfy the interaction conditions. Therefore, FAIFIELD and SCUDDER (1985) proposed that the polar rain particles are enhanced associated with the increasing of a special field-aligned component of the solar-wind electron population called the "strahl" electron. Strahl electrons may be related to the energetic coronal electrons, where densities are low and velocities are high. Usually, electron number flux of polar rain is less than 10^6 els/cm^2 s sr, and a characteristic average energy is less than a few hundred electron volts (WINNINGHAM and HEIKKDLA, 1974). When the polar rain enhancements are observed in the northern or the southern hemispheres, the electron number flux increases to 10^8 els/cm^2 s sr and the energy flux also increases from 10^{-3} erg/cm^2 s sr to 10^{-1} erg/cm^2 s sr. Occasionally very intense polar rain phenomena is also observed and examined by NEWELL and MENG (1992). They showed that electron energy is higher than a few keV and the energy flux is up to a few tens of an ergs/cm^2 s sr. Fluxes of this magnitude can make the entire polar cap glow and comparable to the total energy flux precipitating into the auroral oval.

In this paper, we examined the relationship between polar rain electron flux and other region's precipitating electrons and ions, for example cusp and plasma mantle. To our knowledge, it is not well understood the effect of other precipitating regions when the polar rain enhancement occurs. We presented the preliminary results about cusp, plasma mantle and polar rain sources using the polar rain enhancement data.

2. Polar Cusp Precipitations and Polar Rain Enhancement

Many researchers examined the characteristics of polar cusp particles (FRANK, 1971; BURCH, 1972; FORMISANO and BAVASSANO-CATTANEO, 1978; HAERENDEL *et al.*, 1978; MENG, 1981; CANDIDI and MENG, 1984). Cusp particles are directly precipitating from the magnetosheath and the location and the width of cusp are controlled by IMF variations and also geomagnetic activities. The precipitating electron number flux is larger than 10^8

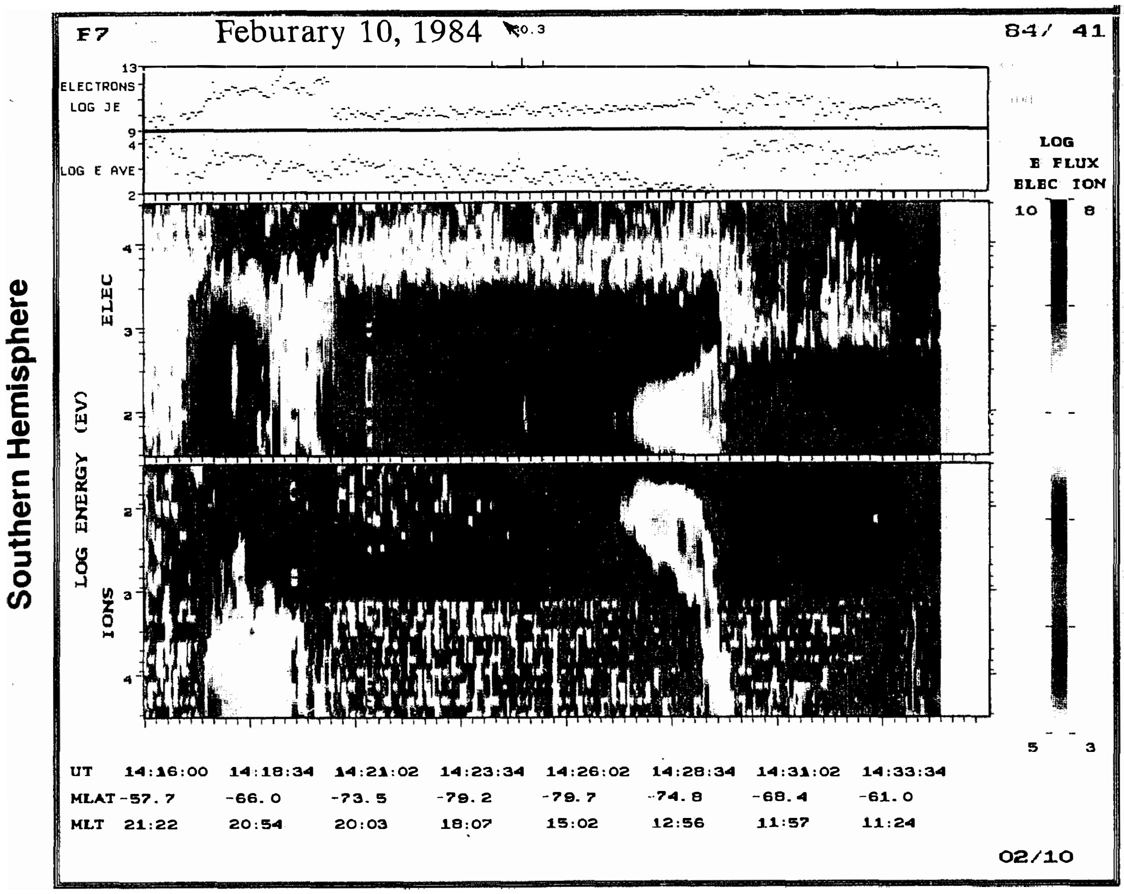

Fig. 1. A typical polar rain enhancement event in the southern hemisphere. The upper panel is electron data and the lower panel is ion data. On the day side (right hand side), electron precipitations of cusp (73.1–76.4 MLAT) and polar rain (> 76.4 MLAT) are continuously observed without a gap. The boundary between cusp and polar rain is recognized from the ion precipitation data, where the intense and dispersive ions are sharply decreases at 76.4 MLAT.

els/cm^2 s sr and its average energy is usually less than 100 eV. For ion particles, the number flux is larger than 10^7 ions/cm^2 s sr and average energy is a few keV. The cusp region is characterized by the energy dispersion of ion precipitation. Namely, a few keV ion precipitates near the lower latitude side of cusp and its energy becomes lower as reaching to the poleward boundary of cusp. In this paper, the polar cusp region is determined by the ion dispersion region and also intense low energy electron precipitation.

The polar rain flux is usually low and its number flux is less than 10^6 els/cm^2 s sr and the average energy is less than 100 eV. When the asymmetric polar rain enhancement occurs, the electron number flux occasionally reaches to 10^8 els/cm^2 s sr. However, ion precipitations are not found in this polar rain region. Since polar rain electrons increases in the polar cap, it becomes difficult to separate the boundary between cusp and polar rain region by using only electron data. Figure 1 illustrates the polar rain enhancement event observed in the southern hemisphere during the interval from 1416 to 1433 on February 10, 1984. Although the solar wind data are not available in this period, however, there is IMF data obtained at 05 h UT (9 hours before). In this time, IMF $B_x=4.3$ nT, $B_y=7.0$ nT and $B_z=-0.3$ nT, solar wind velocity=402 km/s and density=9.5/cm^3, respectively. It is speculated that IMF is toward sector till the beginning of this event. The particle data examined here is obtained by DMSP/F7 satellite, which is a sun-synchronous polar orbiting satellite and its altitude is about 840 km. The detected energy range for electrons and ions are from 30 eV to 30 keV. In this figure, the upper and the lower panels shows electron and ion data, respectively. The satellite traverses from the nightside to the dayside during this interval. In the nightside region, high energy electron and ion related to auroral oval are seen at the latitude from 61.3° to 72.3°. Near the dayside, the remarkable electron and ion precipitation region is found at the latitude from 71.6° to 73.1°. The average electron energy is about 100–300 eV and the ion energy is about 1–10 keV. These particles seems to be related to the low latitude boundary layer (NEWELL and MENG, 1992). At the higher latitude side of this region, low energy electrons (~100 eV) and energy dispersion of ion can be observed at the latitude from 73.1° to 76.4°. This region seems to correspond to the cusp region. The enhanced polar rain precipitations are beginning at the latitude from 76.4° in the dayside. The number flux of polar rain is larger than 10^7 els/cm^2 s sr and electron energy is less than 500 eV. There is no ion precipitation in this enhanced polar rain region. it is noted that the enhanced polar rain precipitations are also found in the cusp region. Since the polar rain and cusp particles seem to be located at the similar field lines, thus, the fluctuation of cusp and polar rain electron number flux seem to have some relations. In order to make clear this tendency, the number flux of cusp and polar rain particles are examined when polar rain enhancement occurs. The polar rain enhancement events are selected on the basis of DMSP/F7 satellite data obtained in 1984. It is a selected criteria that the polar rain peak number flux is higher than 10^7 els/cm^2 s sr and the typical cusp structure can be seen along satellite passes. The total events picked up here are 15 days. They are Feb. 16 (N), Feb. 17 (N), Mar. 23 (N), Mar. 30 (N), Apr. 30 (S), May 1 (S), May 2 (S), May 12 (N), May 13 (N), May 14 (N), May 16 (N), May 27 (S), May 28 (S), May 30 (S) and Dec. 15 (N). The sign of N or S indicates the enhanced hemisphere of polar rain. Among these days, 130 passes are examined for the comparison between cusp and polar rain number flux including both hemispheres. Figure 2 illustrates the relationships between the electron number flux of cusp and polar rain. In this analysis,

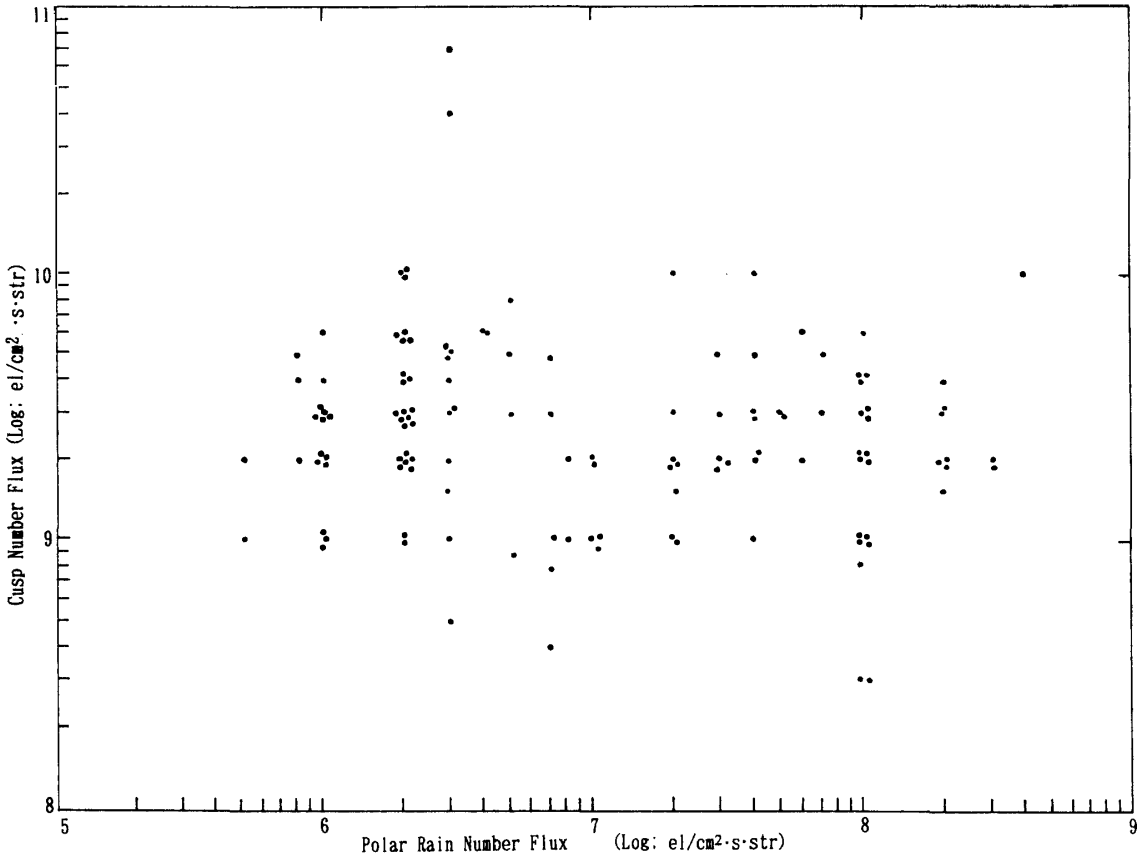

Fig. 2. The relationships between the electron number flux of cusp and polar rain. There is no clear correlation between these two events. This result indicates that the origins of cusp and polar rain are different.

simultaneous cusp and polar rain electron peak number flux in the same hemisphere are plotted. If the cusp electron increases associated with the polar rain flux, the cusp flux is correlative with the polar rain flux. However, there is no clear correlation between electron number flux of cusp and polar rain. It suggests that the origin of particles are different each others.

3. Polar Rain Enhancement and Plasma Mantle

The low energy electrons less than a few hundreds eV are frequently observed at the higher latitude side of cusp and auroral oval. These particles are called plasma mantle and sometimes mixed with polar rain. From optical auroral observations, plasma mantle precipitation may relate to the excitation of the sun-aligned arc. Since precipitating particles originated from plasma mantle and polar rain are observed in the polar cap region, thus, the characteristics of these two precipitations may have some similarities. In this section, a typical plasma mantle event is selected and examined the characteristics between plasma mantle and polar rain.

Figure 3 illustrates the low energy pulsive electron precipitations in both hemispheres

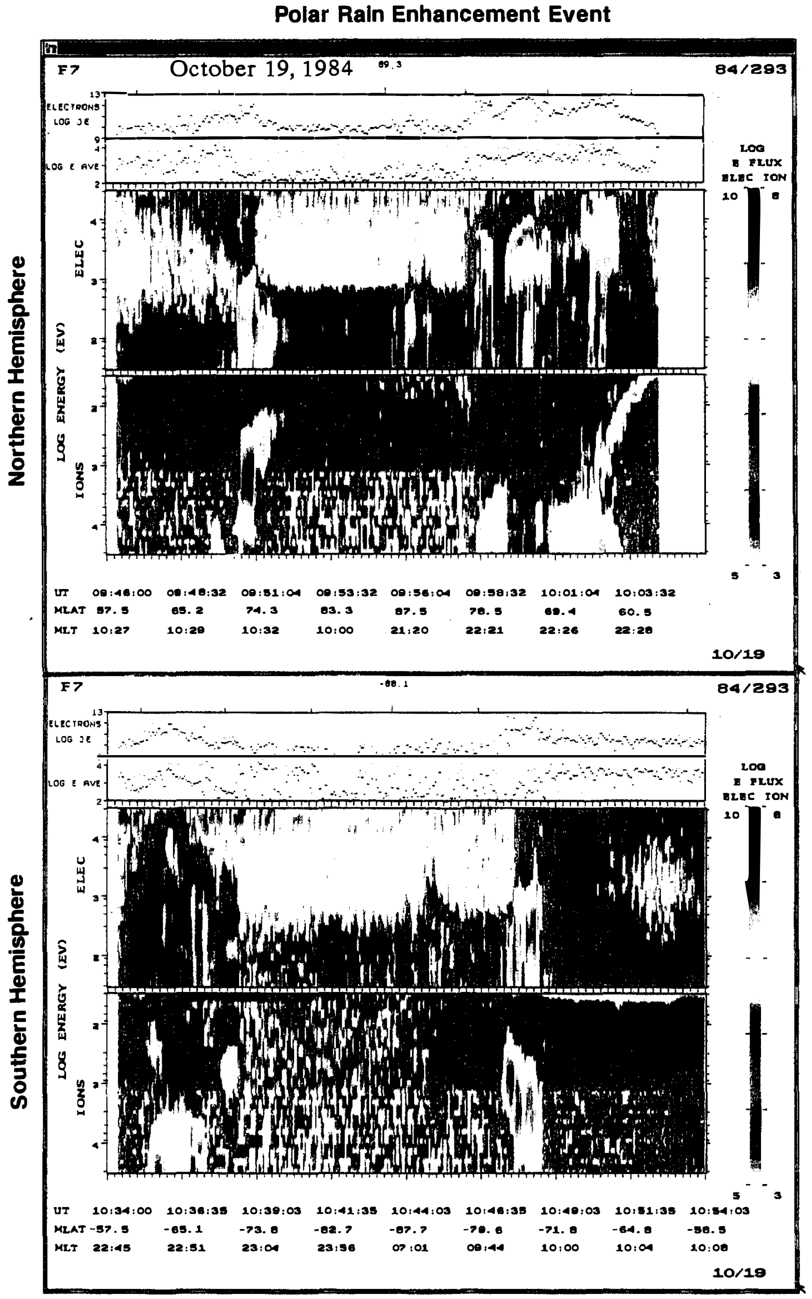

Fig. 3. *Low energy impulsive electrons (plasma mantle) in both herispheres during the northern polar rain enhancement period. The upper panel shows the northern pass where the plasma mantle is seen in the evening polar cap region (83.0–86.4 MLAT). The lower panel shows the southern pass where the plasma mantle is seen in the morning polar cap region (82.6–87.7 MLAT).*

during polar rain enhancement period. The data was obtained on October 19, 1984. The solar wind data was not available in this period. However, one hour before data in this event (08–09 h UT) is available. The solar wind velocity is 621 km/s, density is $10^7/cm^3$ and IMF $B_x = -9.3$ nT, $B_y = 7.3$ nT and $B_z = -4.7$ nT. It indicates that the IMF is away sector during this interval. The upper panel illustrates the electron and ion data obtained in the northern hemisphere. The satellite traverses from the dayside to the nightside during the interval from 0946 to 1003 UT. From 72.3° to 74.3° magnetic latitude in the dayside, low energy electrons less than 1 keV and a few keV ions are observed and this region seems to be LLBL region. In the higher latitude side of this region, electron less than 200 eV and ion less than 1 keV with energy dispersion structure are observed from 74.3° to 77.0° latitude. This region corresponds to typical cusp region. The enhanced polar rain precipitations are embedded all over the polar cap region where is higher latitude side of polar cusp. It is noted that the low energy pulsive electrons are recognized at the latitude from 83.0° to 86.4° in the evening sector. There is no ion precipitation corresponding to this pulsive electron region and such pulsive electrons are seen at the higher latitude side of polar cusp. Therefore, we defined this pulsive electron as the

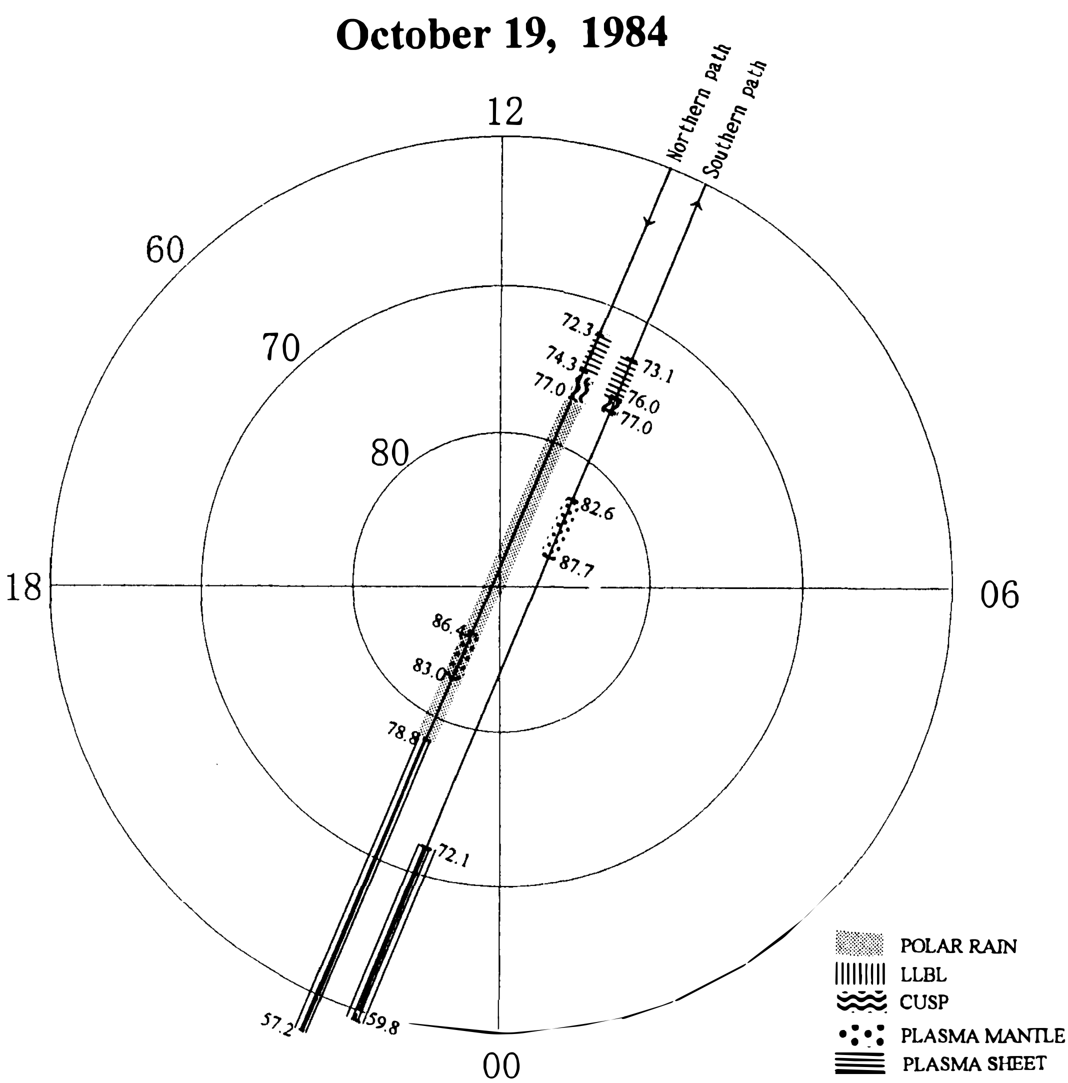

Fig. 4. Precipitation regions of polar rain, LLBL, cusp, plasma mantle and plasma sheet along the northern and southern passes as described in Fig. 3. On the dayside, the location of LLBL and cusp regions are similar in both herispheres. Plasma mantle regions show dawn-dusk herispherical asymmetry.

plasma mantle. The precipitation of plasma mantle mixes in the enhanced polar rain region. Since the source region of plasma mantle and polar rain may be different, thus the mixing of these two particles seems to be occurred by the movement of plasma mantle from the magnetopause to the tail lobe. In the nightside, the auroral oval is expanded to the wide area and it is recognized at the latitude from 57.2° to 78.8° in this time.

The lower panel illustrates the electron and ion data obtained in the southern hemisphere. The satellite traverses from the nightside to the dayside and the data was obtained during the interval from 1034 to 1054 UT. This observation time was about 50 min after the time of the northern pass. In the dayside sector, a few hundreds eV electrons and a few keV ions are seen in the latitude from 73.1° to 76.0°. The characteristics of these particles are corresponding to LLBL. In the higher latitude side of this region, electrons less than 200 eV and ions less than a few keV with energy dispersion are observed between 76.0° and 77.0°. This region corresponds to cusp region. There is no polar rain enhancement in the southern polar cap, however, low energy pulsive electron precipitations are recognized at the latitude between 82.6° and 87.7° in the morning sector. This precipitation seems to correspond to the pulsive electron precipitaion in the northern polar cap region as described above.

In order to compare precipitation regions in both hemispheres, the satellite orbits and particle precipitating regions are illustrated in Fig. 4. It shows that precipitating regions related to LLBL and cusp in the dayside are very similar in the northern and the southern passes. On the other hand, plasma mantle precipitations are seen in the morning sector (82.6°-87.7°) for the southern hemisphere and in the evening sector (83.0°-86.4°) for the northern one. The asymmetric plasma mantle precipitations in the northern and the southern hemispheres depend on the IMF B_y polarity (HEPPNER, 1972; LASSEN and DANIELSON, 1978; MOSES *et al*., 1985; MAKITA *et al*., 1991). For example, when IMF B_y is positive, the northern sun-aligned arc appeared in the evening sector and southern sun-aligned arc appeared in the morning sector. According to IMF data at one hour before of this phenomena, IMF B_y was positive value. Thus, the tendency of this dawn-dusk asymmetric precipitation due to IMF B_y polarity seems to be consistent to the previous researchers' results. In this example, although the polar rain enhancement occurs in one hemisphere, the pulsive precipitating electrons (plasma mantle) are simultaneously observed in both hemispheres. These results suggest that particle origins seem to be different, respectively.

4. Summary and Conclusion

On the basis of DMSP/F7 particle data, the relationships among polar rain, cusp and plasma mantle particles are examined when the polar rain enhancement occurs. Our preliminary results are summarized as follows.

(1) The precipitating region of polar rain and cusp looks like overlapping in the dayside when polar rain enhancement occurs. However, the number flux of cusp and polar rain does not correlate well. This result indicates that the origin of precipitating particles are different, respectively.

(2) The precipitating region of plasma mantle (low energy pulsive electron) is mixed with the polar rain region. It is noted that plasma mantle particles are observed in both

hemispheres simultaneously, although the dawn-dusk asymmetry exist due to the IMF By polarity. Since the polar rain enhancement shows clear asymmetry in both hemispheres, so the origin of plasma mantle is quite different from that of polar rain.

From the low and high altitude particle observations near the dayside regions (Formisano, 1980; Newell and Meng, 1992), magnetosheath, cusp, LLBL, plasma mantle and polar rain electron spectra are examined for the relationships between their source region in the magnetosphere and precipitating region at the ionospheric altitude. On the other hand, Bame *et al.* (1983) examined electron data at the distant magnetotail ($\sim$70 R_E) and showed five distinct plasma regimes; magnetosheath, low latitude boundary layer, plasma mantle, tail lobe and plasma sheet. Greenspan *et al.* (1986) presented results of a study comparing intense polar rain measured by DMSP with concurrent measurements of electrons by ISEE 1 in the near tail lobes ($<$20 R_E). They found several cases in which the ISEE 1 and DMSP spectra were nearly identical. Those results and also other researchers' reports suggest that distinct different particles sources are existing in the magnetosphere and these particles from different origin must be possible to separate each others near the low altitude.

Since our statistical study suggests that the variation of cusp particle and polar rain number flux show no correlation, thus the origin of solar wind particles are different, respectively. Namely, cusp particles are related to the ordinary solar wind particles and enter the magnetosphere without special interaction between IMF and geomagnetic field. So, the amount of cusp particles and also their precipitation region are determined by the dayside magnetospheric structure. On the contrary, the enhancement of polar rain are observed, when the special solar wind particles (strahl electron) increase and also the interactive condition between IMF and geomagnetic field is satisfied.

We presented that plasma mantle are occasionally mixed with the polar rain region. Since the source of plasma mantle is observed near the magnetopause boundary, the mixing in the polar cap may be due to the movement of plasma mantle by electric field drift. For example, the dawn to dusk electric field in the equatorial plane will induce plasma mantle drift from magnetopause to inner magnetosphere (tail lobe). If the dawn to dusk electric field is 1 mV/m and magnetic field intensity near the magnetopause is 1 nT, then particle drift velocity becomes 10 m/s. It is noted that the northern and southern asymmetry of the plasma mantle seems to be controlled by IMF B_y polarity. From the low altitude particle observations, the plasma mantle region will gradually mix to the polar rain precipitation region when the IMF turns to the northward. Recently, Obara *et al.* (1994) reported the clear relationships between spiky low energy electron precipitation (plasma mantle) and div $E<0$ in the polar cap during the northward IMF period. This result suggests that the upward field aligned current is related to the precipitation of plasma mantle. At the present, the detail precipitation process of plasma mantle during northward IMF period is not clearly understood yet, however it seems important to examine plasma mantle precipitation mechanism in order to understand a solar wind and magnetosphere coupling.

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