Auroral Activity and Its Connection with Magnetospheric Processes —Magnetic Field Conjugacy between the Polar Ionosphere and the Magnetosphere—

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Correlation between auroral structures and the magnetospheric structures, together with magnetic field conjugacy between the polar ionosphere and the magnetosphere is studied using the magnetic field models proposed by TSYGANENKO and USMANOV (1982) and TSYGANENKO (1987, 1989). The spatial extent where the nightside aurora expands is correlated with the tail plasma sheet, and the magnetospheric sources of radial structures of the dayside aurora are located in the tail flank. It is also shown that these models have a limitation, or rather a systematic error, especially in between the region-1 and region-2 field-aligned current sheets. This limitation is due to the fact that the magnetic effects of these field-aligned currents are not consistently taken into consideration in these models. The real footprint of a synchronous satellite estimated by correlating the magnetic field changes at synchronous orbit with an auroral expansion front is deviated 300–400 km east of the footprint estimated by these models at the auroral altitude in the dusk sector. At the same time, it is shown that the magnetic field due to the field-aligned current associated with these auroral structures is spatially limited, and, subsequently, is useful for studying the magnetic field conjugacy between the polar ionosphere and the magnetosphere.

1. Introduction

An observation of a plasma quantity measured by a satellite, (d/dt) , can be understood only when it is divided into a temporal variation $(\partial/\partial t)$ and a change due to spatial structures $(\mathbf{v} \cdot \partial/\partial \mathbf{r})$. A single satellite observation is ineffective to this. On the other hand, various ground observations of the ionospheric phenomena, *e.g.*, optical observation of auroras and network observation of waves and magnetic field variations, could provide us information of two-dimensional distribution and its temporal evolution.

The space time separation of the satellite observation can be achieved if (d/dt) at the satellite is correlatively compared with temporal-spatial changes, $(\partial/\partial t + \mathbf{v} \cdot \partial/\partial \mathbf{r})$, at the ionospheric level or the auroral altitude along the footprint trajectory of the satellite, together with a consideration of the propagation path and time of particles, waves or currents from the magnetosphere to the ionosphere. Such a reliable comparison of satellite observations with the ionospheric level observations, although easy to say, actually is a fairly laborious task. Not many successful comparison in

rigorous meaning has been known even with low altitude satellites. No reliable result of the comparison has ever been obtained between distant satellites and the polar ionosphere.

The correlation study of a certain phenomenon at the ionospheric level with its magnetospheric correspondent is a crucial procedure to know magnetic field line connection between them in one direction, and the examination of field line connection is an essential procedure to study magnetospheric plasma processes based upon spatial-temporal changes from the ionospheric level correspondents in the opposite direction. Thus, the study of magnetic field distribution and that of the magnetospheric plasma processes are mutually interacting elements of iteration for a successive approximation to reach the real understanding both of them.

This paper describes magnetic field line connections between auroral activities in the polar region and magnetospheric processes or structures, together with some results of examination of the magnetospheric magnetic field models proposed by TSYGANENKO and USMANOV (1982), and TSYGANENKO (1987, 1989). We will first show that these models appear quite reliable for studying large scale auroral and magnetospheric structures, and, next, that the models have a limitation due to the lack of magnetic fields of the large scale field-aligned currents especially in the inner magnetospheric region in between the region-1 and region-2 currents. The transient nature of the magnetospheric magnetic field will also be briefly discussed as one of reasons in shortcomings of these statistical models in studying the conjugacy between small scale auroral and magnetospheric structures.

2. Large Scale Structures

A large scale auroral structure such as the auroral oval must be connected with a large scale magnetospheric structure with magnetic field lines. When based upon the magnetic field model proposed by TSYGANENKO and USMANOV (1982) and TSYGANENKO (1987, 1989), it is highly probable that the dayside small portion of the auroral oval is connected with the outermost part of the magnetosphere, whereas most of the oval, from 14 to 10 MLT through the night sectors, is connected with the tail plasma sheet as seen in Fig. 1.

Figure 1 is a reproduction from OGUTI (1989) showing loci of magnetic footprint of the outermost magnetosphere, 0.3, 1, 2 and 3 R_E inside from the magnetopause. This figure shows that the positive and the negative potential peaks in the polar cap, that is, the two convection centers, are connected with the tail plasma sheet inside the magnetotail, not with the high latitude magnetopause. Therefore, if the magnetospheric magnetic flux connected with the solar wind magnetic flux provides the driving force for the magnetospheric convection, then the directly-connected (directly driven) region must be a part of the polar cap. This region must be a belt elongated in the Sun-Earth direction from the dayside cusp to the nightside oval through the center of the polar cap.

The rest parts of the polar cap including the potential peak regions, must not be directly driven by the solar wind, and, instead, indirectly driven by "frictional" force caused by the directly driven part. The "friction", or penetration of the electric field, mainly occurs within the ionosphere. The indirectly-driven parts, therefore, are subject to the motional induction. The Pedersen current due to the motional induction brings

Fig. 1. Projection of the outermost part of the magnetosphere onto the polar ionosphere along magnetic field lines by use of Tsyganenko-Usmanov field model (TSYGANENKO and USMANOV, 1982). The smallest elliptic locus is the projection from $0.3 R_E$ inside from the magnetopause. From the second smallest to the largest each corresponds to that from 1, 2 and $3 R_E$ inside (OGUTI, 1989). The dayside auroral region, ± 2 hours around the magnetic noon, is connected to the boundary layer with the thickness less than $1 R_E$.

force charge separation. The electric potential caused by this charge separation must be the source of the positive and the negative potential peaks in the polar cap. This is the scenario of the driving of the magnetospheric convection based upon the dayside reconnection idea.

However, this scenario has a fatal discrepancy with observation. If this scenario is operative, then the charge separation in the potential peak regions is due to Pedersen currents caused by the motional induction, and, therefore, the field-aligned current in this region must be opposite to the observed region-1 currents by IJIMA and POTEIRA (1976). Thus, this scenario fails.

One may claim that the magnetic field models used here are not accurate enough for estimating the location of the magnetospheric source regions of the potential peaks in the polar cap, and the potential peak regions may be connected with the magnetopause. This is equal to claim that the whole polar cap fluxes are connected with the solar wind fluxes. If this is the case, the potential difference across the polar cusp in the east-west direction should be equal to the total potential difference across the polar cap. Natural consequence of this is a presense of strong eastward electric field within the dayside cusp. Actually, however, this is not the case. Enhancements in the north-south component of electric fields sometimes are found in the dayside cusp associated with the changes in IMF-By, but this is not for the east-west component.

One may further claim that the size of the dayside cusp, connected with the magnetopause boundary layers could be much larger than the esimated one. If this is the case, the eastward electric field in the cusp may be reasonably reduced to meet with observations even if the potential across the cusp is the same as that across the polar cap. Problem here is the east-west size of the dayside polar cusp, although much larger cusp is difficult to be expected from the magnetic field models based upon observation by HEOS satellite (HAERENDEL *et al.*, 1978). In order to examine this point, we search

further observational evidence along with an examination of the magnetic field model used here.

2.1 Limit of the auroral expansion

The first point is a probable limit in MLT of the auroral expansion from the nightside. An auroral expansion is normally initiated around the midnight meridian, and expands westward and eastward along the auroral oval, together with poleward and equatorward expansion, in an almost symmetric fashion to the noon-midnight meridian. The point here is the boundary between the midday auroras around the polar cusp and nightside auroras which expands from midnight meridian.

We have not many examples of sequential pictures taken from satellites that show the very last phase of expansion evolution around the dayside cusp, mainly because of the limitation of observation time. Instead, however, we know many individual pictures which suggest the presence of the expansion boundary mentioned above. In Fig. 2 the shaded region is a schematic illustration of a fully developed auroral expansion. The broadening tendency of the oval during an auroral expansion tends to be limited around 10 and 14 MLT. The auroral expansion from nightside rarely reaches the dayside polar cusp beyond the limits at $\text{noon} \pm 2$ hours.

Fig. 2. Nightside auroral region and the dayside auroral region. An auroral expansion from nightside tends to terminate around 10 and 14 MLT as the shaded region illustrates. Comparing this with Fig. 1, a reasonable guess is that the region of nightside aurora is connected to the plasma sheet inside the magnetosphere, deeper than $1 R_E$ from the magnetopause.

The propagation direction of auroral activities also suggests the presense of the boundary between the dayside auroras and the nightside auroras. When the auroras in the dayside are closely examined on the ground by a sensitive TV camera, we often notice that a change in the propagation direction occurs around 10 MLT and 14 MLT. Before about 10 MLT auroral activity normally develops from the nightside, while it comes from dayside after 10 MLT. In the afternoon sector, auroral activity develops from dayside before 14 MLT, whereas it comes from nightside after 14 MLT.

Figure 3 shows an example of this change in the propagation direction observed at Ny Ålesund (geographic lat., 78.9°; long., 11.9°; geomagnetic lat., 75.9°; long., 114.6°), Spitzbergen. This figure gives a position-time displays of auroras along an east-west line as well as that in a north-west line. For the east-west display the top is to the east and the bottom is to the west. The darkness indicates the auroral luminosity. Dark streaks going up with time indicate eastward propagation, while those going down show the westward propagation. Evidently the propagation direction changes from eastward (from the night side to the dayside) to westward (from the dayside to the nightside) around 10 MLT (7 UT). This propagation reversal, occurring around 10 and 14 MLT, also appears to show presence of the boundary between dayside auroras and nightside auroras.

Fig. 3. A position-time display of dayside aurora along the north-south (top row) and the east-west (bottom row) lines. Top is to the north and bottom is to the south in the north-south display, and top is to the east and bottom is to the west in the east-west display. Darkness shows auroral luminosity. Before 7 UT (approx. 10 MLT) the auroral activity develops from the west (nightside) to the east (dayside) while after 7 UT from the east (dayside) to the west (nightside). The westward propagation after 7 UT is not well recognized in the figure except that at 07:20 because of the short-lived activity of dayside aurora. January 7, 1986. Ny Ålesund, Spitzbergen.

Figure 4 suggests the reason of this situation (OGUTI, 1989). This figure shows a projection of field lines connected with the region-1 field-aligned current obtained by IJIMA and POTES (1976). The magnetospheric equatorial crossing of these field lines are shown by small circles. The region-1 current 30° off-noon at the ionospheric level is connected with the magnetospheric flank, and beyond that the current source is located in the tail plasma sheet inside the magnetosphere. Although the boundary is seen around 45° off-noon in Tsyganenko-87 and 89 models (TSYGANENKO, 1987, 1989) observations suggest it around 30°. The boundary between the dayside cusp aurora and the nightside aurora around 10 and 14 MLT appear to be connected with the boundary between the magnetopause boundary layer and the tail plasma sheet.

We know that a nightside auroral expansion starts from somewhere in the tail plasma sheet. Also we know that the nightside aurora, though sometimes stepwise, expands without any particular discontinuity during the course of an expansion. Therefore, it is a reasonable guess that the region where the nightside aurora expands in the polar ionosphere is connected with the tail plasma sheet, and, subsequently, the nightside auroral expansion is limited within the tail plasma sheet. On the other hand, the spatial extent of noon $\pm$ 2 hours of dayside aurora suggests that the dayside aurora must be connected with the outermost region of the magnetosphere with thickness less

Fig. 4. A projection of magnetic field lines footings at the region-1 field aligned current at the auroral altitude with the magnetic field model by TSYGANENKO and USMANOV (1982) onto the X-Y plane. The equatorial crossing of each field line is shown by a small circle. Off-noon meridian angle of the ionospheric footprint of each field line is given at each magnetospheric end point. The shaded region schematically illustrates the magnetospheric source linked to the potential peak region in the polar cap, around 90° off-noon. The reason why the shaded region is elongated in the X-direction is that there is a ambiguity of the equatorial crossing in the X-direction, depending on the models.

than $1 R_E$ as inferred from Fig. 1, whether low latitude boundary layer (LLBL) or plasma mantle (PM), or entry layer all together.

The extent of ± 2 hours around the magnetic noon is not large enough for allowing us to expect the reasonable reduction of the eastward electric field in the cusp provided that the potential across the polar cusp is the same as the trans-polar cap potential. This result supports the suggestion that the regions of the electric potential peaks, positive in the dawn and negative in the dusk in the polar cap, are connected with well inside the magnetosphere, not with the magnetopause. A reasonable consequence of this is that the regions of the electric potential peaks in the polar cap cannot be connected with the solar wind, and, therefore, the potentials are not directly supplied from the solar wind in terms of $\mathbf{v}_{sw} \times \mathbf{B}_{sw}$. The idea that the connected fluxes are the source of the magnetospheric convection must be disclaimed. This naturally leads to the disclaim of validity of the dayside reconnection idea (OGUTI, 1989).

Note that since the guess of the connection between the auroras and the magnetospheric structures mentioned above is reasonable, it in turn suggests the reliability of the magnetic field model used here in estimating the field line connection between the large scale structures in the polar ionosphere and those of the magnetosphere.

2.2 Radial structures of the dayside auroras

We know that the dayside auroras around the polar cusp sometimes show radial structures focusing to the dayside cusp (*e.g.*, AKASOFU, 1976; MENG and LUNDIN, 1981). The magnetospheric source regions of the characteristic radial auroras are likely located within the LLBL through plasma mantle and a little more inside most probably in the tail flank. Figure 5 illustrates a model distribution of the radial auroras along with the magnetic field lines, footed along the radial structure of auroras, and projected onto X-Y and Y-Z planes using Tsyganenko-87 model (TSYGANENKO, 1987). As seen

in the figure, the magnetospheric sources of the dayside radial auroras are most likely located at the flank especially in the tail. The sources are probably the plasma irregularities in the magnetopause boundary layers and a little more inside, produced by penetration of plasma blobs, or, small plasmoids, into the magnetosphere as LUNDIN and DUBININ (1984, 1985) suggest. Since the sheath plasma is highly turbulent, presence of small plasmoids is expectable within the magnetosheath. These small plasmoids, some may be non-magnetized and some other may be magnetized with o-type field, can penetrate the magnetopause and get into the magnetopause boundary layers.

Fig. 5. A model distribution of the radial structures of the dayside auroras (left top) and their field line connection to the magnetosphere, projected onto X-Y plane (center) and Y-Z plane (right). Magnetic field model by TSYGANENKO (1987) is used. The magnetospheric sources of the radial auroral structures are located within LLBL and a little more inside mainly in the tail flank. The Y-Z section is at $X = -10 R_E$.

The penetration of small sheath plasmids into the magnetosphere, whether magnetized or not, is quite easy to occur. The force which pushes back the penetrating plasmoids is mainly the magnetic pressure gradient in the magnetosphere. Due to the effect of the magnetopause current, the magnetic field gradient is very small in the outermost part of the magnetosphere, *e.g.*, to a few R_E depth from the magnetopause.

The magnetic field gradient becomes smaller and smaller from the dayside to the tail flank. For example, Fig. 6 shows magnetic field intensity distribution at the equatorial plane along the noon and the dusk meridian based upon the Tsyganenko-87 model. The field distribution in this figure is not much different from more simple estimation with a magnetic dipole and a plane magnetopause. This figure strongly suggests that small sheath plasmoids most likely penetrate into the magnetosphere in the tail flank. If penetrating plasmoids are non-magnetized, then the pressure current as well as the motional induction current of the plasmoid will produce an HM wave to propagate down to the dayside cusp causing a transient magnetic field impulse on the ground. When the plasmoid is magnetized with o-type field, then its magnetic field merging with the magnetospheric magnetic field within the boundary layer would also produce some other transient effects. The other two models (TSYGANENKO and

USMANOV, 1982; TSYGANENKO, 1989) give the same conclusion. The small plasmoid injection into the LLBL and further inside may well account for the radial structures of the dayside auroras (MENG and LUNDIN, 1981). This may also explain transient magnetic field variations in the dayside cusp, although this is accounted for in terms of transient patchy reconnection (*e.g.*, SOUTHWOOD, 1987), or solar wind pressure pulses (*e.g.*, FRIIS-CHRISTENSEN *et al.*, 1988).

Fig. 6. Magnetic field intensity distribution along the equatorial plane in the noon and the dawn meridian estimated with Tsyanenko-87 model. Due to the magnetopause current, the magnetic field gradient is extremely small in the outermost part of the magnetosphere. Small sheath plasmoids easily penetrate into the boundary layer with small field gradient where the magnetic pressure gradient is negligible. Because of the smaller field gradient, magnetospheric tail flank is more preferable the plasmoids to penetrate into the boundary layer than the dayside magnetopause.

In any way, the reasonable connection between the dayside radial auroras and the boundary layer in the tail flank also supports the reliability of the magnetic field models used here. These magnetic field models appear reasonably accurate in estimating the connection between large scale auroral structures and large scale magnetospheric structures especially in the outermost region of the magnetosphere.

3. Medium Scale Structures

What we call medium scale structures here are a westward expansion front of an expansion aurora and a large scale fold or protrusion of aurora which develops along the poleward (and westward) expansion front during a course of an auroral substorm. The size, some hundreds km across at the ionospheric level, outwardly appears to be large enough to correlate the auroral structure with the magnetospheric counterpart, but, actually not. No reliable result has so far been obtained in connecting these auroral structures and the magnetospheric source structures. For example, synchronous altitude, $6.6 R_E$, is not very far from the Earth. Still it is not easy to find reliable connection between the aurora and the corresponding magnetospheric region where plasma parameter shows relevant variations. We examine the correlative changes between these auroral structures and magnetic field variations at the synchronous orbit.

3.1 Westward expansion front in the dusk sector

It is well known that characteristic magnetic field changes occur at the synchronous orbit during an auroral substorm (*e.g.*, NAGAI, 1982). Upward field-aligned currents are connected with the active part of an expansion front (*e.g.*, KAMIDE and ROSTOKER, 1977; OPGENOORTH *et al.*, 1983). NISHITANI and OGUTI (1988) examined individual auroral structure in the vicinity of the estimated footprint of a synchronous satellite (GOES-6, -108.0°), and showed that a characteristic magnetic field variation occurs at the satellite only when an auroral activity breaks out near the footprint of the satellite, estimated using the magnetic field model proposed by TSYGANENKO and USMANOV (1982) and TSYGANENKO (1987, 1989).

They further show that the magnetic effects of the field-aligned current is localized probably surrounded by some return current sheath caused by the ionosphere. This is in contrast to the so-called "current wedge" idea where the magnetic field of the current circuit is observable at a synchronous satellite as if they were in vacuum (*e.g.*, MCPHERRON *et al.*, 1973; NAGAI, 1982). Close examination of the fast magnetic field variations at synchronous orbit and the development of auroral expansion front in the vicinity of its footprint is the main subject here.

When an auroral structure in the dusk sector is examined around the estimated footprint at the time when the characteristic magnetic field variations occur at the synchronous satellite, we notice that the auroral structure systematically tends to deviate from the estimated footprint. The magnetic field changes begin at the satellite beforehand at the time when the westward expanding auroral forms do not yet reach the footprint. The auroral expansion front is usually found to be located about 300–400 km east of the footprint. Figure 7 indicates an example of January 7, 1986. The lower panel of the figure shows temporal variations of magnetic fields at GOES-6. A characteristic magnetic field variation occurred at 02:45 UT as indicated with an arrow. The upper panel shows sequential pictures of the auroral distribution around the time of the onset of the magnetic field variation. In each picture the estimated footprint of the GOES-6 satellite is shown with a small circle designated as GOES-6. Evidently, the auroral expansion front did not yet reach but was about 400 km away east of the estimated footprint when the magnetic field changes began (02:45 UT) at the satellite.

The magnetic field variation at 02:45 UT strongly suggests that the satellite encountered with the localized field-aligned current region at that time. This is examined by comparing magnetic field variation at GOES-6 with that at GOES-5 (-74.6°) which is 33.4° east of GOES-6. When the two satellites are located in the dusk sector, the onset time of the magnetic field changes at GOES-6 lags behind that at GOES-5 as the expansion front evolves westward. This fact supports the idea that the magnetic field variations associated with the field-aligned currents are spatially limited. It is a reasonable guess that the aurora, located about 400 km east of the estimated footprint, is actually connected with the current region in which GOES-6 located. That is, the estimated footprint is not correct, but the real footprint is located at the active auroral front at this moment.

The systematic deviation of the estimation from the real field is highly probable. This is because GOES-6 satellite was probably located in between the region-1 and the region-2 current sheets, and the distant magnetic field line in this region in the dusk was distorted toward dayside as getting away from the Earth. As is seen in the modeling procedure of these models, the magnetic effects of the large scale field-aligned

Fig. 7. Sequential pictures of auroral evolution at the westward expansion front along with the magnetic field variations at GOES-6 satellite. Magnetic field is given in the normal H (northward, parallel to the dipole), V (outward, perpendicular to the dipole) and D (azimuthal, eastward) components. Magnetic footprint of GOES-6 estimated by Tsyganenko-87 model is shown by a small circle designated as GOES-6 in each auroral picture. At 02:45 UT when magnetic field changes started at GOES-6 in 19 MLT sector the relevant aurora has not yet reached but located about 400 km east of the estimated footprint. This is a general tendency in the dusk sector.

Fig. 8. Sequential pictures of auroral evolution at the north-westward protrusion along the expansion front and magnetic field variations at GOES-6 satellite. This example shows that the magnetic field changes occur at 07:27 UT at GOES-6 in 24 MLT sector when the southern part of the aurora develops into N-S aligned arcs. This example also shows that the fast magnetic field changes at a synchronous satellite occur at the time when the N-S aligned arcs develops about 400 km east of the estimated footprint.

currents is not consistently taken into consideration. Through the least squares method determining the parameters, some part of the field-aligned current effects might be included. But the functional form used in these models, even though might be enough for representing the field-aligned current effects in the distant tail, is evidently not fine enough to express the field-aligned current effects near the Earth. Moreover, the effects of the field-aligned currents are smeared out because of the averaging procedure for each Kp activity. Because, even with the same Kp value, the distribution of the field-aligned currents is variable. Simple averaging procedure must tend to significantly reduce the magnetic field due to the field-aligned currents. Thus, the additional azimuthal component of magnetic field in between the region-1 and the region-2 current sheets in these models must be very much smaller than that in the real field even if partially involved. Thus, the systematic eastward deviation of the satellite-conjugate aurora from the footprint estimated using these models is a reasonable consequence.

3.2 Auroral protrusion in the midnight sector

When a synchronous satellite is located near the midnight at the time of an auroral expansion, the magnetic field variation at the satellite occurs also prior to the auroral activity to reach the estimated footprint.

Figure 8 shows an example of January 7, 1986 again. The auroral activity examined here is a development of a north-westward auroral protrusion of an expansion front. The protrusion in Fig. 8 began to develop above Shamattawa at 07:19 UT, then developed westward reaching the field of view of Fort Smith at 07:23 UT. The development of the large, active protrusion, however, had no coincident magnetic field changes at GOES-6 satellite despite its occurrence in the vicinity of the estimated footprint. It was not until 07:27 UT when north-south aligned auroral arcs developed about 400 km east of the footprint that the fast magnetic field changes began at the satellite.

Since the development of an auroral protrusion is normally associated with an enhancement of upward current in the protrusion region (*e.g.*, BAUMJOHAN *et al.*, 1981), classical current wedge model fails to explain this absence of the magnetic field variations at GOES-6 satellite during the development of the protrusion. This clearly indicates that the magnetic field of the field-aligned currents associated with the protrusion was almost shielded and localized by counter currents, and did not reach GOES-6 satellite during the development of the protrusion. This localized nature of the magnetic field of the field-aligned current justifies the consideration in the previous and this sections that the coincidental magnetic field changes at synchronous orbit and a local auroral activity is an indication that the two regions, approximately at least, are connected with each other.

The time when the fast magnetic field changes started at GOES-6 was 07:27 UT, coincident with the development of the north-south aligned arcs. Then, this fact suggests that the two phenomena are connected with each other, and, subsequently, a reasonable guess is to locate the real footprint somewhere in the auroral structure.

In the previous section we mentioned that the magnetic field models used here appeared to be accurate enough in correlating large scale auroral structures and large scale magnetospheric structures. Also, a reasonable guess was that the models were useful in the outermost region of the magnetosphere. However, in concluding this section, we claim that these magnetic field models appear to have a systematic error in the dawn and dusk sectors especially in between the region-1 and the region-2 current

sheets. In the dusk sector, the real footprint of a satellite located in between the region-1 and region-2 field-aligned currents is normally located 300–400 east of the estimated footprint. In the dawn sector the deviation would be to the opposite direction although we have not yet examined. We must be careful to apply these models to this region.

4. Small Scale Structures

As seen in the previous sections, the model fields are quite useful in studying the field line connection between large scale auroral structures and large scale magnetospheric structures. It was also shown that in the region between the region-1 and region-2 currents there is a systematic deviation of the footprint but is expectable from the large scale field-aligned currents. However, this is not the case for small scale structures. Actually, it is extremely difficult to correlate small scale auroral structures of tens of km sizes such as small auroral folds and auroral patches with magnetospheric structures. Successful comparison have so far been made in very limited cases. They are, for example, the study using low altitude satellite such as MAGSAT where the field line tracing is reliable or that don't need accurate spatial comparison.

For example, OGUTI *et al.* (1986) compared dB/dt changes obtained by MAGSAT satellite traversing above pulsating auroral patches, with auroral pulsations and ground magnetic pulsations. Based upon the electric conductivity distribution estimated from the space-time variations of the pulsating auroral luminosity, the field-aligned currents as well as the ionospheric currents, and subsequent magnetic field variations above and below the pulsating aurora were calculated. The magnetic field changes at the MAGSAT satellite, dB/dt , were successfully correlated with the space-time variations of ionospheric currents along the footprint trajectory, $\partial \mathbf{j} / \partial t + \mathbf{v} \cdot \partial \mathbf{j} / \partial \mathbf{r}$ deduced from auroral luminosity changes and the satellite movements. This is an example of a successful comparison of small auroral structures with plasma parameters measured by a low altitude satellite.

Another example is seen in comparison between magnetic field variations at synchronous orbit and well developed pulsating auroras (*e.g.*, OGUTI *et al.*, 1986). In this case, it was not necessary to know the accurate field line connection between a certain auroral patch and a certain magnetospheric structure in reaching the conclusion. The sufficient condition was that the pulsating auroral patches were distributed in a large spatial extent, and the footprint of the satellite was located somewhere within the pulsating auroral area. In order to indicate no compressional HM wave was taking role for pulsating precipitation of electrons it was enough to show that no magnetic field changes occurred at the synchronous satellite when the large spatial extent of pulsating auroras together with a drift, guaranteed the footprint sometimes must encounter with some pulsating auroral patches.

The magnetospheric magnetic field is highly variable. The magnetospheric sub-storm is associated with a large transient change in the magnetic field configuration. Therefore, the statistically averaged model, although useful in the study of large scale structures, has a limitation to apply to the study of the field line conjugacy between small scale structures in the ionosphere with those in the magnetosphere. Magnetic field distribution and its changes obtained through MHD simulation studies of the magnetosphere (*e.g.*, OGINO, 1986; OGINO *et al.*, 1986) may be useful to estimates the

fluctuation in the connection between the small scale magnetospheric sources and the small scale auroral structures.

5. Conclusion and Discussion

The knowledge of accurate magnetic field conjugacy between the ionosphere and the magnetosphere is an essential requirement in studying the magnetospheric processes by inferring the spatial structures and temporal variations as compared with the ionospheric phenomena. This requirement appears to be almost satisfied by the magnetic field models used here when we correlate large scale auroral structures with large scale magnetospheric structures. We may safely state that the magnetic field models proposed by TSYGANANKO and USMANOV (1982) and TSYGANENKO (1987, 1989) are fairly useful in studying the connection between the auroral oval and the magnetospheric structure, and between dayside auroras and the boundary layers. The most likely guess along this line is to connect the dayside aurora between 10 and 14 MLT with the outermost part of the magnetosphere, and the most of the oval 14 to 10 MLT through midnight with the tail plasma sheet. This also indicates that the regions of the electric potential peaks, positive in the dawn side and negative in the dusk side of the polar cap, are connected with the plasma sheet well inside the magnetosphere, not with the magnetopause, in contrast to the broad belief that the potential is supplied at the interface of the solar wind and the magnetosphere in terms of $\mathbf{v}_{sw} \times \mathbf{B}_{sw}$.

However, in the inner magnetospheric region in between the region-1 and region-2 currents the magnetic field configuration is significantly deviated from these magnetic field models. Azimuthal component of magnetic field due to the region-1 and the region-2 field-aligned current sheets are not involved actually in these models. When we apply these models to estimate the magnetic footprint of synchronous satellite, for example, located between the two current sheets, we must take this into consideration. Probably, some appropriate correction to these models by introducing the region-1 and region-2 field-aligned currents would very much improve these models. Also, magnetic field distribution obtained in the computer simulation of the magnetosphere (*e.g.*, OGINO, 1986; OGINO *et al.*, 1986) would be quite useful for studying the transient variations in the field line connection between the polar ionosphere and the magnetosphere.

To obtain accurate information of magnetic field connection between the polar ionosphere and the magnetosphere, comparison of small scale structures in both regions must be efficient. However, as already mentioned, a reliable comparison of small scale structures is extremely difficult in the distant magnetosphere. This is because there are many small structures, and, therefore, identification of a certain structure among others is almost impossible unless 2-dimensional information in the ionosphere and 3-dimensional information in the magnetosphere are simultaneously obtained. Another problem must be transient fluctuations of magnetic field in the magnetosphere because the fluctuation could be large enough to make the ionosphere-magnetosphere correspondence fluctuate when small structures concern.

Our next step would be to examine the field line conjugacy between the medium scale auroral structures and the medium scale plasma structures measured by a satellite in the distant tail. This is an essential requirement to study the distant magnetospheric processes. For example, we have so many guesses on the initiation of an auroral sub-storm. But little is known based upon observations. Where in the magnetosphere the

auroral substorm starts is an interesting question of all space scientists, but yet nobody knows. Moreover, little effort has been made even to examine in what direction the examination could be searched for. We emphasize that there is no short cut to solve this problem. It is possible only when an examination is based upon a laborious work to compare d/dt at a satellite with $\partial/\partial t + \mathbf{v} \cdot \partial/\partial \mathbf{r}$ along the footprint trajectory of the satellite at the ionospheric level, where we can separate the temporal changes from the effects of spatial structures.

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