Chapter 5. Summary and Conclusions of this study

Main purpose of this study was to analyze auroral substorm evolution in detail as possible as we can, using the global auroral observation by the AKEBONO UV imager (ATV-UV) and the local auroral observations by the ground-based instruments (the meridian scanning photometer (MSP) and the all-sky SIT-TV camera) at Syowa and Asuka stations in Antarctica in 1989. Austral winter in 1989 was our target period because simultaneous observations by the ATV-UV and MSP/SIT-TV were accomplished only during this period.

We have searched such an event where the global auroral substorm evolution was observed by the ATV-UV with a sufficiently long period from the initial brightening, and the local auroral substorm signature, the auroral poleward expansion, was observed by the MSP and the SIT-TV camera at Syowa and/or Asuka stations. As described in the Chapter 2, the only one such event was found. Such a very small number of the event is largely due to the orbital configuration of AKEBONO and the instrumental configuration of the ATV-UV.

We have analyzed the special event on June 6-7, 1989 in detail in the Chapter 3. The very fortuitous distribution of the ground-based observations relative to the location of the global auroral substorm evolution enabled us to analyze in detail the evolution from beginning of the growth phase to middle of the expansion phase. Growth phase evolution of the auroral activities and ionospheric convection toward the expansion phase onset was analyzed in detail in the section 3.1. Detailed evolution of auroral bulge and substorm current system during the expansion phase was analyzed in the section 3.2.

Through the period from the late growth phase to the middle of the expansion phase, it was found that a characteristic auroral activity, which we called the NPSBL aurora, should give us an important information and play an important role in the auroral substorm evolution. The NPSBL aurora clearly appeared around the ionospheric PSBL region a few minutes before the onset, and was clearly intensified a few minutes after the onset. It continued to exist around the same location until the local further poleward expansion. The local further poleward expansion started with a significant intensification and a significant enlargement of the latitudinal width of the poleward-most auroral activity. The initial rapid poleward expansion of the bulge started at lower latitudes well away from the NPSBL aurora, and was suddenly slowed around the latitudes of the NPSBL aurora, which was true both in the global auroral evolution and the local auroral poleward expansion. This NPSBL aurora was one of our new findings in this study.

It was also found that there were three distinct stages in the auroral bulge evolution. The Stage-1 was characterized by a rapid poleward and rapid azimuthal expansion in a short time. The next Stage-2 was characterized by a very slow poleward and nearly symmetric slower azimuthal expansion. The last Stage-3 was characterized by a sudden re-activation of the rapid poleward and rapid azimuthal expansion. Such a three-stage evolution was also found in the local poleward expansion. Simultaneous observations by the ATV-UV and MSPs at Asuka and Syowa stations revealed that the global auroral bulge expansion during the Stage-3 proceeded as a successive azimuthal propagation of such a local three-stage evolution. As mentioned above, the NPSBL aurora played an important role in the three-stage evolution. Looking at the evolution of the NPSBL aurora, the three-stage evolution was a systematic one, not accidental or episodical one.

We have searched the similar events of the local poleward expansion as shown in the detailed study of the special event, and found the total 13 events in the MSP data in 1989, as described in the Chapter 4. In all the 13 events, the similar evolution of the NPSBL aurora, and its similar association with the stepwise three-stage evolution were found. The statistical study in the Chapter 4 suggests that such features (the NPSBL aurora and the three-stage evolution) should appear when the initial poleward expansion occurs at sufficiently lower latitude region around midnight hours. If the initial poleward expansion occurs at higher latitude region and off-midnight hours, the characteristics of the poleward expansion should be different from the three-stage evolution, as shown in the section 2.2.2 in the Chapter 2.

Other important findings in the detailed study in the Chapter 3 were as follows.

1. It was found that evolution of the nightside convection during the growth phase was closely associated with the evolution of the FEM arc. Toward the onset, both the FEM arc and the peak velocity of the return flows of the two-cell convection moved equatorward from around the PSBL region to lower latitudes.
2. The UV auroral breakup occurred around the demarcation region of the two-cell convection in a pre-midnight localized area at a little higher latitudes of the FEM arc around the poleward edge of the proton main oval.
3. The clear waveform of the initial Pi2 pulsations was observed only during the Stage-1, and was significantly damped afterward.
4. The intensification of the Pi1B pulsations was delayed from the Pi2 onset by about 80 sec, and the initial Pi1Bs were damped during the transition phase from the Stage-1 to Stage-2.
5. The negative and positive potentials of the substorm current wedge (SCW) system should be located on the equatorward-westward and poleward-eastward sides of the bulge, respectively, from the beginning of the bulge formation. Hence the central part of the bulge did not correspond to the central location of the negative potential from the beginning.
6. The demarcation region, between the electrojet within the bulge and the return currents outside of the bulge, was located around the boundary of the bulge.
7. The SCW system showed a stepwise evolution, being closely associated with the three-stage evolution of the auroral bulge.
8. During the local second stage, an intense electron discrete auroral activity appeared around the interface region between the NPSBL aurora and the equatorward-side main auroral region.
9. During the local third stage, the bright electron emission region was bifurcated into the poleward expanding part and the equatorward moving part. The pulsating auroral activity appeared in the equatorward part soon after the bifurcation.
10. The proton auroral emission co-existed with the electron emission within the bulge during the local first stage and second stage, and almost disappeared soon after the bifurcation of the electron auroral region during the local third stage.
11. The increase of the energetic particle flux at the geosynchronous orbit, observed at the eastern

side of the bulge, also showed a stepwise evolution.

Above findings 8, 9, and 10 were confirmed in the 13 events in the Chapter 4. Other findings listed above should be confirmed in the future studies.

Based on these observations and a great amount of previous works by other people, as introduced in the Chapter 1, we have discussed the substorm evolution in the magnetosphere. Some important points of the discussions are as follows:

1. It was inferred that the NPSBL aurora should be closely associated with the reconnection process at the near earth neutral line (NENL).
2. The initial rapid poleward expansion during the Stage-1 should be caused by the rapid tailward propagation of the initial disturbance from the near earth onset region down to the location around the NENL.
3. The start of the significant poleward expansion during the Stage-3 should reflect a start of the significant dipolarization in the magnetosphere, which should be caused by a significant increase of the reconnection rate due to the start of the lobe field line reconnection at the NENL.
4. The successive stepwise azimuthal expansion of the auroral bulge suggests that the sequence, from the tailward propagation of the initial disturbance to the start of the lobe field line reconnection at the NENL, should occur successively at the azimuthal edge of the substorm disturbance region, and the location of the lobe field line reconnection should expand in the azimuthal direction.
5. It was inferred that the source region for the FEM arc should move earthward during the late growth phase.
6. The source region for the FEM arc should be located around the earthward edge of a very thinned region in the tail. Hence the earthward movement of the source region suggests that such a significant thinning should spread earthward during the late growth phase.
7. The initial Pi2 wave should be associated with the large scale field line oscillation during the Stage-1. The rapid damp of the initial Pi2 wave and the delayed start of the Pi1B pulsations in the transition phase suggests that such a large scale oscillation should be disturbed by the smaller scale bursty oscillation in the magnetosphere.
8. The effective earthward injection of particles should occur around the edge of the substorm disturbance region, where the lobe field line reconnection just begins at the NENL.
9. Within the substorm disturbance region, the precipitation population of the ions should decrease due to the significant dipolarization.

Almost all of the existing substorm models are basically a model only for the onset mechanism or for the magnetospheric processes. It can be said that even now there are no comprehensive models which can explain consistently the relationship between the magnetospheric processes and the ionospheric processes, especially, the auroral bulge evolution. In this study, we tried to find such a consistency. Further event studies and statistical studies should be done in the future toward this direction, using both the ionospheric and magnetospheric observations.