Global MHD simulation study on auroral substorm

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A substorm is one of the drastic disturbances taking place in the magnetosphere and the ionosphere. The substorm begins with a growth phase, followed by an expansion phase and a recovery phase. The expansion onset is manifested by sudden brightening of aurora in a latitudinally narrow region in the pre-existing auroral oval. The bright aurora expands poleward and westward, resulting in the formation of a surge. During the expansion phase, strong auroral electrojet flows in the ionosphere. A large amount of energy exceeding 10^{11} W is consumed. One of the central issuees of the auroral/ionspheric substorm is the generation of field-aligned currents (FACs) beucause of the following reasons. First, the upward FAC is associated with the electrons precipitating into the ionosphere so as to cause the bright aurora. Secondly, the FACs guide the electromagnetic energy into the ionosphere. Thirdly, the presense of the FACs gives rise to the formation of the auroral electrojet together with the increase in the ionospheric conductivity. We have used the global magnetohydrodynamics (MHD) simulation, REPPU, to study the auroral/ionospheric substorm. The REPPU code is known to reproduce many aspects of the auroral/ionospheric substorm, including auroral electrojet, positive bay, equatorial overshielding, and westward traveling surge. The following is the summary of the evolution of the substorm acquired by the global MHD simulation.

Quiet time. When the interplanetary magnetic field (IMF) is northward, the magnetosphere and the ionosphere are magnetically quiet. Thin auroral structures (or arcs) appear in the high-latitude ionosphere. The simulation result shows that small-scale structures of plasma pressure are developed by an instability due to the interaction between the high-latitude magnetosphere and the ionosphere. The small-scale structures of the plasma pressure results in the thin FACs that are responsible to auroral arcs.
Growth phase. When the interplanetary magnetic field turns southward, a substorm growth phase begins. The small-scale structures of the plasma pressure start moving toward the equatorial plane, which is seen as equatorward moving auroral arcs.
Expansion onset. When magnetic reconnection takes place in the near-Earth magnetotail, the earthward and anti-earthward plasma flows start to appear near the equatorial plane. The earthward flow is compressed in the dipolar region, enhancing the plasma pressure. At off-equator, the plasma coming from the lobe traverses the magnetic separatrix toward the equatorial plane. The plasma is then deflected toward dusk and dawn at off-equator where the plasma pressure is high. The change in the direction causes the formation of shear, and generates strong FACs. When the strong FACs reached the ionosphere, the aurora starts to be bright, and the expansion phase onset begins.
Expansion phase. In the ionosphere, the conductivity is intensified in the region of upward FAC due to precipitation of electrons. The gradient of the ionospheric conductivity gives rise to overflow of the Hall current. The overflow near the poleward/westward edge of the bright aurora results in accumulation of space charge, which causes small-scale vorticity (shear) in the low altitude magnetosphere. The small-scale vorticity generates a thin upward FAC, moving westward. The lack of space charge near the opposite side results in the opposite processes, reducing the upward FAC. By repeating these processes, the bright aurora (surge) travels westward, or poleward.
Recovery phase. The Region 2 FACs develops in association with the incrase in the plasma pressure increases in the inner magnetosphere. As the Region 2 FACs are connected to the equatorward of the auroral oval, the electric field with its polarity opposite to the convection electric field appears. This is called overshielding. At the dayside magnetic equator, westward electrojet appears due to the overshielding electric field.