Global MHD simulation study on the evolution of substorms

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Aurora is the natural light that always appears in the polar ionosphere as if it encircles the magnetic pole. The auroral ring is called an auroral oval. Occasionally, the brightness of the aurora dramatially increases in a narrow region of the auroral oval on the nightside. The area occupied by the bright aurora expands poleward and westward. The sequence of the evolution of the aurora is called a polar substorm. The bright aurora is primarily caused by precipitating electrons from the magnetosphere in the region where the upward field-aligned currents (FACs) are intensified. Thus, the central issue is the generation of upward FACs. The purpose of this study is to investigate the origin of the upward FACs by using the global magnetohydrodynamics (MHD) simulation. When the interplanetary magnetic field (IMF) is northward, no significant disturbances occur in the magnetosphere and the ionosphere. In quiet time, thin auroral structures (arcs) are found 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 structure results in the thin FACs that are responsible to auroral arcs. When the interplanetary magnetic field turns southward, a substorm growth phase begins. The small-scale structures start to move toward the equatorial plane, which is seen as equatorward moving auroral arcs. When magnetic reconnection takes place in the near-Earth magnetotail, the earthward plasma flows. The earthward flow is compressed in the dipolar region, enhancing the plasma pressure, and reducing the magnetic field. The plasma coming from the lobe is decelerated, enhancing the magnetic field. The strong magnetic gradient is established at off-equator, accelerating plasma toward the equatorial plane. The accelerated plasma deflects toward dusk and dawn at off-equator. The change in the direction causes the formation of shear, and strong FACs. When the FACs reached the ionosphere, the aurora starts to be bright, and the expansion phase onset begins. 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 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. This may correspond to the westward traveling surge. The evolution of the auroral substorm is reasonably explained for the first time.