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On the plasma sheet variations at the time of substorm onset: A case study of THEMIS observations

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In a series of our studies, the time development of Earth's magnetosphere during substorms has been investigated by adopting a superposed-epoch analysis to the Geotail data. In those studies, time variations during substorms were obtained for the earthward flow velocity, northward magnetic field, total pressure, electric field, and Poynting flux toward the center of the plasma sheet etc. We could confirm various variations which relevant models of substorm are based on or predict. However, none of them could perfectly explain our results. Therefore we proposed a new model called Catapult (Slingshot) Current Sheet Relaxation model. In this model, the initial variation starts at X ~14 Re in the magnetotail rather than X ~-8 Re as predicted by the current disruption model, or X ~-20 Re as predicted by the near-Earth neutral line model.

During the growth phase of substorm, the Poynting flux toward the plasma sheet center enhances the cross-tail current. Then the highly stretched current sheet with small dipole field relaxes resulting in the earthward motion of that current sheet. Simultaneously, the reduction of the total pressure progresses around the flow region at X ~-16 Re, and the Poynting flux toward the plasma sheet center further enhances about 4 min before the auroral breakup. Those variations work as a seed for the disturbances in the inner magnetosphere which was in a marginal state against the instability such as ballooning instability. The occurrence of the instability produces the current disruption and dipolarization of the magnetic field. Meanwhile, the earthward flows produce a very thin current sheet at the boundary between the current sheet with highly stretched dipole field lines and the Harris-type current sheet at X ~-20 Re. The magnetic reconnection starts in this very thin current sheet located at X ~-20Re.

Based on those results, we performed a case study of substorm events observed by THEMIS spacecraft. When the onset was observed at ~0811UT on March 21, 2008, five THEMIS spacecraft were located in the region from -8 Re to -15 Re in the X(GSM)-direction, and from 5 Re to 7 Re in the Y(GSM)-direction. A sudden increase of the northward magnetic field (Bz) was observed at 0808UT by P1 spacecraft located at X ~-15 Re and P2 located at X ~-12 Re. About 1 min later, a similar increase of Bz was observed by neighboring P3 and P4 spacecraft located at X ~-10Re. A gradual increase of Bz was observed at 0811UT at X ~8 Re by P5 spacecraft located at X ~-8 Re. All events were accompanied by the earthward flows and the reduction of the total pressure (the sum of the plasma pressure and magnetic pressure). The variations detected by each spacecraft were almost synchronized with the increase of Bz. These characters were also found in common in the other substorm subsequently occurred at 0928UT.

Those characteristic variations propagated from the region of X ~-15R e to X ~-8 Re, which apparently contradicts with that predicted by the current disruption model in which the current disruption and associated total pressure reduction first occurs at X ~-8 Re and propagates as a form of rarefaction wave toward the down tail region. The variations in the magnetic field, the flow and the total pressure start a few minutes before the substorn onset in the region of X ~-14 Re, which strongly supports the validity of the catapult (slingshot) current sheet relaxation model.