Toward the unified model of substorm

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Numerous models of substorms have been proposed so far, and they are roughly divided into two categories, i.e., an outside-in category that is represented by the NENL model and an inside-out category that is represented by the ballooning instability model. Controversies have been raised for many years over the validity of those models. However, in recent years we have obtained extremely important clues to solve this long-standing issue by separately analyzing THEMIS probe data for substorms and pseudo-substorms. [Fukui et al., 2017]
The key is the plasma pressure in the equatorial region, and in the case of the substorm, it was about 1.4 and 1.2 times larger in the region of X ˜ -7 and -8 Re than in the case of the pseudo-substorm. However, no difference was found beyond X˜ -10 Re. Therefore, the spatial gradient of the plasma pressure in the region of X ˜ -7.5 Re must be a necessary condition for substorm.
An occurrence of abrupt earthward flows originated from the catapult current sheet relaxation and subsequent magnetic reconnection at the NENL just prior to the onset is a common signature for both substorm and pseudo-substorm. Those flows must initiate some instability, possibly the ballooning instability in the earthward side of the flow front.
Substorms do not occur only with the magnetic reconnection. If there is enough plasma pressure gradient, the system can develop into a substorm. Otherwise, it will end up with a pseudo-substorm. We emphasize that both NENL model and the ballooning instability model are partially correct but incomplete, and a true model of substorm can be constructed by combining at least these two.

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