How does interchange reconnection proceed in the terrestrial magnetosphere?

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The term interchange reconnection was first introduced in solar physics to represent reconnection between closed field lines and open field lines of the Sun (Crooker et al., 2002). However, well before it was named, its concept had been being used as an explanation for many solar phenomena, such as the coronal mass ejections (e.g., Shibata et al., 1992). The name "interchange" comes from its feature that the open/closed topologies of the two reconnecting field lines interchange at the time of reconnection. Interchange reconnection in the terrestrial context first appeared in the work of Tanaka (1999), in which he examined a convection system for northward interplanetary magnetic field (IMF). As in the solar magnetic field, interchange reconnection is defined as reconnection between closed field lines and open field lines of the Earth. Open field lines of the Earth are also referred to as lobe field lines, because they thread the northern and southern lobes of the Earth. In addition, Watanabe and Sofko (2009) noted that IMF-to-lobe reconnection is topologically the same as open-to-closed interchange reconnection. The topologies of the two reconnecting field lines (i.e., IMF or lobe) similarly interchange at the time of reconnection. Alternatively, consider a virtual celestial body located at a point at infinity (in the mathematical sense). For this astronomical object, IMF lines and Earth's lobe field lines are regarded as closed and open field lines, respectively, of the body. Thus, IMF-to-lobe reconnection of the Earth is equivalent to open-to-closed reconnection of the celestial body at infinity. Watanabe and Sofko (2009) called IMF-to-lobe reconnection "interchange-type reconnection" in order to distinguish it from the original interchange reconnection. In this paper, however, we do not distinguish the two, because there is no merit for the distinction from the topological point of view. In this paper, we call both types of reconnection interchange reconnection.

Generally, interchange reconnection occurs on a portion of a separatrix that is discontiguous to separators. This characteristic contrasts with "Dungey-type" reconnection that occurs just on a separator. The purpose of this study is to clarify realistic field line geometry of interchange reconnection in the Earth's magnetosphere using numerical magnetohydrodynamic simulations. A widely held misconception of reconnection is the antiparallel geometry of reconnecting field lines. Inside the diffusion region, reconnecting field lines are parallel with the field-aligned electric field representing the reconnection rate (e.g., Hesse et al., 2005). Reconnection is not a cut-and-reconnect process of antiparallel field lines but a merging or exchanging process of parallel field lines. This characteristic is clearly seen in interchange reconnection. Using the Reproduce Plasma Universe (REPPU) code, we obtained a quasi-steady magnetosphere under IMF conditions of $B=6$nT (total intensity) and $\theta=20°$ (clock angle). Ionospheric convection showed so-called reciprocal cells circulating exclusively in the closed field line region, indicating the interchange cycle (Watanabe and Sofko, 2009) that is formed by two sequential processes of interchange reconnection. The global magnetic topology of the magnetosphere is characterized by two magnetic null points and two separators connecting the nulls. We traced the separatrix surface emanating from each null (Σ surface) using a geodesic level-set method with high precision. The separators are determined by the intersection of the two Σ surfaces. In each hemisphere, interchange reconnection occurs on the lobe-closed boundary of Σ and on the IMF-lobe boundary of Σ. We then visualized field-aligned electric fields on Σ and plasma flow crossing Σ. This visualization enabled us to identify the so-called X line of reconnection. The cross-flow direction reverses across the X line. Field lines participating in interchange reconnection converge along the X line on the separatrix (Σ) to form a so-called guide field. Although this field line configuration is theoretically expected, its realistic geometry was elucidated for the first time by this study.

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