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Numerical Modeling of the Three-Dimensional Magnetic Fields and Eruption in the Solar Active Region 11158

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Solar flares and coronal mass ejections (CMEs) are considered as sudden liberation of magnetic energy in the solar corona, which affect geospace in the form of electromagnetic disturbance called geomagnetic storms. Unfortunately, measurement based on vector field observations only provide the two-dimensional information of magnetic field on the photosphere, therefore, we could not reach on a common understanding yet regarding to the three-dimensional (3D) magnetic structure causing the eruptive phenomena and associated dynamics. In order to clarify them, in this study we first extrapolate a 3D coronal magnetic field under the Nonlinear Force-Free Field (NLFFF) approximation based on the vector field, using the Magnetohydrodynamic (MHD) relaxation method developed by Inoue et al. 2014, and then compare the 3D structures before and after the flare. Next we perform an MHD simulation to clarify the dynamics during the flare where the NLFFF prior to the flare is set as an initial condition. Photospheric vector field was observed at 00:00 UT and 03:00 UT on February 15 corresponding to before and after the X2.2-class flare taking place around at 01:50 UT, taken by the Helioseismic And Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO) satellite.

As a result, we found that the NLFFF has strongly twisted field lines; most of them are in the range from half-turn to one turn twist, being resided above the polarity inversion line. Furthermore, we found that a distribution of these footpoints well captures the flare ribbons observed by Hinode where Ca II emission is strongly enhanced. On the other hand, because the most of these strongly twisted lines disappear after the flare, consequently the twisted field lines having more than half-turn twist play an important role on causing the large flare. The MHD simulation successfully shows an eruption of the more strongly twisted lines whose values are over one-turn twist, which are produced through the magnetic reconnection in strongly twisted lines of the NLFFF. Eventually, we found that they exceed a critical height at which the flux tube becomes unstable to the torus instability determining the condition that whether a flux tube might escape from the overlying field lines or not. In addition to these, during the eruption, we found that the distribution of the observed two-ribbon flares is similar to the spatial variance of the footpoints caused by the reconnection of strongly twisted lines with more than half-turn twist. Furthermore, because the post flare loops obtained from MHD simulation well capture that in EUV image taken by SDO, these results support the reliability of our simulation.

Keywords: Active Region, Coronal Magnetic Field, Solar Flare, Coronal Mass Ejections, Numerical Modeling