Three-Dimensional Filament Eruption Driven by an Emerging Flux

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Abstract. Some important observations have shown that the strong correlation between emerging flux and eruptions of quiescent filaments (Feynman & Martin, 1995; Wang & Sheeley, 1999). Chen & Shibata (2000) performed two-dimensional simulations including a flux rope in the corona, and their results suggest that the eruption process is triggered by the emerging flux through the reconnection. Our purpose in this paper is to investigate how a filament is produced and how an eruption process can be initiated by the emerging flux and what effects of three-dimensionality appear in the process of eruption. For that purpose, we performed three-dimensional numerical simulations of the emerging flux model. From our results, a filamentary structure is produced from the coronal arcade field by the reconnection process, and when the reconnection process proceeds effectively, the produced structure is ejected by the magnetic force. These processes can thought to be a new mechanism of the eruption which is different from, for example, the one in Fan & Gibson (2004).

1. Numerical Model

We solve the three-dimensional, nonlinear, time-dependent, resistive, compressible MHD equations in a rectangular computational box. The medium is assumed to be inviscid perfect gas. For the heat loss and gain, Ohmic heating is taken into account, but the thermal conduction and radiative cooling are absent in our simulations. As a initial condition of magnetic field, we prescribe a Gold-Hoyle flux tube beneath the photosphere, and the sheared arcade field uniformly in the corona. These initial configurations of the magnetic field can be seen in Figure 1. In order to excite the magnetic instability of the flux tube, small velocity perturbation is added to the center part of the tube.

2. Results and Discussions

The simulation consists of three succeeding processes leading to the eruption. These are the emerging process of the flux tube, and the deformation and reconnection processes of the arcade field in the corona. Figure 2, 3 show the temporal...
Figure 1. Initial condition of the magnetic field: left panel shows the top view, and right panel shows the side view. In these figures, the blue helical lines are the flux tube embedded in the convective zone, and the yellow lines are part of the arcade field lines extending in the corona. The color on the two-dimensional plane shows the temperature of the atmosphere.

Figure 2. The blue lines show the emerging flux, and the orange lines are the arcade field lines which are involved in the reconnection process, and the green lines are the arcade field lines which are not related to the reconnection process. Isosurfaces of the current density (the gold surface in the left panel) which indicate the current sheets produced by the deformation process at $t = 130$

The evolution of the magnetic field, and each figure shows the deformation process ($t = 130$) and eruption processes ($t = 190$), respectively. It can be seen from these figures that the reconnection process of the arcade produces the long helical field lines, which is ejected upward and the current sheet produced by the deformation process is dissipated by the reconnection process. With the ejection of the magnetic field lines, the plasma which is initially placed below the corona is brought up (Figure 4). These gases are colder and denser compared with the ones in the corona. Left panel in Figure 5 shows the time plot of the height (solid line) and the velocity (dashed line) of this structure. As the reconnection process pro-
Figure 3. The blue lines show the emerging flux, and the orange lines are the arcade field lines which are involved in the reconnection process, and the green lines are the arcade field lines which are not related to the reconnection process. Isosurfaces of the current density (the gold surface in the left panel) which indicate the current sheets dissipated after the reconnection process at $t = 190$.

Figure 4. The isosurface of temperature $T = 40$ at $t = 190$, which indicates the ejected cold plasma.

ceeds, the produced helical structure is accelerated by the magnetic force, and the upward velocity reaches to 30% of the Alfvén velocity. Right panel shows this magnetic energy and kinetic energy of the deformed arcade from $t = 100$. 
Figure 5. Left panel: Height and velocity of the produced filamentary structure. The solid line shows the height, and the dashed line shows the velocity. The height is normalized by the scale height in the photosphere and the velocity is normalized by the typical Alfvén velocity in the corona. Right panel: The magnetic and kinetic energies of the arcade. The left vertical axis and the solid line are for the magnetic energy, and the right vertical axis and the dashed line are for the kinetic energy.

This figure shows that when the emerging flux appears in the corona ($t = 100$), the magnetic energy is stored in the arcade ($100 \leq t \leq 150$). From $t = 150$ the stored magnetic energy is released by the works of the magnetic pressure to the surrounding medium and also by the reconnection, which is the key process for the eruption. As the reconnection proceeds, the ejected field lines go up into higher region, extending its structure with lower surrounding pressure. These results in our simulations can explain the filament formation and eruption processes in the sun.

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References