NUMERICAL SIMULATION OF RECONNECTION BETWEEN EMERGING FLUX AND CORONAL FIELD

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Abstract

Two dimensional resistive MHD numerical simulation is performed for the reconnection between emerging flux and overlying coronal field. Two types of reconnection are investigated. The *'two-sided-loop'* type occurs when the coronal field is horizontal, and a pair of horizontal hot jets and cool magnetic island ejection is produced. The *'anemone-jet'* type reconnection occurs when the coronal field is vertical or oblique, and both a vertical hot jet and a cool jet are generated.

1. Introduction

Interaction between emerging flux and overlying coronal magnetic field is a basic process to release magnetic energy in the solar atmosphere. Shibata *et al.* (1994a) has found two types of such interaction. One of them is the *two-sided-loop type* interaction, which occurs when emerging flux appears in a quiet region where coronal field is almost horizontal or is composed of large scale loops. Hot plasma is ejected along the coronal loops toward both (two) sides of the emerging flux suggesting magnetic reconnection. Another type is the *anemone-jet type* interaction, which occurs when emerging flux appears in a coronal hole where coronal field is vertical or oblique and open to the interplanetary space. Vertical X-ray jets are ejected along this open field due to reconnection. The magnetic feature of this emerging flux region looks like a sea-anemone.

Here we report the results of numerical simulation of these two types of interaction based on magnetic reconnection between emerging flux and coronal field. instability 1993).

2. Models and Numerical Computation

Our simulation is performed by solving numerically the two-dimensional nonlinear, time-dependent MHD equations with uniform gravitational field. The initial hydrostatic plasma layer consists of three regions: corona with uniform high temperature, chromosphere/ photosphere with uniform low temperature, and convection zone with temperature decreasing

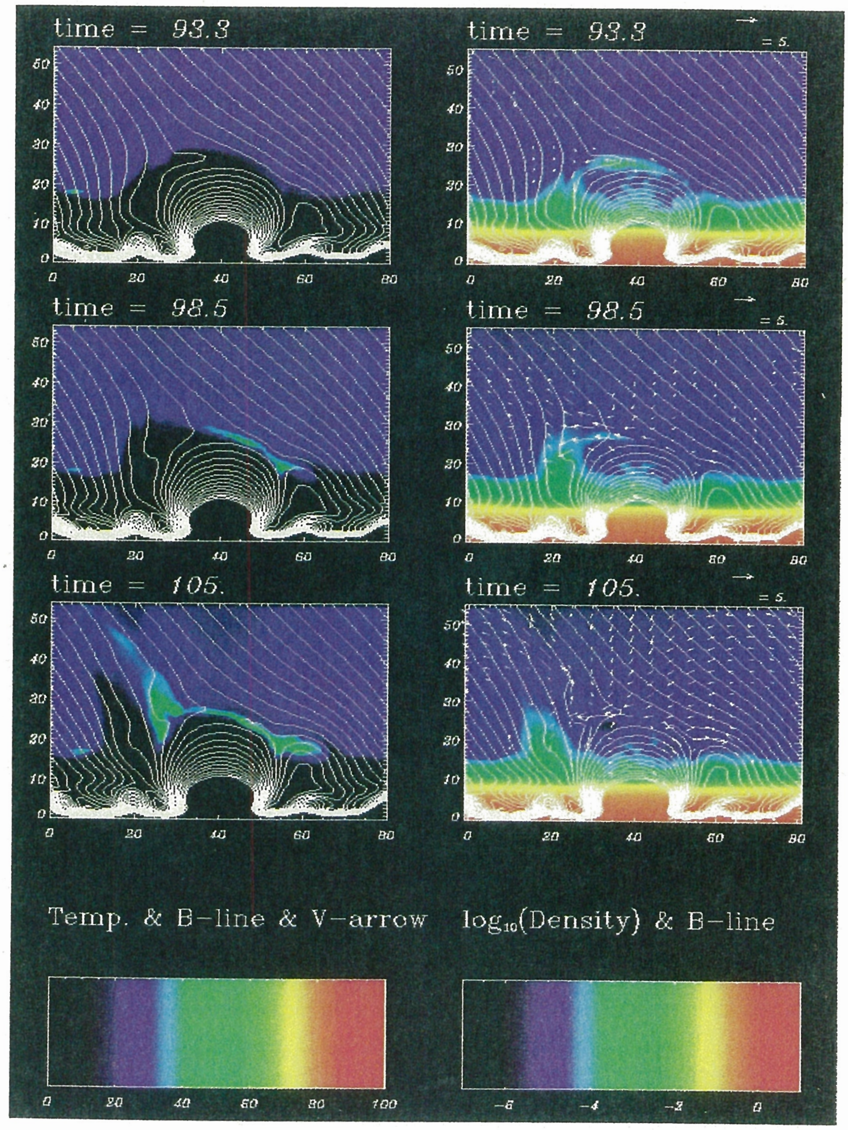

Fig. 1. Results of the 'anemone-jet' type reconnection. Left column shows temperature (T; color map), and magnetic field lines ($\mathbf{B}$; lines). Right column shows density ($\log_{10}\rho$; color map), magnetic field lines ($\mathbf{B}$; lines), and velocity vectors ($\mathbf{v}$; arrows). The times are in units of $\tau = H/C_s \simeq 20$sec, and the illustrated area is $16{,}000$km $\times$ $11{,}000$km.

with height (which is convectively unstable). Magnetic field distribution is composed of two parts. One is horizontal localized flux sheet in the convection zone, while another is nearly uniform field in the corona which is antiparallel to the flux sheet (in the case of the 'two-sided-loop' type reconnection) or oblique (in the case of the 'anemone-jet' type reconnection). took The plasma is assumed to have the anomalous resistivity depending on the electron drift velocity. To excite magnetic buoyancy instability, small velocity perturbation is initially imposed on the magnetic flux sheet within a finite horizontal domain. For simplicity of calculation, we assume the plasma to be inviscid perfect gas. For heat loss/gain, Ohmic heating is taken into account, but effect of heat conduction and radiative cooling is neglected.

3. Anemone-Jet Type Interaction

In the 'anemone-jet' type reconnection, emerging flux is considered to expand in a region where overlying coronal field is almost vertical or oblique. Figure 1 shows the results.

The flux sheet expands by the magnetic buoyancy instability (the Parker instability) to evolve into magnetic loops in the atmosphere. (Simple emergence of magnetic flux is described in detail by Shibata *et al.*, 1989.) Distance between the two footpoints of the expanding loops is about a few thousand kilometer. A dense loop seen at the top of the expanding loops corresponds to an arch filament (Fig. 1.; t=93.3). The rise velocity of this arch filament is about 10 km/sec. Along the rising loops, we can see gravitational downflow, whose velocity is about 30-50 km/sec. When the top of the rising loops enter the coronal level, a current sheet is created between the loop top and the coronal field. In several minutes after the current sheet creation, magnetic reconnection suddenly starts in the sheet due to the onset of the anomalous resistivity.

Just after the onset of magnetic reconnection, cool plasma at the top of the expanding loops is ejected due to the tension force of the reconnected field lines (Fig. 1.; t=98.5). It shows whip-like motion and changes its configuration from the arch filament to a vertical collimated feature. This whip-like motion may be observed as an H_α surge. Following the cool plasma ejection, a hot jet is also ejected just side of it (Fig. 1.; t=105). The hot plasma of this jet is energized at two points. First it is heated up and accelerated at the slow-mode MHD shocks emanating from the reconnecting X-type neutral point. Second after this acceleration by the shocks, it collides with the vertical collimated feature of the cool plasma which is mentioned before. The hot plasma is again heated up at the fast-mode shock which is created by the collision. At the same time of the ejection of the hot jet, a small bright loop is seen which is located at the opposite side of the emerging flux against the hot and cool jet (Fig. 1.; t=105). This is consistent with the observation that small flares or loop brightenings occur separately from the exact foot points of jets (Shibata *et al.* 1994b).

4. Two-Sided-Loop Type Interaction

coronal In the 'two-sided-loop' type reconnection, emerging flux expands into overlying horizontal coronal field. The preliminary results of this numerical simulation are reported by Shibata *et al.* (1992a) and Yokoyama and Shibata (1993). Figure 2 shows the results. The evolution until the onset of the reconnection in the current sheet is roughly the same as that of the 'anemone-jet' type reconnection described in the previous section.

Since the current sheet between the emerging flux and the coronal field is unstable for tearing instability, it is divided into multiple magnetic islands (Fig. 2.; t=89.6). The assumption of the anomalous resistivity model helps this instability; since the plasma density at the X-type neutral points is smaller than that at the O-type neutral points, anomalous resistivity at the X-type neutral points is larger than at the O-type neutral points. Each island confines cool, dense, and high-pressure chromospheric plasma originally in the arch filament. Soon after the creation, the islands coalesce each other (Fig. 2; t=92.8; Tajima and

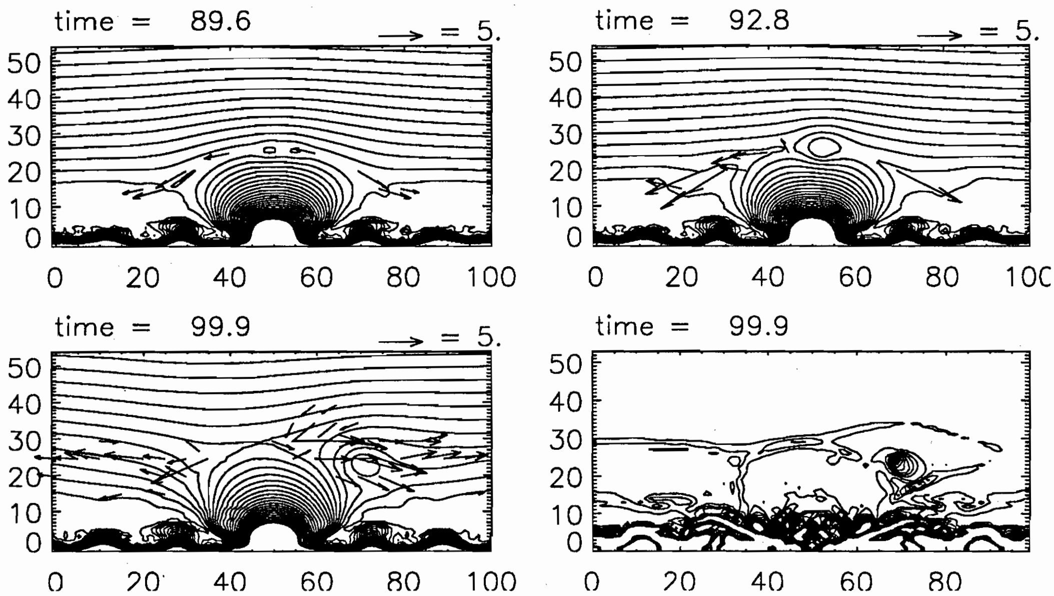

Fig. 2. Results of the 'two-sided-loop' type reconnection. Panels show magnetic field lines **B** and velocity vectors **v** for t=79.6, 92.8, 99.9 and current density J_y. The times are in units of $\tau = H/C_s \simeq 20$sec, and the illustrated area is $20,000$km × $11,000$km.

Sakai 1989). The time scales of the creation and the coalescence are a few seconds, and a few tens of seconds, respectively.

After the coalescence of the islands, one of the X-type neutral points grows into the feature of magnetic reconnection of the Petschek model (Petschek 1964). Two sets of MHD shocks are emanating outward from the X-type neutral point (Fig. 2.; t=99.9). A pair of 'hot plasma jets' are ejected from the X-type neutral point. The velocity (~ 200km/sec) of the jets are roughly the Alfvén velocity. The jets continue to flow along the coronal field and fill it. The temperature of this filling plasma is twice of the coronal temperature, (~ 4MK). This accounts for the observed 'two-sided-loop' brightenings associated with emerging flux. Furthermore, the plasma near the neutral point is heated up to extremely high temperature (~ 10-20 MK) due to shock heating. This accounts for the observed microflares or X-ray bright points. Associated with the hot jets, the magnetic island is also ejected out of the current sheet (the cool jet). The velocity of the cool jet is about 60-80 km/sec. Shibata *et al.* (1992a) points out that this accounts for the observation in which X-ray jets are associated with H_α surges found by Shibata *et al.*(1992b).

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