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NUMERICAL SIMULATION OF MAGNETIC FIELD DYNAMICS IN SOLAR CORONA WITH A SCHEME THAT IS CONSERVATIVE RELATIVE TO MAGNETIC FLUX

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Abstract. Magnetic field behavior in an active region determines development of powerful phenomena, such as solar flares, that are responsible for disturbances in the Earth magnetosphere. MHD simulation of the solar flare encounters problems associated with numerical instability growth on the photospheric boundary because of strong magnetic field gradient. A new version of the Peresvet code has been developed, which stabilizes the numerical instability. In Bastille flare simulating, this code permits to demonstrate formation of two little branches under the current sheet (CS). It is so-called mustaches – slow shocks predicted by Petschek. The similar mustaches above the CS have been revealed earlier. The 3D structure of CS magnetic field is investigated.

Introduction

3D MHD numerical simulation (Bilenko et al., 2002; Podgorny et al., 2003) demonstrated CS formation above the active region NOAA 9077 and energy storage of 5×10^{32} erg before the flare on July 14, 2000. The magnetic field of the active region was approximated by seven vertical dipoles. Positions of the dipoles and their initial parameters (t=0) are presented in the Table. The coordinates and dipole moments are shown in dimensionless units, the dimension of the active region L_0=260000 km being taken as a unit length and average magnetic field above the active region B=300 Gauss as a unit magnetic field. Here we present results of calculations for similar initial (t=0) potential magnetic field, but for different linear change of magnetic dipoles before the flare. Dipole positions and change their values before the flare are presented in the Table. The dimensionless time t is expressed in L_0/V_A, V_A being the Alfvén velocity. In the present paper we consider the influence of the magnetic field inside the CS on coronal plasma ejection during a flare.

No.	*x*	*y*	*z*	$M_y(t=0)$	$M_y(t=0.2)$
1	0.14	-0.135	0.5	-0.007	-0.007
2	0.14	-0.135	0.601	0.005	0.005
3	0.2964	-0.135	0.5	0.01	0.0142
4	0.365	-0.135	0.488	-0.016	-0.016
5	0.4629	-0.135	0.5	0.0132	0.0132
6	0.6485	-0.135	0.5	-0.013	-0.013
7	0.815	-0.135	0.5	0.0051	0.0051

Calculation technique

The Peresvet code (Podgorny and Podgorny, 2002) is used for solving the system of compressible 3D MHD equations with all dissipative terms included. The plasma thermal conductivity anisotropy in the magnetic field is taken into account. Numerous numerical MHD experiments show that such investigations require a very stable finite-difference scheme. The completely implicit code is used, but even this code does not allow for long-term MHD calculations near the photospheric boundary, where magnetic field gradient is too strong. The instability growth initiated on the photosphere does not permit to make calculations for several tens of Alfvénic times. This numerical instability emerges because rot**B** does not tend to zero during current relaxation in the magnetic field. The magnetic force appears in a numerical solution, which must not appear in the precise one. As a result, the force **j**×**B**/c initiates plasma motion and instability development (Podgorny, Podgorny, 2003). For keeping rot **B** = 0 the code is developed which is conservative with respect to the magnetic flux. It permits to simulate CS formation and its long time evolution, including investigation of its fine structure.

Results

The results of calculations are presented in Fig. 1 in the Z = 0.5 plane. This plane is the most convenient for tracing CS formation. The field lines in Fig.1a show CS formation but plasma is not ejected upward and does not produce CME. The plasma ejection upward is prevented by arch magnetic lines stretching. These lines are perpendicular to the plane of the picture (Fig. 1d). The current density distribution (Fig.1b and c) demonstrates two branches of current at the lower CS edge. These branches can be interpreted as a Petschek type plasma outflow from the CS.

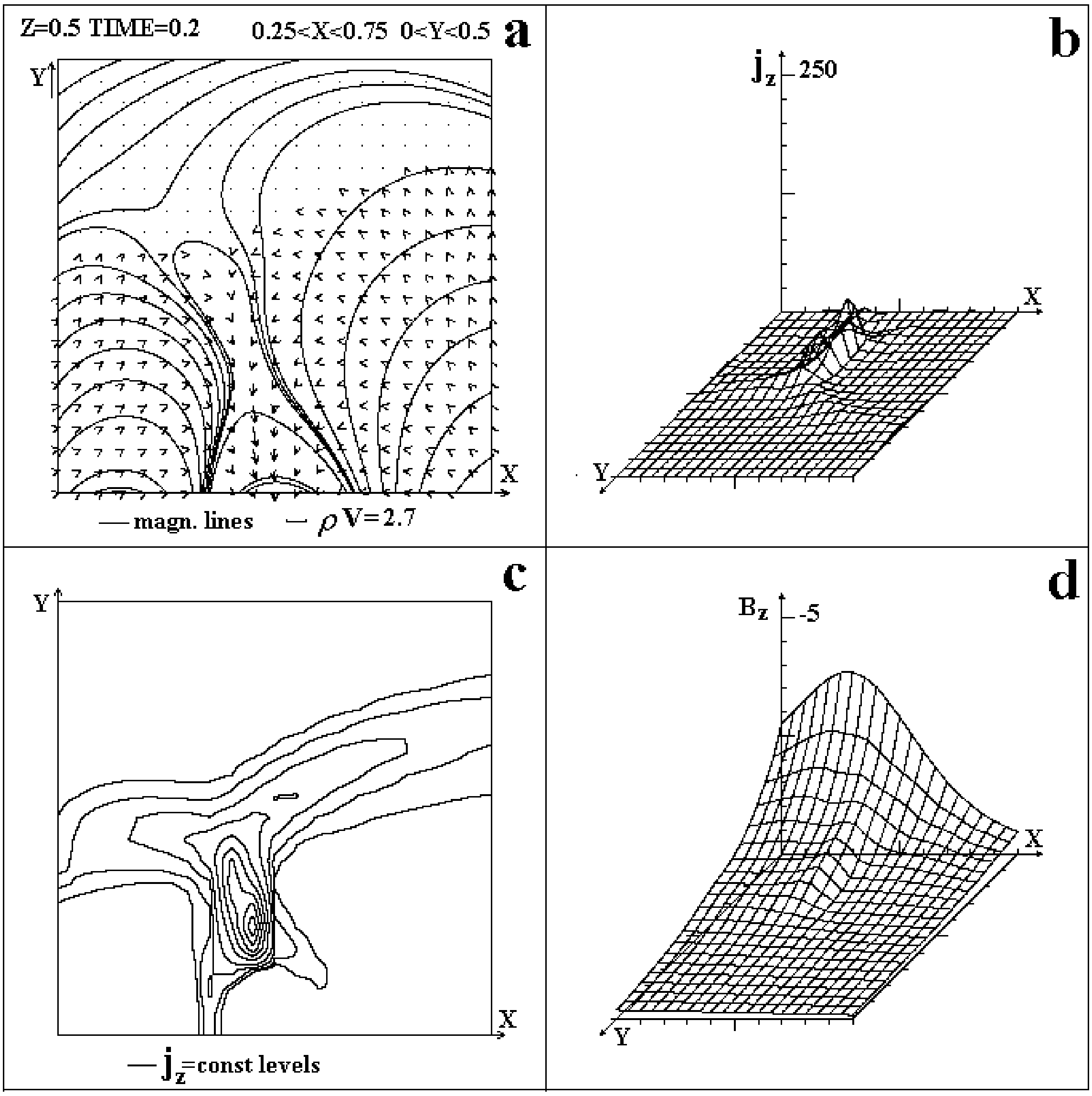

Fig. 1

The downward flow in the CS brings down frozen-in magnetic lines, magnetic lines pile up, and a region of compressed field appears. On the border of the compressed region plasma flow is decelerated and a negative current appears. This negative current can be seen in Fig. 2a and b. The plots of magnetic field, velocity, current, and density at t=0.36 are presented in Fig. 2c-f, respectively. Here, concentrating of plasma density near the photosphere is seen that appears during downward plasma ejection. Such phenomena have been observed after a solar flare ("supra-arcade downflow"). It is responsible for hot post flare formation. Further (at t>0.3), the force jB_n/c , B_n being the magnetic field component perpendicular to the CS, increases and in the upper part of the CS it exceeds the force of B_z magnetic stretching. At t~0.3 typical Petschek mustaches appear also at upper CS edge (Fig. 2b).

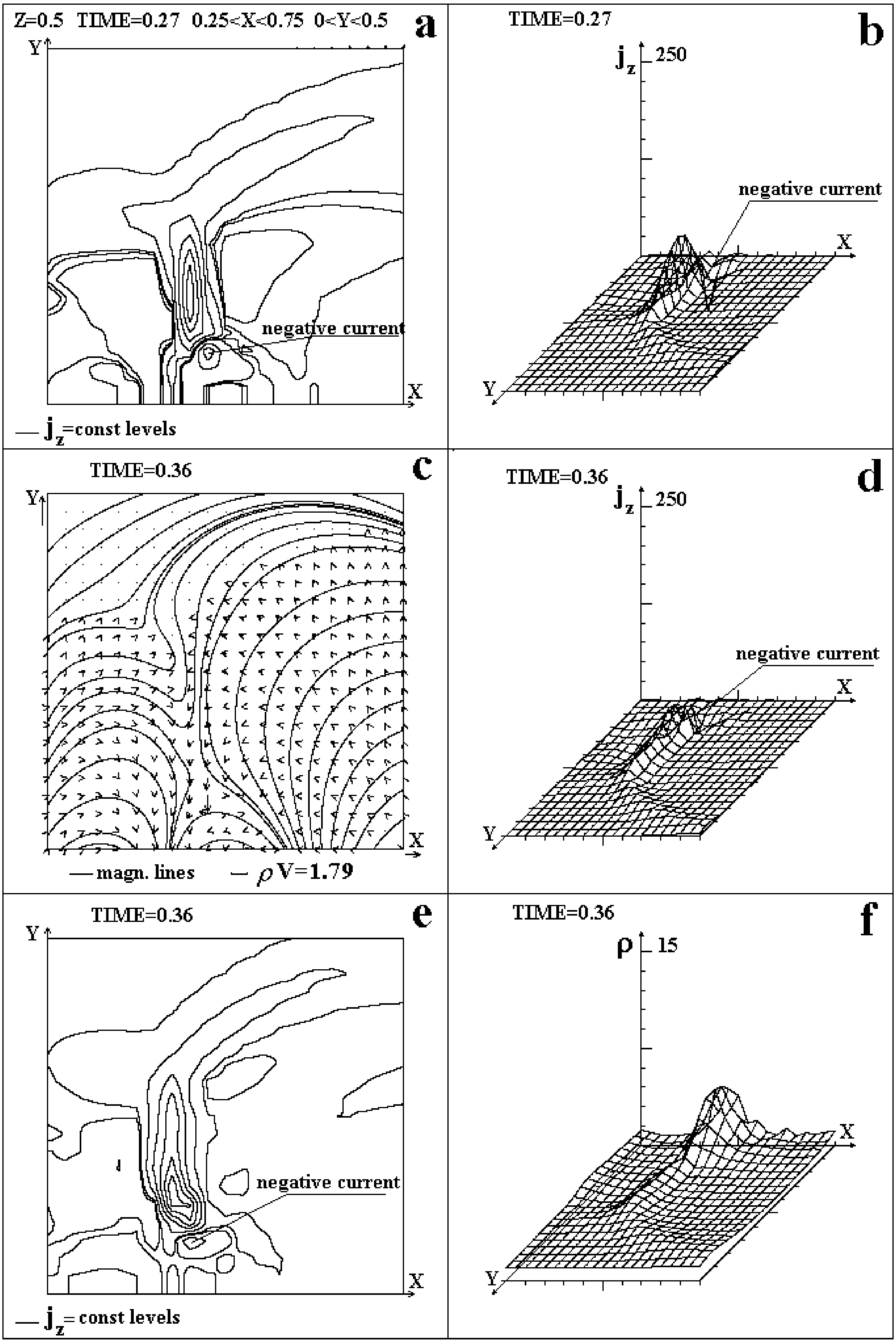
Z=0.5 TIME=0.27 0.25<X<0.75 0<Y<0.5
a
Y
X
negative current
— j_z=const levels
TIME=0.27
b
j_z
250
negative current
X
Y
TIME=0.36
c
Y
X
— magn. lines
— ρV=1.79
TIME=0.36
d
j_z
250
negative current
X
Y
TIME=0.36
e
Y
X
negative current
— j_z= const levels
TIME=0.36
f
ρ
15
X
Y

Fig. 2

The character of plasma flow becomes different, if all dipoles are situated along the same line, e.g. if dipoles 2 and 4 are shifted in the position Z=0.5. In this case, the magnetic field distribution becomes symmetric and magnetic field B_z perpendicular to the CS is equal to 0. Plasma inside the CS is accelerated downward and upward (Fig. 3a). After CS decay, strong upward flow has to produce a coronal mass ejection. The distributions of current density (Fig. 3b,c) and plasma density (Fig. 3d) at B_z=0 also reveal Petschek mustache formation, shown in Fig. 3b.

Conclusion

The jB_n/c force that pushes plasma along the CS and creates CME can be compensated by magnetic stretching of the field lines located in the plane perpendicular to the CS plane. The approximation of magnetic field in the active region by dipoles can not reveal all peculiarities in the flare development, if these forces are comparable. To analyze flare development in this case, information on distribution of all three magnetic field components is needed. It seems necessary to change from approximation by dipoles to setting boundary conditions based on detailed photospheric magnetic chart.

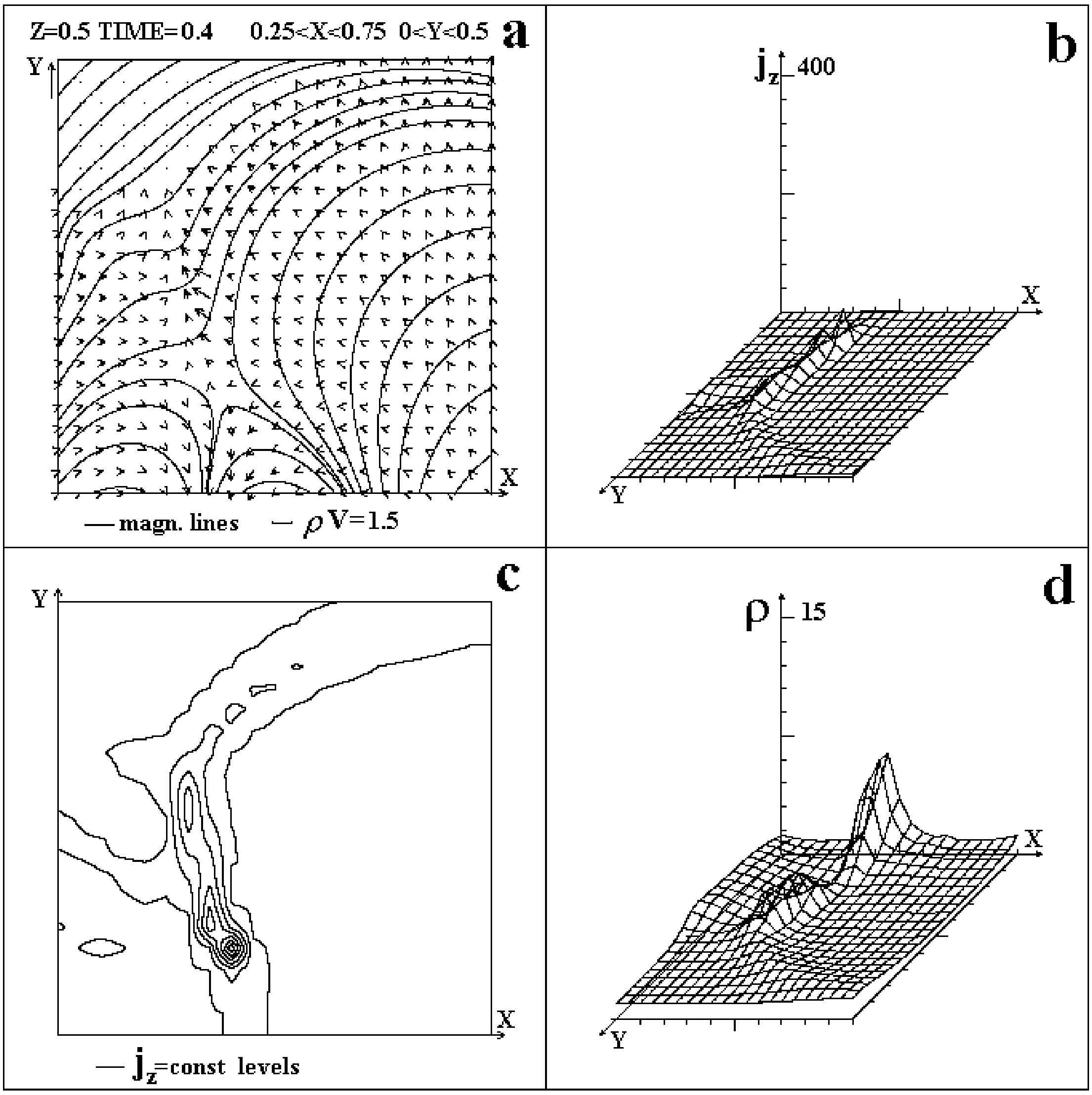

Fig. 3.

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