"Physics of Auroral Phenomena", Proc. XXVII Annual Seminar, Apatity, pp. 87-90 , 2004
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Polar Geophysical Institute

ABOUT THE POSSIBILITY OF USING PHOTOSPHERIC MAGNETIC FIELD CHARTS TO IMPROVE SOLAR FLARE PROGNOSIS

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Abstract. The photospheric magnetic field charts have been used for calculations of the solar flare energy accumulation in the coronal current sheet. The last modernization of Peresvet code is used for solving of MHD equations with conservative relative to magnetic flux difference scheme. The results are necessary for improving the quality of flare prognosis basing on the physical mechanism.

Introduction

The primordial energy release during the solar flare takes place high (from 3×10^9 cm up to 10^{10} cm) in the solar corona [1]. The energy accumulation is explained by the focusing of disturbances with current sheet creation in the vicinity of a magnetic field singular line above an active region. During quasi-stationary evolution the current sheet is transferred in the unstable state and decays, which causes the flare release of accumulated energy. The energy accumulation in the current sheet magnetic field and its explosive release would be the exactly established mechanism of the solar flare, if basing on this mechanism it should be possible to improve the quality of the flare prognosis.

The observational data do not allow one to determine a magnetic field configuration in the solar corona, so to find it, it is necessary to solve the magneto hydrodynamic (MHD) equations in the active region of solar corona, using the observed distributions of the photospheric magnetic fields for setting the boundary conditions. In [2-4] the simulation is carried out proposing approximation of spot fields by the field of dipoles situated under the photosphere. But the sum of dipole fields provides only an approximate distribution. Hereby, it is suggested to use magnetic charts for setting boundary conditions directly. To investigate the possibility of current sheet appearance, and such a way to investigate the possibility of energy accumulation for solar flare, the processes in the region of solar corona are simulated numerically. This calculation region is a cube with the size of 3×10^{10} cm. The lower boundary of the cube ($y=0$, $0\le x\le 1$, $0\le z\le 1$), which is situated in the photosphere, is the square that contains the active region NOAA 9077. This active region has produced Bastille flare 14.07.2000.

The calculation of flare

The system of 3D MHD equations for compressible plasma accounting dissipation terms and anisotropy of the thermal conductivity is solved numerically in an active region of the solar corona:

$$\frac{\partial \mathbf{B}}{\partial t} = \mathrm{rot}(\mathbf{V}\times\mathbf{B}) - \frac{1}{\mathrm{Re}_m}\mathrm{rot}\left(\frac{\sigma_0}{\sigma}\mathrm{rot}\mathbf{B}\right) \quad (1)$$

$$\frac{\partial \rho}{\partial t} = -\mathrm{div}(\mathbf{V}\rho) \quad (2)$$

$$\frac{\partial \mathbf{V}}{\partial t} = -(\mathbf{V},\nabla)\mathbf{V} - \frac{\beta_0}{2\rho}\nabla(\rho T) - \frac{1}{\rho}\left(\mathbf{B}\times\mathrm{rot}\mathbf{B}\right) + \frac{1}{\mathrm{Re}\rho}\Delta\mathbf{V} + G_g\mathbf{G} \quad (3)$$

$$\frac{\partial T}{\partial t} = -(\mathbf{V},\nabla)T - (\gamma-1)T\mathrm{div}\mathbf{V} + (\gamma-1)\frac{2\sigma_0}{\mathrm{Re}_m\sigma\beta_0\rho}\left(\mathrm{rot}\mathbf{B}\right)^2 - (\gamma-1)G_q\rho L'(T) +$$
$$+\frac{\gamma-1}{\rho}\mathrm{div}\left(\mathbf{e}_\parallel\kappa_{dl}(\mathbf{e}_\parallel,\nabla T) + \mathbf{e}_{\perp1}\kappa_{\perp dl}(\mathbf{e}_{\perp1},\nabla T) + \mathbf{e}_{\perp2}\kappa_{\perp dl}(\mathbf{e}_{\perp2},\nabla T)\right) \quad (4)$$

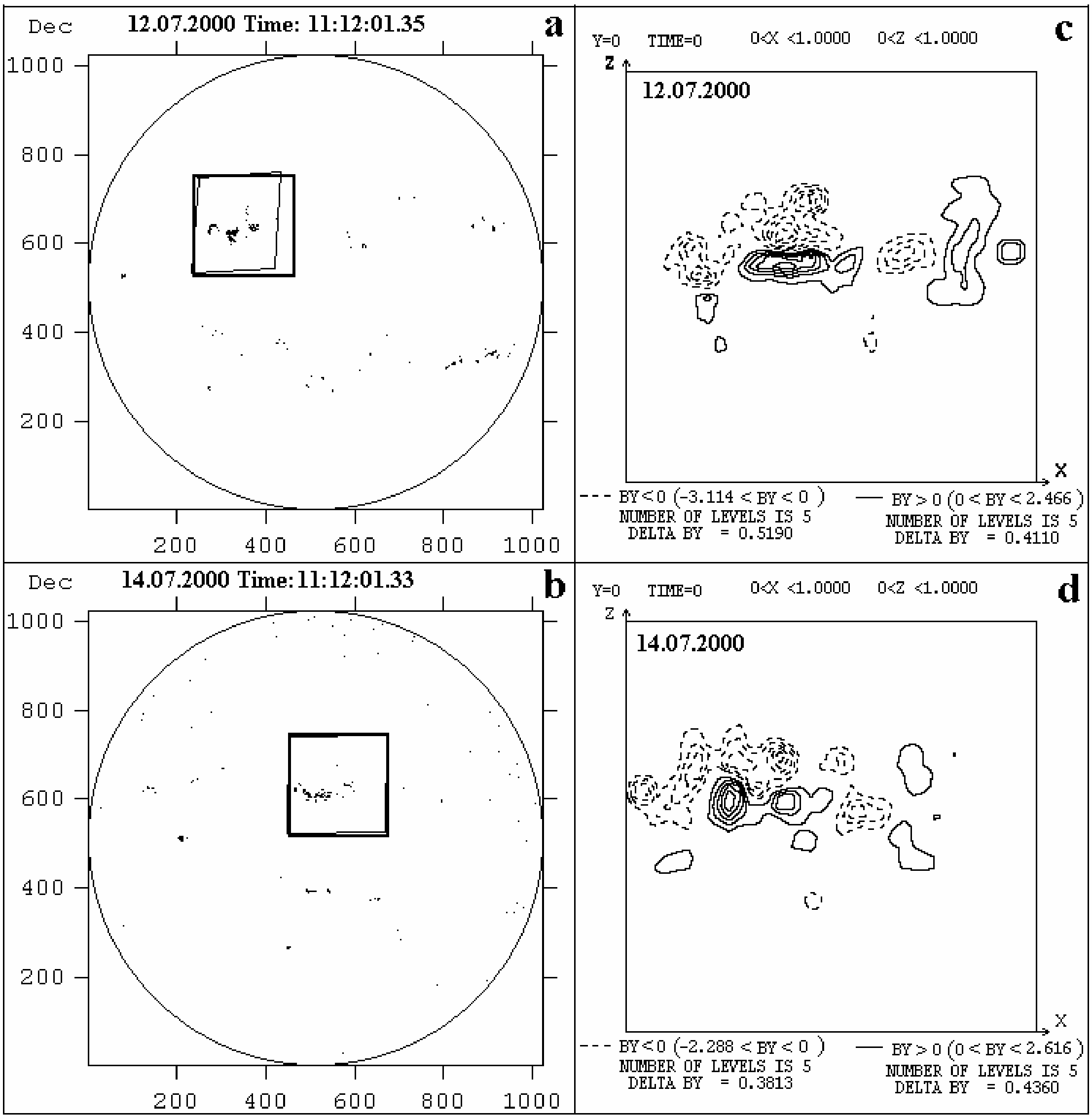
For numerical solving of the system of MHD (1-4) equations the absolute implicit difference scheme is developed [4]. The scheme is conservative relative to the magnetic flux. It is solved by an iteration method. The scheme permits to obtain stable solutions. To decrease the time of calculation a multilevel division of time steps in the places of large gradients is employed.

The solar disk charts of the magnetic field component, which is directed along the line of sight, are used for setting initial and boundary conditions. The data are obtained on board the SOHO satellite (fig. 1a, 1b). The carts are taken from http://soi.stanford.edu/magnetic/index5.html. In fig. 1a, b the positions of photospheric boundaries of calculation regions, which are projections of these regions along the line of sight (e. g. as these plains are seen from the Earth), are marked in the solar disk. Also, the positions of these regions, which should be taken in the case if they are projected on the plane perpendicular to the normal to the photosphere, are marked (e. g. the undistorted images of these photospheric regions). The positions of these projections are only slightly different (fig. 1b), if the region is situated near the disk center.

The potential magnetic field is found in the calculation coronal region for distribution of the photospheric magnetic field component along the line of sight (the magnetic field component along the direction with inclination to the photosphere is known) on the Bastille flare day (fig. 1b) in two bays before it (fig. 1a), and on four days before it. For this purpose the Laplas equation for the magnetic field potential φ with slope derivative as the boundary condition is solved numerically:

$$\Delta\varphi=0;\quad \partial\varphi/\partial l_{sight}|_{PhBoun}=-B_{sight};\quad \mathbf{B}=-\nabla\varphi \qquad (5)$$

For solving equation (5) the difference scheme is used on the grid of conservative relative to magnetic flux difference scheme for MHD equations (1-4). This scheme finds such approximation of the potential magnetic field, that finite-difference analogs of rot**B** and div**B** equal to zero with high precision. It means finding such averaged magnetic fluxes through boundaries of grid cells, that full magnetic flux through the boundary of each cell equals to zero. Using such solution of equation (5) for setting initial conditions for MHD equations permits one to obtain the stable solution of MHD equations with the difference scheme, that is conservative relative to magnetic flux. The slope derivative on the phitospheric boundary is approximated by interpolation between points, which are neighbors to boundary points.



The photospheric boundary of calculation region: —— in the plane which is perpendicular to the line of sight, —— in the plane which is perpendicular to the normal to photosphere direction

Fig. 1. Magnetic field maps

The distributions of normal to photosphere magnetic field component are presented on fig 1 c, d as the equal level lines on the photospheric boundary of calculation region in the moments of two days before flare (12.07.04 11:12:01) and Bastille flare day (14.07.04 11:12:01). The distributions are obtained from potential field which is found by numerical solving of problem (5) with distribution of the photospheric magnetic field along the line of sight (fig. 1a, b). On the Bastille flare day when the region is situated near the center of the Sun this distribution differs only slightly from the distribution along the line of sight.

To define the potential field in the corona above the active region, e. g. for solving the equation (5), it is necessary to set condition in the nonphotospheric boundary. Here the magnetic field is small, and it must not produce any strong influence on the solution inside the region. According to the first method, the normal component in the all nonphotospheric boundary $B_{NoPhBoun}$ is set as a constant. $B_{NoPhBoun}$ is calculated from the condition, that full magnetic flux through all boundary of calculation region is equal to zero (the outgoing flux is equal to the flux directed inside the region). For solving of Laplas equation (5) the condition $\partial\varphi/\partial n= B_{NoPhBoun}$ is set on nonphotospheric boundary. According to other method, the potential φ is set to be zero on nonphotospheric boundary.

The potential magnetic field configurations in the central plane of calculation region (z=0.5) calculated 4 days before flare with both types of conditions on nonphotospheric boundary are presented in fig. 2a and 2b. The comparison of 2a and 2b shows the practical coincidince of configurations in the main part of the region. Some distinctions take place only near the nonphotospheric boundary, where the magnetic field is small, and it does not influence significantly the current sheet creation.

The potential magnetic field in the initial moment of time should be known for setting the initial condition. Physically it means that the calculation begins before the appearance of strong disturbances in the photosphere, which can cause current generation in the corona. The knowledge of the initial magnetic field in the corona and photospheric magnetic field changing before the flare allows one to define the field evolution in the corona by solving of MHD equation system (1-4). During the evolution, the magnetic field above the active region can become nonpotential due to the appearance of a current system in the corona.

For the solving of the system of MHD equation (1-4) with the conservative relative magnetic flux scheme it is necessary to set two magnetic field components on the photospheric boundary, which are parallel to the boundary. So, if only the observations of line of sight field component are available (and the observational data about all three magnetic field components are not), then it is necessary to find the potential magnetic field at different time moments, and its components along the photosphere are used for setting the boundary conditions. Such approximation of the boundary magnetic field means, that the currents appearing high in the solar corona does not produce any strong influence on the photospheric field.

For using the grid 41×41×41 the numerical magnetic viscosity exceeds the physical magnetic viscosity more than by a factor of 10^8. (the numerical Reynolds number is $R_{m,num}\sim 50$, and the Reynolds number in the active region of solar corona is $R_m\sim 10^{10}$). So, if the field on the photospheric boundary is changed in calculations during the time of the order of several days, as it takes place on the Sun, then the current sheet would not be created due to a strong diffusion. In the first turn for prognosis it is important to establish the fact of current sheet appearance with the energy accumulation for a flare, the position of the current sheet in the space, and the character of plasma flow in its vicinity. So, at the present phase of the study the questions of field and plasma flow evolution, which causes the current sheet creation, are not considered. Because of that, in calculations there is set the field change in the photosphere during 0.6 s, although in the real process it lasts during two days. The further calculation is continued with the constant magnetic field on the photosphere boundary.

The results of calculation

Two calculations have been carried out. In both variants the potential magnetic field calculated from line of sight magnetic field component distribution in the photosphere four days before flare (10.07.04 fig. 2a) is taken as initial condition. In the first variant the disturbance on the boundary is set by changing of distributions of the field components along the photosphere from the moment of 4 days before the flare to the moment of 2 days before the flare. The field distributions in the initial moment and the final one are found from calculation of the potential field. Distributions of the field in each moment of this interval are found by the linear interpolation between the initial moment and the final one. Further the calculation continues from the moment 2 days before flare with fixed field distribution on the boundary. The result of this calculation is presented in fig. 2c. There is shown the magnetic field configuration in the plane z=0.575, which contains the most representative magnetic field singularities.

In the second variant at the beginning the evolution in the active region of the solar corona is calculated in the interval between the moments of 4 days before the Bastille flare and 2 days before the Bastille flare as in the first variant. Further, the calculations between the moment of2 days before the flare and the Bastille flare day are carried out. The field configuration obtained as a result of this calculation is shown in fig. 2d.

The first variant has been carried out first of all to study the possibility of improving quality of solar flare prognosis. For this purpose it is necessary to obtain the information about the current sheet appearance, using the observational changes of the magnetic field distributions in the photosphere two days before the flare and earlier.

The first variant of calculation is important also because two days before the Bastille flare the less powerful flare takes place, during which the energy accumulated in the magnetic field magnetic is realized.

The used grid is too rough for such representation of the magnetic field configuration near the sheet. But some conclusions can be done. Fig. 2c and 2d demonstrate a tendency to disturbances focusing in the vicinity of singular lines that show the places of possible flare energy accumulation.

The results of calculations show that it is necessary to use the net with much smaller steps especially near singular lines. The decrease of space steps only in restricted places near the singular lines demands a development of special methods of MHD equations numerical solution. To apply the grid with small steps in the entire region, it is necessary to use a supercomputer. The supercomputer is supposed to be used also for a more detailed simulation of the process developing in time (correspondence of two days interval duration significantly longer interval than 0.6 s). In that case it is necessary to have the detail grid and also significantly lager number of time steps.

If the information about distributions of all three magnetic field components on the photosphere will be available, then the possibility appears to carry out more precise calculation using this information, than calculations with the boundary conditions obtained from the potential field.

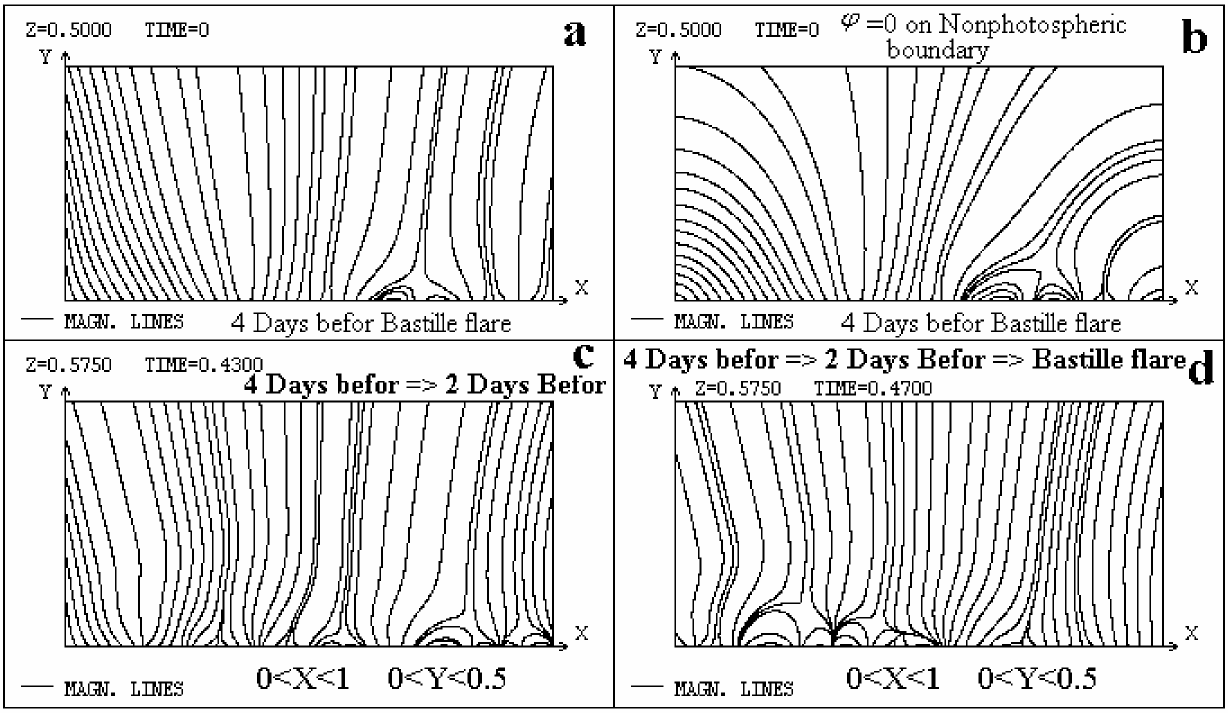


Fig. 2. The calculated potential magnetic field (a, b), and MHD simulation results (c, d).

Conclusion

In spite of the fact, that present simulation shows only tendencies of current sheet creation in the corona with magnetic energy accumulation for the flare, this information can be essential for improvement of solar flare prognosis. Now the prognosis with rather acceptable quality is realized using only the magnetic field charts on the photosphere without any imaginations about the field configuration in the corona [5, 6]. The time of calculation with the grid 41×41×41 on the personal computer with frequency 2.4 GHz is sufficient for realizing the flare prognosis during 1-2 days. The finding of potential field demands ~ 2 min., and the time of MHD equations solving is 3-4 hours.

Acknowledgments. This paper is supported by Astronomiya State Program of Russia.

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