Development of a divergence-free scheme for the MHD relaxation method

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Various explosive phenomena in the solar atmosphere are considered to be a sudden magnetic energy liberation process. In order to clarify and predict those phenomena, information on the three-dimensional distribution of the magnetic field in the solar atmosphere is required. However, a high-quality direct observation of coronal magnetic fields is still challenging though vector magnetic fields on the photosphere are provided. Therefore, methods extrapolating the magnetic field from the photosphere have actively been developed so far.

The magnetohydrodynamic (MHD) relaxation method [1] reconstructs the magnetic field in the solar atmosphere as a converged solution of simplified viscous/frictional MHD equations, and is one of the powerful methods to analyze the fields in solar active regions [2]. Careful parameter tuning, however, is required to obtain a converged solution stably since the numerical scheme adopted in previous relaxation methods, however, is based on classical centered finite difference. Also, in the previous scheme, the divergence of the magnetic field is numerically suppressed by advection and diffusion because it is difficult to preserve the solenoidality of the magnetic field strictly on the boundary. Therefore, in this study, a robust and high-resolution divergence-free scheme for the the MHD relaxation method is developed applying modern numerical techniques for MHD. The performance of our divergence-free scheme is evaluated particularly by comparing with the semi-analytical solution of the nonlinear force-free magnetic field [3].

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