

Data-driven MHD Simulation of Successive Solar Plasma Eruptions

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Solar flares and plasma eruptions are sudden release of magnetic energy stored in the plasma atmosphere. The energy release was driven by magnetic reconnection and magnetohydrodynamic (MHD) instabilities. To evaluate the critical condition of MHD instabilities and the possible energy release, three-dimensional magnetic fields from the photosphere to the corona must be analyzed¹. The solar photospheric magnetic fields are observable in detail, whereas the coronal magnetic fields cannot be measured directly. One method for inferring the coronal magnetic fields is performing data-driven simulations, which involves time-series observational data of the photospheric magnetic fields with the bottom boundary of MHD simulations. In the data-driven simulations, we expect to reproduce realistic evolution of the coronal magnetic fields following the change of the photospheric magnetic fields. There are two critical issues to introduce observational data to the numerical simulations. One is mismatch of dimension: the observational magnetic data are two-dimensional (only in the surface), while we need three-dimensional data (in the different height). The other is absence of the velocity fields consistent with the evolution of the photospheric magnetic fields. To overcome these issues, several numerical techniques have been developed^{2,3}.

In this study, we developed a new data-driven method in which temporal evolutions of the observational vector magnetic fields can be reproduced at the bottom

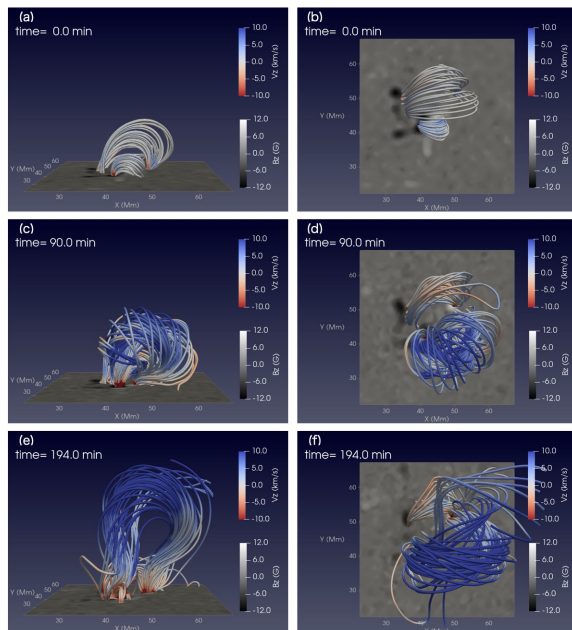


Figure 1. Temporal evolution of the coronal magnetic fields. Lines and colors on the lines represent the magnetic field lines and vertical velocity, respectively. The gray scale on the bottom surface represents the vertical component of the magnetic fields.

boundary in the MHD simulation by introducing an inverted velocity field. This velocity field is obtained by inversely solving the induction equation and applying an appropriate gauge transformation⁴. By imposing the velocity field to the bottom boundary condition for the equation of motion, the physical consistency between the plasma motion and the evolution of magnetic fields is guaranteed. Using this method, we performed a data-driven simulation of successive small plasma eruptions observed by the Solar Dynamics Observatory (NASA GSFC, USA) and the Solar Magnetic Activity Research Telescope (Hida observatory, Japan) in 2017 November. The simulation well reproduced the converging motion between opposite-polarity magnetic patches, demonstrating successive formation and eruption of helical flux ropes⁵ (Fig. 1). The nonpotential (free) magnetic energy continuously injected by the converging motion. Hence, the nonpotential energy was regained between the first and the second eruptions (Fig. 2). The released energy was around 10% of the stored energy in both eruptions.

References

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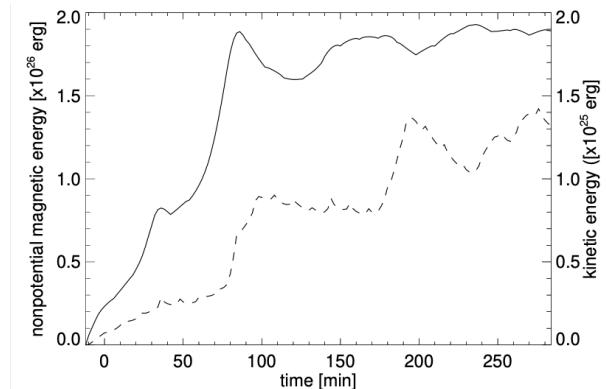


Figure 2. Temporal evolution of the nonpotential magnetic energy (solid) and the kinetic energy (dashed).