§31. Multi-scale Simulation Study of Solar and Heliospheric Plasmas

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The sun and the heliosphere is a complex plasma system, in which processes at vastly different scales interact to each other. The objective of this study is to develop a numerical framework, which is capable to simulate multi-scale processes occurring in the sun and the heliosphere, aiming at improving our understanding and advancing the predictability of space weather and space climate. We have developed several element models respectively for solar active region, the solar corona, and the interplanetary space, which constitute a suite of heliophysical simulation framework. In FY 2009, we focus on the development of solar active region model.

Solar active region is a region where there is much strong magnetic field than the other part of the solar surface, and is also productive region for explosive eruptive events, which could be observed as solar flare and coronal mass ejection (CME). In order to reveal the physical condition for the eruption, it is crucially important to analyze the three-dimensional structure of magnetic field. Therefore, first, we have developed a numerical model to reconstruct the three-dimensional force-free equilibrium above an active region based on the vector magnetogram observation by Solar Optical Telescope (SOT) onboard the solar physics satellite Hinode.

Figure 1 shows the reconstructed magnetic field lines of the active region NOAA 10930, which produced the major X-class solar flares in December 2006. The result indicates that only small fraction of magnetic flux is subject to more than one turn due to the rotation of sunspot. It means that the active region was still stable to ideal MHD mode even right before the onset of solar flare, and hence it is concluded that not only the sunspot rotation but also some additional activity should be needed for the onset of solar flare.

Second, we have performed some numerical experiment of the solar flare in terms of the three-dimensional magnetohydrodynamic (MHD) simulation adapting the force-free field extrapolated from the observation as the initial condition as well as imposing some ad-hoc perturbation on the solar surface as the trigger process. Figure 2 represents the snapshot of an experiment, in which the initial magnetic field was given by the force-free field shown in Fig.1, and slow converging motion into the flare site was imposed on the solar surface boundary for triggering the flare. As a consequence, magnetic reconnection proceeds and forms flux rope, which was ejected to south-east. The iso-contour in the figure indicates the super-Alfvenic jet, and the result clearly shows that magneto-acoustic shock is formed propagating into south-east. The structure and the dynamics of shock are well consistent with the observation of soft X-ray wave front, which was observed to propagate also to south-east by an X-ray/EUV telescope (XRT) onboard Hinode satellite. The spectroscopic observation by EUV imaging spectrometer (EIS) onboard Hinode revealed that the wave front corresponds to a shock of Alfven Mach number of 1.4. The results are well consistent with our numerical experiment, in which shock with the Alfven Mach number of 1.5 was formed on the front of flux rope.

All the results imply that the numerical experiments based on the high-accurate magnetogram observation is able to well capture the eruptive dynamics subsequent to magnetic reconnection, even though the trigger of reconnection is still unpredictable. Finally, we can conclude that some data-driven simulation of solar storm is almost feasible and it might be used even for forecasting space weather caused by strong solar storm.

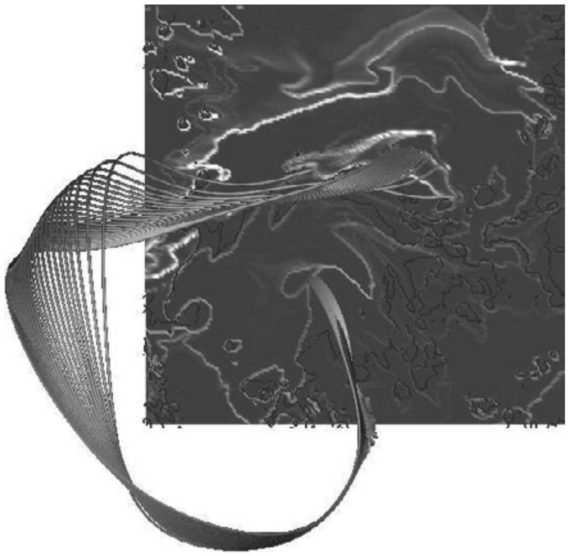

Figure 1: Magnetic field lines of force of the solar active region NOAA 10930. Gray scale indicates the distribution of magnetic separators on the solar surface.

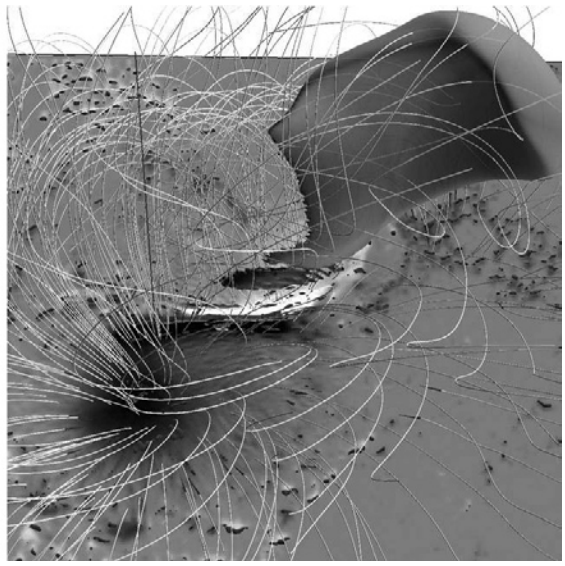

Figure 2: The result of numerical experiment of the solar flare occurring on December 13, 2006. Super-Alfvenic jet (contour) and magnetic field lines are plotted. Gray scale on the bottom shows the normal component of magnetic field on the solar surface.