Thesis for the Degree of Doctor of Philosophy

Investigation into Force-Freeness of a Solar Active Region and Application of Force-Free Models to a Flare-Producing Active Region

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Abstract

Active phenomena observed on the Sun, such as solar flares and coronal mass ejections, frequently occur in solar active regions where intense magnetic flux exists. To understand their generating mechanisms, it is important to derive the structure of active region magnetic field from observational data. Potential field is one of the simplest magnetic fields used to reconstruct active region magnetic fields, which can provide information on the field line connectivity of active region magnetic fields. It is, however, not appropriate for investigating their quantitative properties because potential field does not have free magnetic energy to produce those active phenomena. On the other hands, force-free magnetic field is reasonable for coronal magnetic structure since corona is under low-beta condition. The aims of this thesis are i) we used a modeled active region to study how valid force-free approximation is (force-freeness of active region magnetic fields). ii) on the basis of force-freeness study, we use NLFF field models to investigate quantitative properties of an observed flare-producing active region (application of NLFF field models).

Toward the first aim, we have performed magnetohydrodynamic simulations for the formation of an active region to investigate the force-freeness of active region magnetic fields via virial theorem. Our focus is on how the force-free range of active region and how the range depends on the twist of magnetic field composing an active region. For this purpose the simulations are systematically performed by changing the twist of an emerging flux tube, which produces active regions with different magnetic configurations. An investigation using virial theorem shows that as an emerging flux region evolves, the upper limit of the force-free range continuously increases while the lower limit is asymptotically reduced to the order of a photospheric pressure scale height above the solar surface. As the twist of an emerging flux rube becomes strong the force-free range extends toward the solar surface. Based on simulation results, we discuss the applicability of NLFF field models of coronal magnetic field.

Toward the second aim, we use NLFF field models of coronal magnetic fields to investigate the distribution characteristics of coronal electric current density in a flare-producing active region (AR12158; SOL2014-09-10). A time series of reconstructed NLFF fields shows the spatial development of coronal current density distributed in this active region. A fractal dimensional analysis shows that a concentrated coronal current forms a structure of fractal spatiality. Furthermore, the distribution function of coronal current density is featured with a double power-law profile, and the value of electric current density at the breaking point of a double power-law fitting function shows a noticeable time variation toward the onset of an X-class flare. We discuss that this quantity will be a useful indicator for the occurrence of a flare.

In appendix, we explain the methods for active region modeling. The numerical scheme and accuracy for our NLFF field models are also explained there.

Keywords. Sun: flux emergence – Sun: solar flare –Sun: force-free field

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