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Magnetohydrostatic Modeling of the Solar Atmosphere

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Gaining insight into the magnetic fields and plasma in solar active regions is very important for studying various solar activities. So far, the main approach to obtain the three-dimensional (3D) magnetic field structure of active regions is to extrapolate the magnetic field from magnetograms measured in the photosphere. A basic assumption in the past was to completely neglect all plasma effects and to perform the so-called force-free field (FFF) extrapolations [1]. Couple of methods (e.g PFSS, linear FFF, nonlinear FFF) are available. Among these methods, till now, the NLFFF performed the best when compared with observations. While the force-free assumption is well justified in the solar corona, it is not the case in the photosphere and chromosphere. New approaches, like for example magnetohydrostatic (MHS) extrapolation which takes into account plasma forces (e.g., plasma pressure and gravity), developed rapidly in the last decade [2]. The MHS extrapolation shows promising results when applied to reconstruct known reference models. Moreover, a few applications of the MHS extrapolation to real magnetograms have also been reported. However, we also found the MHS extrapolation is very time-consuming compared with the NLFFF extrapolation and the inconsistency problem remains between the magnetogram and the MHS assumption as is the case in the force-free situation.

We tried to solve the first problem by combining the MHS extrapolation with the NLFFF extrapolation [3]. The non-force-free region is thin in the lower atmosphere which is modeled by the MHS extrapolation. However, the vast majority part of an active region is high in the corona which can be modeled efficiently by the NLFFF extrapolation with the magnetogram at some force-free height created by the MHS extrapolation below. Following a number of test runs, we found the new approach is capable of reconstructing the magnetic fields in multi-layers accurately and efficiently (See figure 1). Such approach facilitates the application of the MHS extrapolation to magnetograms with very high spatial resolution (DKIST, GST).

As to the second problem, we proposed an optimization algorithm to preprocess the non-MHS magetogram before it is used in the MHS extrapolation [4]. By applying Gauss' theorem and assuming an isolated active region on the Sun, we found a set of surface integrals as criteria for the MHS equilibrium. Based on the criteria, an optimization method is used to change the magnetogram to minimize its deviations from the criteria as well as the measured value.

References
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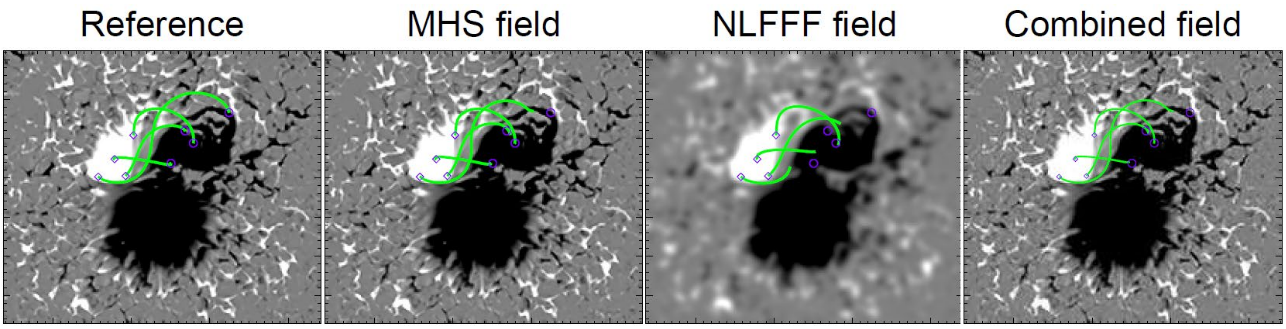

Figure 1: Field line configurations of different models. The same start points marked with rhombus are selected for all panels. End points of the referenced field lines are marked with circles.