Numerical analysis of the time series magnetic fields in solar active regions for solar flare forecasting

Han He[1]

[1]National Astronomical Observatories, Chinese Academy of Sciences

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Abstract

The present space-based solar observing facilities, such as the Helioseismic and Magnetic Imager (HMI) instrument aboard the Solar Dynamics Observatory (SDO) satellite, can obtain time series photospheric vector magnetograms of solar active regions with high spatial and temporal resolution. The time evolution of the photospheric vector magnetic fields can be traced continuously for nearly all active regions appearing on the solar disk except for the marginal area near the solar limb. This facilitating condition is a huge benefit to the solar flare forecasting. By numerical modeling of the coronal magnetic fields based on the sophisticated nonlinear force-free field model from the observed photospheric vector magnetograms, the time series data of the coronal magnetic fields corresponding to the time series photospheric vector magnetograms can also be obtained. Then, the numerical analysis can be performed on the coronal magnetic field data, and the time evolution of the internal coronal magnetic structures as well as the evolution of the nonpotentiality in solar active regions can be revealed. The deduced quantitative measures of the coronal magnetic fields from the numerical analysis, such as the electric current density, the force-free factor, and the magnetic energy density, can be utilized in the solar flare forecasting and for establishing the solar flare prediction model. Samples of electric current analysis are presented. Through the numerical analysis of the time series magnetic fields in solar active regions, it is expected to predict flare locations, flare classes, and timing of flares.

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Numerical Analysis of the Time Series Magnetic Fields in Solar Active Regions for Solar Flare Forecasting

National Astronomical Observatories of China
Chinese Academy of Sciences

Han He[1,2,3]

[1] National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China, [2] CAS Key Laboratory of Solar Activity, Chinese Academy of Sciences, Beijing, China, [3] University of Chinese Academy of Sciences, Beijing, China. Correspondence to: hehan@nao.cas.cn

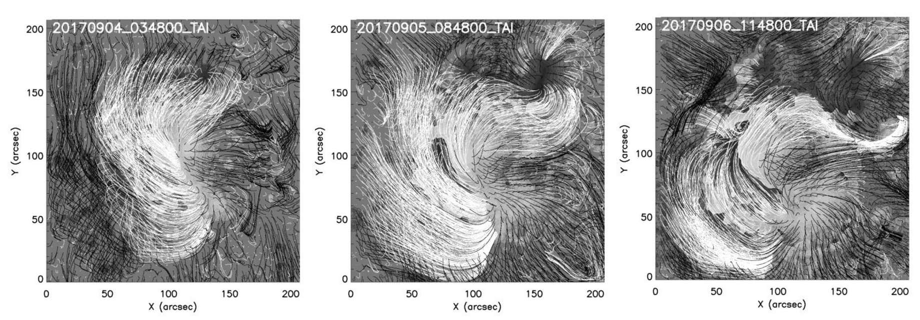
Abstract. The present space-based solar observing facilities, such as the Helioseismic and Magnetic Imager (HMI) instrument aboard the Solar Dynamics Observatory (SDO) satellite, can obtain time series photospheric vector magnetograms of solar active regions with high spatial and temporal resolution. The time evolution of the photospheric vector magnetic fields can be traced continuously for nearly all active regions appearing on the solar disk except for the marginal area near the solar limb. This facilitating condition is a huge benefit to the solar flare forecasting. By numerical modeling of the coronal magnetic fields based on the sophisticated nonlinear force-free field model from the observed photospheric vector magnetograms, the time series data of the coronal magnetic fields corresponding to the time series photospheric vector magnetograms can also be obtained. Then, the numerical analysis can be performed on the coronal magnetic field data, and the time evolution of the internal coronal magnetic structures as well as the evolution of the nonpotentiality in solar active regions can be revealed. The deduced quantitative measures of the coronal magnetic fields from the numerical analysis, such as the electric current density, the force-free factor, and the magnetic energy density, can be utilized in the solar flare forecasting and for establishing the solar flare prediction model. Samples of electric current analysis are presented. Through the numerical analysis of the time series magnetic fields in solar active regions, it is expected to predict flare locations, flare classes, and timing of flares.

Principle

- **Key idea:** tracing time-series variations of magnetic structure and nonpotentiality in solar active regions (ARs)
- **Purpose:** solar flare short-term forecasting (where, class, when)
- **Numerical modeling approach:** nonlinear force-free field (NLFFF) reconstruction of time-series coronal magnetic field
- **Numerical analysis approach:** time-series evolution of spatial distributions of physical parameters in corona

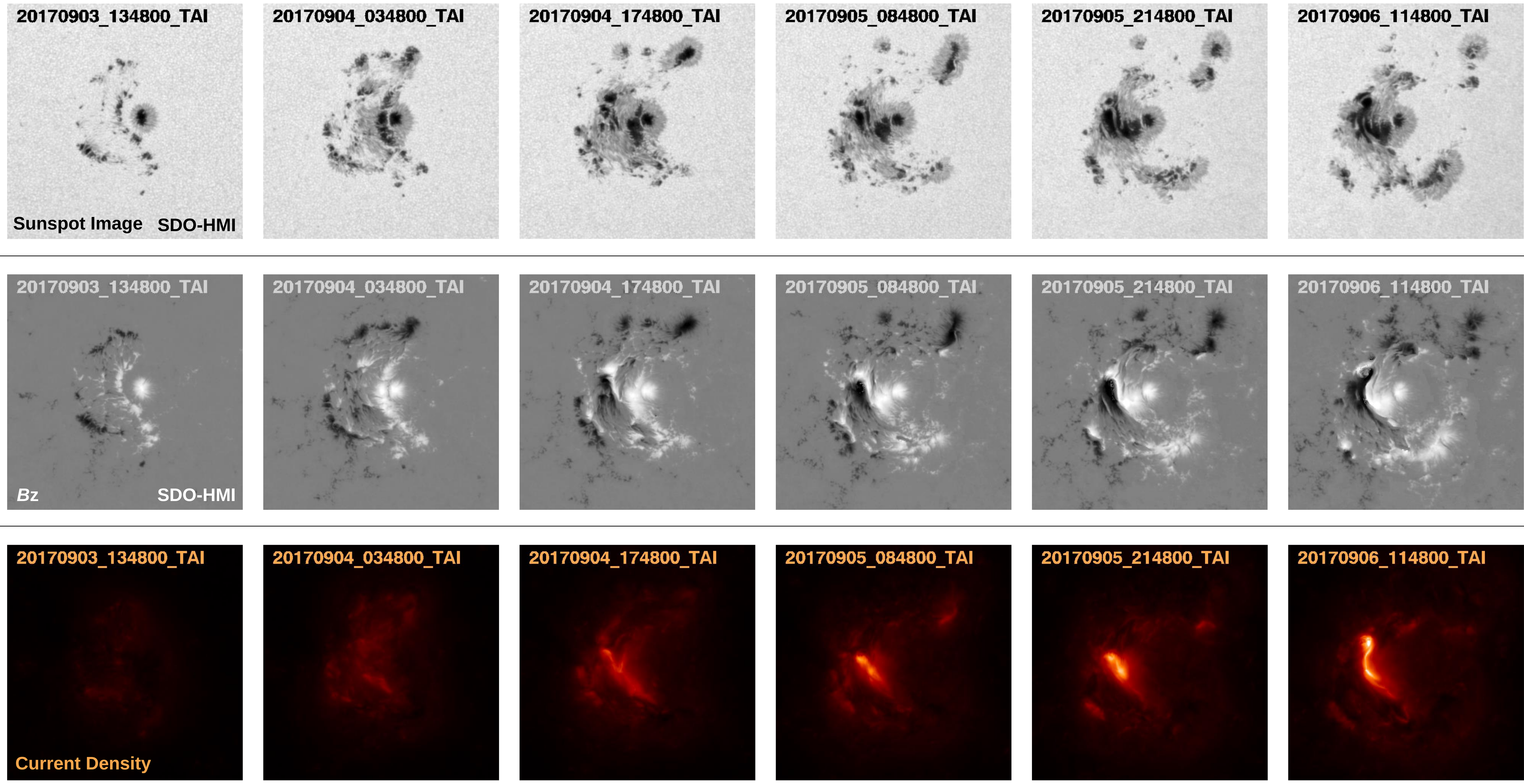
Reconstruction of time-series coronal magnetic field

Time-series photospheric vector magnetogram → $\nabla\times\mathbf{B}=\alpha(\mathbf{r})\mathbf{B}$, $\mathbf{B}\cdot\nabla\alpha=0$ → Time-series 3-D coronal magnetic field



Time sequence

NLFFF algorithm and code: He et al., JGR-SP, 2008; 2011; 2014 (based on direct boundary integral equation, Yan & Li, ApJ, 2006)



Physical parameters in corona

Electric Current Density:

$$j=(1/4\pi)(\nabla\times B)$$

indicating **key area of activity in active regions**

Force-Free Factor α of NLFFF:

$$\alpha=\frac{(\nabla\times B)\cdot\mathbf{B}}{B^2}$$

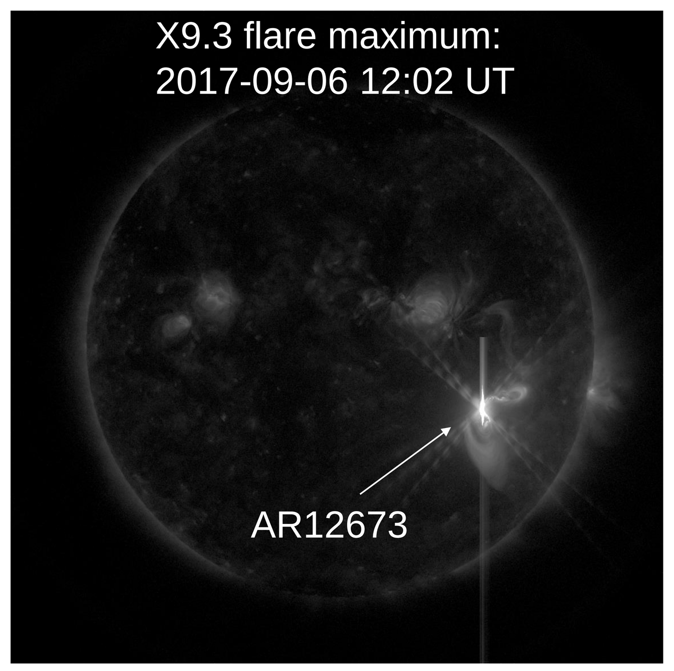
reflecting **magnetic connectivity, helicity & twist**

Magnetic Energy:

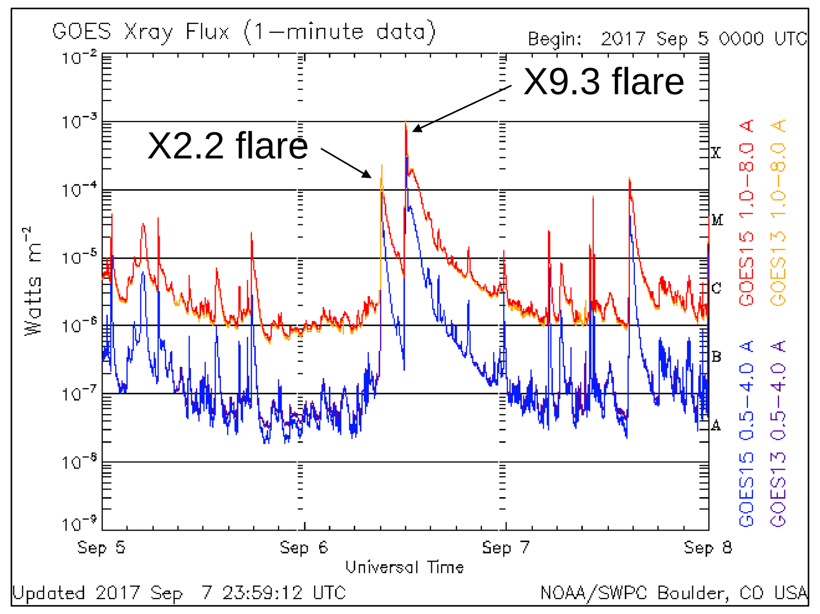
$$E_{\text{Free}}=E_{\text{NLFFF}}-E_{\text{PF}} \qquad E=\int_\Omega\frac{B^2}{8\pi}\,\mathrm{d}\Omega$$

giving **upper limit of flare class**

AR12673 flare events (6 September 2017)



SDO-AIA 94Å image



X9.3: begin 11:53 UT, maximum 12:02 UT
X2.2: begin 08:57 UT, maximum 09:10 UT

Incorporating artificial intelligence (AI) forecasting technique

- **Where：** AI model on *time series of electric current spatial distribution vs. flare onset locations*
- **Class：** AI model on *electric current intensity vs. flare classes*
- **When：** AI model on *time-series evolution of electric current vs. timing of flares*

Team at *CAS Key Laboratory of Solar Activity*

Han He, Long Xu, Xin Huang, Juan Guo, Huaning Wang, Zhanle Du, Yan Yan

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