A Statistical Study on Photospheric Active-Region Magnetic Nonpotentiality and Associated Flares During Solar Cycles 22 – 23

YANG Xiao, ZHANG HongQi, GAO Yu, GUO Juan, LIN GangHua (E-mail: yangx@nao.cas.cn)
Key Laboratory of Solar Activity, National Astronomical Observatories, Chinese Academy of Sciences
Huairou Solar Observing Station, National Astronomical Observatories, Chinese Academy of Sciences

Introduction

The accumulation of magnetic nonpotentiality in active regions may provide enormous energy for severe solar eruptions such as flares and coronal mass ejections, which are prone to affect the solar-terrestrial environment. At Huairou Solar Observing Station, the Solar Magnetic Field Telescope (SMFT) [1] has been steadily working for more than 20 years. Based on these precious vector magnetograms of active regions, we statistically studied the strength evolution of several magnetic nonpotentiality measures, along with a magnetic complexity parameter – effective distance [2], and also their relationships with associated flares during the latest 22nd and 23rd solar cycles.

Within 30° from the solar disk center, only one magnetogram of an active region is picked up each day from all the vector magnetograms. 2173 magnetograms containing 1106 active regions from June 1988 to March 2008 are selected as samples for the calculations. These samples are divided into the flare-productive part and flare-quiet part, according to whether the active region produced flares with FI ≥ 10.0 (M1.0 equivalent) or not within 24 h. And then the yearly mean values of each nonpotentiality parameter are calculated separately for each part (Fig. 3). Other values of the FI threshold and following time are adopted as well. Based on these data and flare records, the flaring potential of each active region at its specific observing time is also statistically calculated. Furthermore, an effective machine learning method is used to verify the flare-prediction performance of these magnetic nonpotentiality parameters.

Fig. 1 Solar Magnetic Field Telescope at Huairou Solar Observing Station, NAOC

Magnetic Nonpotentiality Parameters

Fig. 2 shows an example of magnetograms observed by SMFT. The analyzed magnetic nonptentiality parameters are $\overline{\Delta\varphi}, \overline{\Delta\psi}, \overline{|J_z|}, \overline{|h_c|}, |\alpha_{av}|, \overline{\rho_{free}}, d_E$, and d_{Em}. They are all macroscopic and averaged quantities, which represent the nonpotentiality or complexity of a whole active region. The equations for calculating each measure are briefly listed as follows.

- Planar magnetic shear angle

$$\Delta\phi = (\widehat{\boldsymbol{B}_{to}, \boldsymbol{B}_{tp}}) = \arccos\left(\frac{\boldsymbol{B}_{to} \cdot \boldsymbol{B}_{tp}}{|\boldsymbol{B}_{to}||\boldsymbol{B}_{tp}|}\right)$$

- Shear angle of vector magnetic field

$$\Delta\psi = (\widehat{\boldsymbol{B}_{o}, \boldsymbol{B}_{p}}) = \arccos\left(\frac{\boldsymbol{B}_{o} \cdot \boldsymbol{B}_{p}}{|\boldsymbol{B}_{o}||\boldsymbol{B}_{p}|}\right)$$

- Vertical current density

$$J_z = \frac{1}{\mu_0}(\nabla \times \boldsymbol{B})_z$$

- Current helicity density

$$(h_c)_z = B_z(\nabla \times \boldsymbol{B})_z$$

- Force-free field factor

$$\alpha_{av} = \frac{\sum(\nabla \times \boldsymbol{B})_z \cdot \mathrm{sign}[B_z]}{\sum|B_z|}$$

- Free magnetic energy density

$$\rho_{free} = \frac{\boldsymbol{B}_s^2}{8\pi} = \frac{(\boldsymbol{B}_o - \boldsymbol{B}_p)^2}{8\pi}$$

- Effective distance of longitudinal fields

$$d_E = \frac{R_p + R_n}{R_{pn}}$$

- Longitudinal-field weighted effective distance

$$d_{Em} = d_E\overline{|B_z|}$$

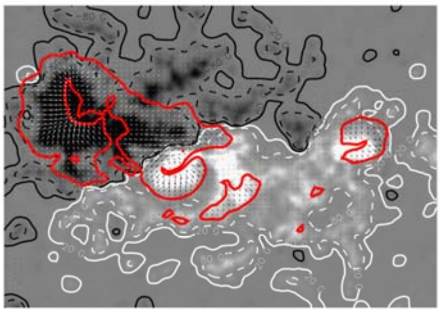

Fig. 2 A vector magnetogram of NOAA AR 5356 at 02:12 UT on 15 February 1989. The white and black regions correspond to the positive and negative longitudinal magnetic fields, respectively. The arrows indicate the directions of transverse fields, the length of which denote their magnitudes. Only the arrow vectors with B_t > 50 G are shown in the figure. The white and black solid contours indicate B_l = ±20 G; the white and black dashed contours indicate B_l = ±80 G. The red solid contours are for B_t = 200 G.

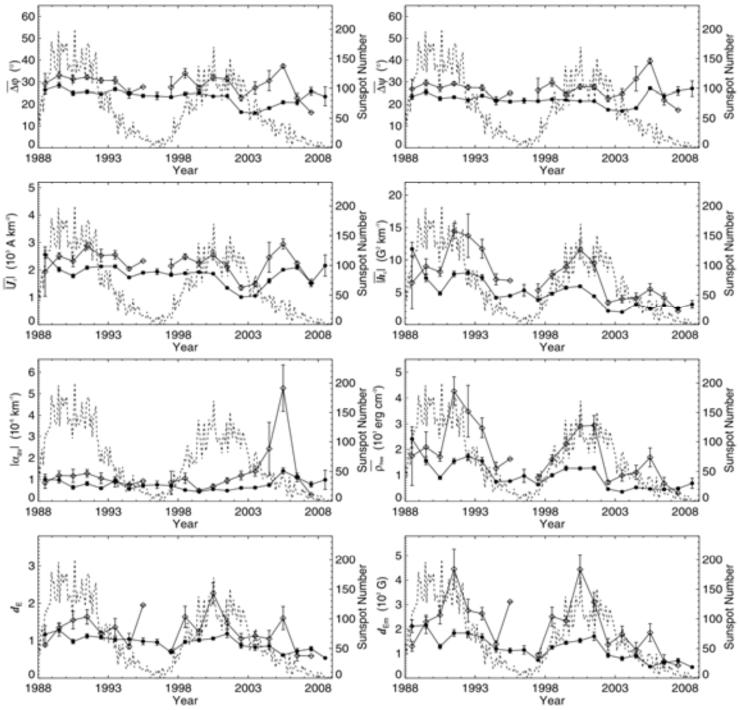

Fig. 3 Yearly mean values of $\overline{\Delta\varphi}, \overline{\Delta\psi}, \overline{|J_z|}, \overline{|h_c|}, |\alpha_{av}|, \overline{\rho_{free}}, d_E$, and d_{Em} of active-region samples during 1988 – 2008. Dots represent the yearly mean values of the samples that did not produce flares with FI ≥ 10.0 in the following 24 h (flare-quiet samples). Diamonds denote the yearly mean values of the samples that produced flares with FI ≥ 10.0 in the following 24 h (flare-productive samples). The monthly mean sunspot numbers during the same period are overlapped (dashed line) for reference. (FI: flare index [3,4])

Results

- On average, two mean magnetic shear angles, mean vertical current density, absolute twist factor, and effective distance in active regions do not change significantly with the global solar activity level. However, it is more likely that these parameters show higher values in the solar maximum than in the solar minimum.
- The mean absolute current helicity density, mean free energy density, and modified effective distance show high positive correlations with each other. The Pearson linear correlation coefficients of the above three with the yearly mean sunspot numbers are larger than 0.59.
- Due to the loss of the information of magnetic field strength in the parameter of effective distance, the modified effective distance (including the strength of the magnetic field) turns out to be much better in indicating the magnetic activities of active regions.

All of the eight parameters show positive correlations with the flare productivity of active regions. Verified by our machine learning model, the combination of different nonpotentiality parameters will be effective in assessing the flaring probability of active regions. More detailed description of the work and results can be found in the paper [5].

* Thanks to the HSOS staff and GOES team.

References

[1] Ai, G.X., Hu, Y.F.: 1986, Publ. Beijing Astron. Obs., 8, 1.
[2] Chumak, O.V., Zhang, H.Q., Guo, J.: 2004, Astro. Astrophys. Trans., 23, 525.
[3] Antalova, A.: 1996, Contrib. Astron. Obs. Skaln. Pleso, 26, 98.
[4] Abramenko, V.I.: 2005, ApJ, 629, 1141.
[5] Yang, X., Zhang, H.Q., Gao, Y., Guo, J., Lin, G.H.: 2012, Sol. Phys., 280, 165.