Photospheric Vector Magnetic Field Parameters as A Predictor of Major Solar Flares

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Abstract. Photospheric vector magnetic field data which have several Space-weather HMI Active Region Patches (SHARP) parameters are used to study active regions that produced major solar flares. SHARP parameter data obtained from the Helioseismic Magnetic Imager (HMI) instruments onboard Solar Dynamics Observatory (SDO) have a good spatial and temporal sampling. We consider three SHARP parameters with high F-scores, namely total unsigned vertical current, total photospheric magnetic free energy, and total unsigned current helicity as a useful predictor for major solar flares. In this paper, we present the data analysis procedure and sample results focusing only on major solar flares (M and X class flares). The preliminary results showed in some cases, one of SHARP parameters for the M-class flare almost has the same value as X-class flare in which ideally should be higher.

Keyword: Photospheric Vector Magnetic Field and Major Solar Flares

1. Introduction

Solar flares are common and powerful phenomenon in the sun which can release huge energy (Kopp et al. 2015). But there is no single model or method yet that can predict correctly when flare will erupt. Many studies of prediction of solar flare have been done by physicist. These studies exploit all possible physical process and all relevant data using various method of simulations and data analysis. Yokoyama and Shibata (2001) studied flare through magnetohydrodynamics simulations. Others more concern on analyse observational data from photospheric level to coronal level. For instances, Leka & Barnes (2003) analyse photospheric magnetic field data using discriminant analysis, Falconer (2009) studied magnetogram dynamic of active region to make a prediction of flare and CME. Muhamad (2017) combine simulation and observational data to find parameters that can be used for a prediction of flare.

Many people believed that the enormous energy from solar flare is generated by magnetic field mostly in the active region. Thus, studying the nature of magnetic field on active region is critical to understand and ultimately predicting solar flares. The physical parameters that can be used to study the magnetic field is called non-potential parameters which is described as the deviation of a potential (current-free) field to a non-potential state, i.e. becomes more sheared and/or twisted, the energy will be stored in the stressed magnetic field and finally it will be released as flares, eruptive filaments and/or coronal mass ejections (CMEs) (Gary et al. 1987; Sakurai 1989; Schrijver et al. 2008; Sun et al. 2012). These parameters also well known as photospheric vector magnetic field parameters and widely used to study the solar flare. For examples, Leka & Barnes (2003) became the first to classify photospheric magnetic field properties of flaring versus flare-quiet active regions. Mason & Hoeksema (2010) followed their work but employed different method. Bobra & Couvidat (2015) applied non-
linear algorithm classifier, called support vector machine, to determine the features that useful for discriminating between flaring and non-flaring active regions from vector magnetic field data.

These parameters can be obtained through observing magnetic activity in the sun surface using magnetogram. Since 2010, there is an instrument called Helioseismic Magnetic Imager (HMI) onboard Solar Dynamic Observatory which can detect magnetic activity every 12 minutes. This high cadence data is great dataset to make a good result to understand the nature of magnetic field before the flare empirically. From the previous research, we only know which parameters that can be used to predict solar flare but we still do not know yet its value. And in this work, we try to extract the value of non-potential parameters before the occurrence of the flare. These values are can be treated as the threshold energy of active region before its produce energy. If an active region passes these values, it became a warning that in the near time the flare will erupt.

2. Data and Methodology

There are two dataset that have been used in this research, i.e. peak time of flares and magnetic features of active region. For data flares, we used flares with peak magnitude above the M1.0 which correspond to $10^{-5}$ W m$^{-2}$ or only major flares based on data from Geostationary Operational Environment Satellite (GOES) X-ray flux. We do not include C-class flares because its impact on earth environment not to significant. Active region ’s magnetic features can be described by non-potential parameters that represented by SHARPs (Space-weather HMI Active Region Patches, Bobra 2015) parameters. These parameters are the derivation product of HMI data which automatically identifies active region patches in the vector magnetic field data. From the work of Leka & Barnes (2003) and Bobra (2015), we know several non-potential parameters to identify the behavior of magnetic field on the active region, and we only choose three parameters with highest F-score (a statistical value to determine the best value) on predicting flare i.e. total photospheric magnetic free energy, total unsigned current helicity, and total unsigned vertical current. The SHARP data can be downloaded from Joint Science Operation Center (JSOC) that operated by Stanford University. Table 1 is the mathematical expression of these parameters. We use the data from May 2010 until November 2016 and test the result using data on 2017. We only select SHARP parameters at 3, 6, 9, 12, and 24 hours prior to the peak time of major flares. The diagram below shows the step of our work.

![Diagram of data analysis steps]

Figure 1. The detail steps to analyze the data.
Table 1. SHARP Active Region Parameter Formulae

| Keyword   | Description                                           | Formula                                           |
|-----------|-------------------------------------------------------|---------------------------------------------------|
| TOTUSJH   | Total unsigned current helicity                        | $H_{\text{total}} \propto \sum |B_x \cdot J_z|$                                    |
| TOTPOT    | Total photospheric magnetic free energy density        | $\rho_{\text{tot}} \propto \sum (B_{\text{obs}} - B_{\text{Pot}})^2 dA$ |
| TOTUSJZ   | Total unsigned vertical current                        | $J_{z\text{total}} = \sum |J_z| dA$                                                        |

3. Results

We divided the analysed data into two part, the data for M-class flare and X-class flare. So, we can get the threshold for each major flare. At figure 2 to figure 7, the single dot represented the mean data for each epoch (24, 12, 9, 6 and 3 hours) prior to the peak flare. As we can see, TOTPOT and TOTUSJZ show the similar pattern at all selected epoch. At the 24-hours before flare, the value has the lowest point around $9.4 \times 10^{23}$ Ergs cm$^{-1}$ and $5.9 \times 10^{13}$ Amperes, respectively (figure 2 and figure 3). And reach the highest at 9 hours prior to the peak. The TOTUSJH parameter (figure 4) more fluctuate but still 24-hours before flare is the lowest value and 9-hours and 3-hours have the highest. This parameter span around $100 \text{ G}^2 \text{ m}^{-1}$ from the lowest to the highest with lowest value at $3415 \text{ G}^2 \text{ m}^{-1}$.

![Figure 2](image2.png)  
**Figure 2.** Total photospheric magnetic free energy for M-class flare until 24 hours before peak time.

![Figure 3](image3.png)  
**Figure 3.** Total unsigned vertical current for M-class flare until 24 hours before peak time.

![Figure 4](image4.png)  
**Figure 4.** Total unsigned current helicity for M-class flare until 24 hours prior to peak time.
As for non-potential parameters for X-class flare (figure 5 to figure 7), we see the same pattern for all those three physical parameters with the lowest value at 12-hours prior to peak time and the highest at 9-hours before peak time. TOTPOT and TOTUSJZ parameter (figure 5 and figure 6) have the exact pattern at all epoch and this pattern arouse suspicion. Maybe there is positive correlation between these parameters. The TOTPOT parameter has a value that ranged from 1.27 to 1.39 x 10^{24} \text{Ergs cm}^{-1} and TOTUSJZ parameter has a value that ranged from 7.05 to 7.55 x 10^{13} \text{Amperes}. TOTUSJH parameter (figure 7) has different pattern compare to the two at 6-hours prior to peak time. The patterns closer to 3-hours while other closer to pattern at 9-hours before peak time.

![Figure 5](image1.png)  **Figure 5.** Total photospheric magnetic free energy for X-class flare until 24 hours before peak time.

![Figure 6](image2.png)  **Figure 6.** Total unsigned vertical current for X-class flare until 24 hours before peak time.

![Figure 7](image3.png)  **Figure 7.** Total unsigned current helicity for X-class flare until 24 hours prior to peak time.

The summary value of these parameters can be seen at table 2.

| Parameters     | M-class flare                  | X-class flare                  |
|----------------|--------------------------------|--------------------------------|
| TOTPOT         | 9.4 to 9.7 x 10^{23} \text{Ergs cm}^{-1} | 1.27 to 1.39 x 10^{24} \text{Ergs cm}^{-1} |
| TOTUSJZ        | 5.9 to 6 x 10^{13} \text{Amperes} | 7.05 to 7.55 x 10^{13} \text{Amperes} |
| TOTUSJH        | 3415 to 3530 G m^{-1}        | 4125 to 4410 G m^{-1}         |

Comparing these results to the recent flare that occurred at 2017 (figure 8), we can see that for M-class flare case, the recent flare value for all those parameters higher than our results at peak time. TOTUSJH and TOTUSJZ almost 1.5 times more than results. And for TOTPOT is slight high. For the
case of X-class flare (figure 9), TOTPOT and TOTUSJH parameter show double value than our result. But TOTUSJZ has quite similar value as M-class flare case.

Figure 8. All three parameters for active region AR 12665 that appeared at mid-year of 2017. This active region produced M-class flare at July 15, 2017. AREA_ACR indicate the area of active region. Dash red line is the centre meridian of the sun which passed by this active region approximately at the end of July 11, 2017.

Figure 9. All three parameters for active region AR 12673 that appeared at September 2017. This active region produced X-class flare at September 08, 2017. AREA_ACR indicate the area of active region. Dash red line is the centre meridian of the sun which passed by this active region approximately at the end of September 04, 2017.

4. Conclusion
Solar flare is the common phenomenon in the sun surface which can release very huge energy but we cannot predict it yet, correctly. One of the effort to make a prediction of flare is through the analysis of magnetogram data which can be described by vector magnetic field parameters. Only the top three
parameters which statistically have a higher chance for flare prediction have been used in this research namely total photospheric magnetic free energy, total unsigned current helicity, and total unsigned vertical current. The first two parameters have similar pattern at 24, 12, 9, 6, and 3 hours prior to M and X-class flare peak time. While the last one is quite different at 6-hours prior to the peak time. The ranged values of those parameters for X-class flare cases is higher than M-class flare. But if we compare it to the ‘unseen’ flare data which occurred in the last year, the total unsigned vertical current in quite same for X and M class flare.

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