Photospheric magnetic field properties of active region 12740

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Abstract. Active regions, which are mainly responsible for the energetic blast from the Sun so-called flare, have a highly concentrated magnetic field. Almost all flares have been attributed to the dynamics of its magnetic field on the photosphere. One method to know the changings is through studying their properties using magnetogram data. The data that are obtained from Helioseismic Magnetic Imager (HMI) instruments onboard Solar Dynamics Observatory (SDO) have a good temporal resolution which can make a better analysis. We analyze three properties of photospheric magnetic field namely total photospheric magnetic free energy (TOTPOT), total unsigned vertical current (TOTUSJZ) and total unsigned current helicity (TOTUSJH) of the active region (AR) 12740 which produced almost M-class flare at the very minimum phase of solar cycle 24. Then, we compared their values to the average values of all the corresponding parameters for almost one solar cycle. The results showed that the values of each parameter in AR 12740 was below the average values of C-flare-productive ARs. The TOTPOT was half of the average while TOTUSJH and TOTUSJZ were around one-third of the average.

1. Introduction
The study of solar flares is still being carried out by scientists today. Solar flares are sudden rapid intense brightening in the solar atmosphere [1] and play a very important role in space weather. The radiation from large solar flares can ionize and expand the Earth’s upper atmosphere. This can cause radio blackout, atmospheric drag, as well as degradation on satellite communication. Large solar flares were originated from ARs with very strong magnetic fields. Therefore, studies on photospheric magnetic fields are important to understand the dynamics of flare-productive AR and useful for predicting flare occurrence.

Leka & Barnes [2] classified solar photosphere magnetic fields by analyzing ARs without flare compared to those with flares. Their work was based on Gary et al. [3] result. Bobra & Couvidat [4] have conducted studies on the Sun's magnetic field using the data from GOES and SDO/HMI. They analyzed the Sun’s AR with SHARP parameters, then observed the peak value of the x-ray flux.

There are still many opportunities to do research on this topic since there are an abundant amount of data and massive use of machine learning in all fields of study including solar physics. Florios et al. [5] used magnetogram data and machine learning to make a prediction of solar flares. Teh [6] studied the photospheric magnetic field properties of ARs associated with M- dan X-class flares. Lim [7] also used vector magnetic properties to do forecasting of daily major flares. In this paper, we used magnetogram data to analyze AR 12740 as a case study because we believe that the properties of several ARs cannot be generalized. This paper consists of 4 sections, namely introduction, data and methods, results, and conclusion.
2. Data and Methods

2.1. Data

The *Helioseismic and Magnetic Imager* (HMI) [8] that onboard the *Solar Dynamics Observatory* (SDO) [9] provides almost continues full-disk observations of the three components of the photospheric magnetic field. The scientific team of HMI has modified the data to develop the Space Weather HMI Active Region Patches (SHARPs), which are a solar regions-of-interest cut-outs images along with some parameters that can be used for solar flare prediction [10]. For this study, we use only cylindrical equal-area (CEA) SHARP metadata to investigate some SHARP parameters on AR 12740 which released the maximum energy equal to C9.9 *Geostationary Operational Environmental Satellite* (GOES) class flare. The SHARP data map can be obtained from the Joint Science Operations Center (JSOC). In this paper, we used the data during SDO-era (2010-2017) for ARs within the heliographic longitude of ≤ 70°.

To relate SHARP parameters with flare events, we used the Python module for solar physics (Sunpy) [11] to access the GOES soft X-ray measurements. We downloaded SHARP data during the appearance of AR 12740 on the Earth-side solar disk and all flares originating from it.

2.1.1. AR 12740

AR 12740 first appeared on the earth-side solar disk in early May 2019. At that moment, the Solar cycle has entered its minimum phase which was indicated by the low sunspot number and 10.7 cm radio flux. We examine its physical characteristics through the data prepared by the NOAA/SWPC and processed by SpaceWeatherLive.com team. AR 12740 appeared with a simple magnetic configuration and lasted for 12 days until it rotated to the back-side of the solar disk (Table 1). However, AR 12740 unexpectedly produced several C-class flares with one of them reach almost M-class flare after approximately 3 months of spotless and no-flares condition. Therefore, we are interested to analyze this AR. In total, AR 12740 released 9 C-class flares. The C9.9 flare occurred on 6 May 2019 and peaked at 05:10 UT.

| Date (2019/05) | Spot count | Area (MH) | Magnetic class | Spot class | Location |
|---------------|------------|-----------|----------------|------------|----------|
| 4             | 1          | 260       | α              | Hhx        | N12E80   |
| 5             | 2          | 270       | α              | Hhx        | N09E67   |
| 6             | 4          | 280       | β-δ            | Dho        | N08E54   |
| 7             | 4          | 200       | β-δ            | Cso        | N07E40   |
| 8             | 6          | 240       | β              | Cso        | N08E28   |
| 9             | 3          | 160       | β              | Cao        | N08E14   |
| 10            | 4          | 120       | β              | Cao        | N08W00   |
| 11            | 3          | 110       | α              | Hax        | N08W13   |
| 12            | 3          | 100       | α              | Hax        | N08W27   |
| 13            | 2          | 70        | α              | Hax        | N08W40   |
| 14            | 1          | 10        | α              | Hrx        | N08W53   |
| 15            | 1          | 10        | α              | Axx        | N08W67   |

MH is an acronym for millionths of a solar hemisphere, with 1 MH corresponding to 3.0437 million square kilometers.

2.1.2. SHARP Parameter
The information that can be derived from SHARP data is the photospheric magnetic field properties. Based on Bobra et al. [10] work, there were more than 10 parameters we can use to study solar flare prediction. In this paper, we study the empirical relationship between the top 3 parameters having the highest F-value based on the parameters that Bobra & Couvidat [4] have previously examined. The three parameters are total photospheric magnetic free energy (TOTPOT), total unsigned vertical current (TOTUSJZ), and total unsigned current helicity (TOTUSJH). Table 2 tells us the mathematical formulation for each parameter. TOTPOT describes the difference of photospheric magnetic energy between the observed magnetic field and the potential magnetic field at AR. While TOTUSJZ describes the vertical component of electric current density. In a simple way, TOTPOT and TOTUSJZ tell us how much energy contained in AR. Flare tends to occur from an AR with high magnetic energy. In consequence, the TOTPOT and TOTUSJZ value are more likely to increase during flare events. While TOTUSJH describes the probability of AR to produce flare. This parameter is strongly correlated with the magnetic topology of the solar corona. When the magnetic field strongly sheared or twisted, the value of TOTUSJH will typically be increased [11].

Table 2. Three SHARP parameter.

| Keyword   | Description                                      | Formula |
|-----------|--------------------------------------------------|---------|
| 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                   | \( J_{\text{total}} = \sum |J_z| dA \) |
| TOTUSJH   | Total unsigned current helicity                   | \( H_{\text{total}} \propto \sum |B_z \cdot J_z| \) |

2.2. Methods

We downloaded C- and M-class flare events during SDO-era of 2010-2017 from GOES by using the Sunpy module [12] in Python. This data revealed the peak time of each flare and its associated AR. Then we downloaded the SHARP parameters of those flare-productive ARs within 24 hours prior to the peak time of each flare with a 3-hours interval. We averaged the values of TOTPOT, TOTUSJZ, and TOTUSJH for each flare class and used them as approximations of threshold values. These mean values of each parameter were compared to the SHARP parameter values of AR 12740 within 24 hours prior to C9.9 flare peak time. We also investigated the behavior of each parameter prior to single and multiple flares.

3. Results

In this section, we elaborate on the photospheric magnetic field properties of AR 12740 and its position within the mean value in almost one solar cycle for each parameter. We also describe the behavior of SHARP parameters within 24 hours prior to C9.9 flare peak time. From Figures 1 and 2 we can see the behavior of these parameters within 24 hours before the flare peak. The value of these parameters reaches the highest at flare peak time for M-class and C-class flare. However, the value of M-class is higher than C-class.

As you can see in the left panels of Figure 1 to 3, the highest mean value of all three parameters coincides with the peak time of both C and M flares. While the mean values of all three parameters for M flares are higher than that of C flares.
Figure 1. Mean value of TOTPOT within 24 hours prior to the peak time of C (yellow) and M (red) flares derived from SHARP data during 2010-2017 (left) compared to TOTPOT value of AR 12740 within 24 hours prior to C9.9 flare peak time (right). Orange vertical line denotes the flare peak time.

Figure 2. Mean value of TOTUSJZ within 24 hours prior to the peak time of C (yellow) and M (red) flares derived from SHARP data during 2010-2017 (left) compared to TOTUSJZ value of AR 12740 within 24 hours prior to C9.9 flare peak time (right). Orange vertical line denotes the flare peak time.

Figure 3. Mean value of TOTUSJH within 24 hours prior to the peak time of C (yellow) and M (red) flares derived from SHARP data during 2010-2017 (left) compared to TOTUSJH value of AR 12740 within 24 hours prior to C9.9 flare peak time (right). Orange vertical line denotes the flare peak time.
peak time.

From figure 4 we can see a general pattern for SHARP parameters including the line of sight area of active pixels (AREA_ACR), TOTPOT, TOTUSJH, and TOTUSIZ of AR 12740 during its appearance on the earth-side solar disk. Vertical lines with different colors denote the peak time of individual flares originating from this AR. Two days before C9.9 flare, we can see that the value for each parameter increases until peak time. The value kept going up until the next day and the region produced more flares with a lower class. After that, the AR was decaying and the value of parameter gradually decreased until it reached the limb. There was no flare at all during this time.

We assume that the magnetic class has an important role. It is shown in table 1 that AR 12740 has a \( \beta \)-\( \delta \) magnetic class during flare time. As the values of SHARP parameters decreased, the magnetic class become \( \beta \). Meanwhile, the area of AR 12740 has no positive correlation with flare time based on the upper left graph in Figure 4. Of course, we need further investigation to confirm this assumption with more cases and data.

![Graphs showing SHARP parameters of AR 12740](image)

**Figure 4.** All three parameters and areas of AR 12740 during its appearance on 3-16. Colored-vertical-lines denote the peak time of all C-class flares originating from this AR, including the C9.9 flare. The black dash line is the central meridian of the Sun’s disk.

### 4. Conclusion

The photospheric magnetic field parameters namely TOTPOT, TOTUSJZ, and TOTUSJH of AR 12740 which produced almost M-class flare have a lower value than the mean value for 2010-2017 data for the same parameters. TOTPOT value of AR 12740 is one-half of the mean value, while TOTUSJH and TOTUSIZ values are one-third of the mean ones. This is probably because we averaged the values over all flare-productive ARs without considering regions that produced multiple flares of different classes. All flares originating from AR 12740 occurred when the magnetic class of the region has \( \beta \)-\( \delta \) configuration and at increasing value of the parameters. From this research, we suggest that analysis of mean value photospheric magnetic field parameters is not sufficient for flare prediction purposes or to determine the probability of flare occurrence in an AR. We have to conduct further researches related to coronal data and others.
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