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SMALL SOLAR FLARES AND LOCAL POLARITY INVERSION LINES OF THE LONGITUDINAL MAGNETIC FIELD OF THE ACTIVE REGION

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Abstract. Using photospheric data and data on the longitudinal magnetic field from the SDO satellite, as well as observations in the Hα line from GONG ground stations, we have studied the flare activity of the NOAA 12673 sunspot group, which in September 2017 produced the largest X9.3 class flare in the last decade. The active region was distinguished by rapid development, complex topology, and magnetic field dynamics. We have established that in the active region almost throughout the development period due to movements of diverse polar magnetic fluxes and their convergence, numerous local polarity inversion lines (LPIL) of the magnetic field were formed. Small solar flares have been found to be closely related to LPIL and to occur in those areas of LPIL where the gradient of the longitudinal magnetic field over time reaches maximum values.

Keywords: active regions, small solar flares, longitudinal magnetic field structure, polarity inversion lines (PIL).

INTRODUCTION

Understanding the mechanisms of energy accumulation and release in solar flares is one of the fundamental questions in solar-terrestrial physics. According to statistics, ~1.5 % of powerful flares with an energy of $\approx 3 \cdot 10^{32}$ erg occur on the Sun [Borovik, Zhdanov, 2017]. The highest probability of such flares is observed in active regions with delta configuration of the magnetic field and with an intense photospheric magnetic flux [Cui et al., 2006]. The most powerful flares (class X) tend to occur in active regions with strong gradients and complex magnetic field structure. Numerous studies indicate that the dynamics of sub-photospheric magnetic fields plays an important role in flare formation, due to which the free magnetic energy excess with respect to the energy of the potential field of sunspots and background magnetic fields accumulates in the lower corona and the upper chromosphere. A significant role in the energy accumulation is played by shear currents parallel to the neutral line, rotation of sunspots and plages [Hagyard et al., 1984a, b; Raman et al., 1993; Fletcher et al., 2011; Benz, 2017]. Flares are assumed to occur due to a number of instabilities arising in coronal magnetic fields owing to penetration of a new magnetic flux into the active region. In the region of contact between oppositely directed magnetic fluxes, current sheets are formed. During their breakup and the subsequent magnetic reconnection, the excess energy is converted into the kinetic energy of accelerated particles and the thermal energy of plasma [Priest, 1992; Rust, Gauzzi, 1992; Somov, 1992]. The emerging flux in this case acts as a trigger that causes the free energy accumulated by the magnetic field of the active region to be released.

Powerful flares are relatively rare solar events. Most solar flares (over 90 %) are low-power with an energy of $\approx 10^{29}$ erg [Borovik, Zhdanov, 2017]. It is evidence that conditions for the occurrence of small flares (SF) in the solar atmosphere prevail. SF are usually referred to as background events; in rare cases, they are considered as phenomena accompanying large flares. At the same time, differing from large flares in area and power, small flares have a number of similar features: they emerge and develop along polarity inversion lines of the longitudinal magnetic field, have an explosive phase and multiple bursts of intensity, and are followed by filament activation and disappearance. Among them are flares covering sunspot umbra, two-ribbon and white flares. Small flares are accompanied by radio bursts, X-rays of different power (including X class), and proton fluxes [Borovik, Zhdanov, 2019, 2020]. They usually release energy during the impulsive phase. A single burst of hard X-rays lasting for about one minute is the most characteristic. In soft X-rays, SF feature low heights, small volumes, high energy densities, and short time scales. The current concept is that small flares are assigned to a simple loop type structure. It is assumed that SF, like large flares, arise during emergence of a new magnetic flux [Heyvaerts et al., 1977; Masuda et al., 1994]. In this respect, they do not differ fundamentally from large flares, and their study can clarify the question of whether flares of different power are based on a single physical process, or they are different in nature.

At present, spacecraft observations with high spatial and temporal resolution make it possible to address the SF problem at a higher qualitative level.

OBSERVATIONS AND DATA PROCESSING

This paper reports preliminary findings of studying the dynamics of magnetic fields in the region of small solar flares. We have examined flare activity of the sunspot group NOAA 12673, which in September 2017 produced an X9.3-class flare, the largest in the last decade. The active region is distinguished by rapid development, complex topology and dynamics of the magnetic field [Yang et al., 2017; Verma, 2018; Romano et al., 2019]. In addition to four X-class flares, many small flares occurred in the active region. To explore them, we have used data from SDO HMI and AIA [http://jsoc.stanf ord.edu] and observations in the Hα line at 6563 Å made with telescopes of the Global Oscillation Network Group (GONG) [https://gong.nso.edu]. We examined the dynamics of the longitudinal magnetic field, using HMI magnetograms with an angular resolution of 0.5″ pixel^{-1} and a frame rate of 45 s. Photospheric processes were analyzed from HMI images of the full solar disk continuum. We employed AIA data in the 171 Å line to identify flares in UV.

RESULTS

Analysis of magnetograms of the longitudinal field has shown that during almost the entire period of the development of the active region, numerous local polarity inversion lines (LPIL) were formed in it due to movements and convergence of magnetic fluxes of different polarities (Figure 1).

We have analyzed a total of five small flares in the immediate vicinity of LPIL, indicated by arrows in Figure 1. According to the International Classification of Optical Flares in the Hα line [Smith, Smith, 1966; Altyntsev et al., 1982; Temmer et al., 2001], all the flares considered belong to class S. The results proved to be similar for all small flares.

Figure 2 displays the September 4, 2017 flare (00:00:10 UT). The area of SF study was limited by 25×25 pixels (green square in Figure 2) and two-hour interval: from 23:00 UT on September 3, 2017 to 01:00 on September 4, 2017, an hour before and an hour after the flare. All the magnetograms were centered with a high degree of accuracy and converted for two intensity ranges: weak fields to 50 G and fields above 50 G. This allowed us to keep track of weak changes in the fields and the emergence of new magnetic fluxes. Moreover, to monitor changes in magnetic fields in the selected area, we obtained digital strength matrices for each frame.

Analysis of the data revealed that the flare was accompanied by clear-cut changes in the structure of the active region's magnetic field (Figure 3). Before the flare, this was manifested in convergence and coalescence of sunspots, in an increase in their area. After the flare, the sunspots split into separate fragments (mainly the sunspots of north polarity). A similar pattern was observed in magnetograms.

We have found out how the magnetic field strength and gradient changed in the close vicinity of LPIL before and after the small flare. To do this, a series of segments perpendicular to LPIL was drawn on the magnetogram at 00:00:00 UT with a step of approximately one pixel and 1–3 pixels long. Then, the position of LPIL was transferred to previous and subsequent frames, and for 161 magnetograms we calculated strengths at endpoints of the segments and magnetic field gradients. The resulting graphs (Figures 4–6) were smoothed with the Savitzky–Golay filter.

Figure 4 indicates that in segments 1, 2, and 3, where, according to observations in the Hα line, the flare f1 occurred, the magnetic field gradient increased respectively 45, 20, and 45 min before its onset. The maximum gradient in segment 1–3 was 1.34 G/km. After the flare, segments 1 and 2 showed a decrease in grad *H*.

Approximately 30 min after the first flare, the second SF f2 occurred at 00:36:10 in LPIL in segments 4–6. Graphs in Figure 5 show a similar increase in grad *H* before the flare and a subsequent decrease. The maximum field gradient in this case was 1.46 G/km. Figure 6 depicts variations in the magnetic field gradient in segments 7–12, where there was no SF during the time period considered.

In these graphs, the pattern characteristic of flares is virtually absent, with the possible exception of a short burst of grad *H* in segment 7 before f2.

The results also show that in some segments of LPIL (1, 6–8, 10–12) there was a strong (>0.9) correlation dependence between strengths of fields of different polarities. Attention is drawn to the fact that before and after the flares in LPIL, magnetic fields changed their polarity (1, 6, 10, 11), which could be associated with cancellation of magnetic fluxes of opposite polarity.

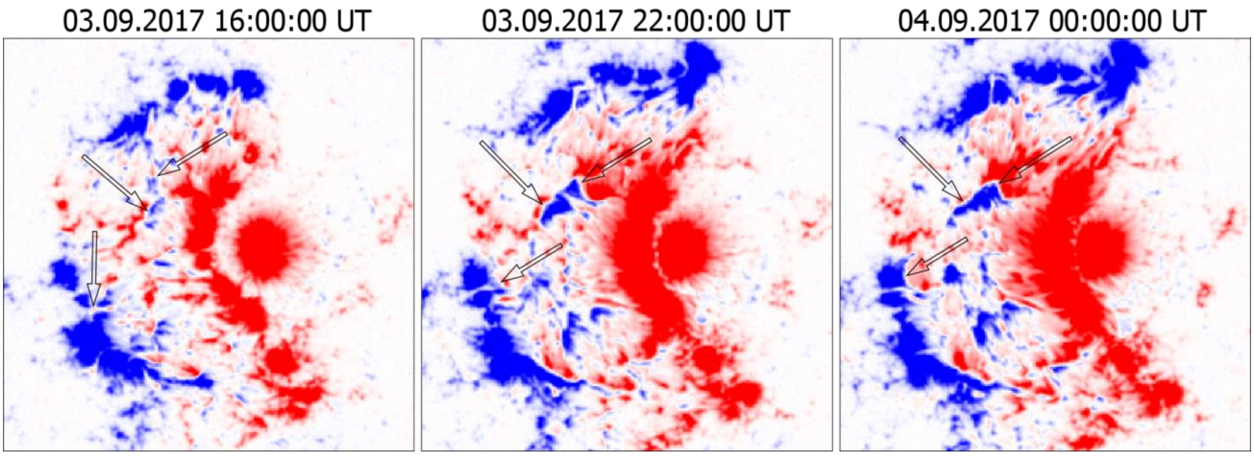

Figure 1. Formation of LPIL in the active region NOAA 12673. In the HMI/SDO magnetograms, north and south polarity fields are marked in blue and red respectively. Arrows indicate three regions of LPIL formation

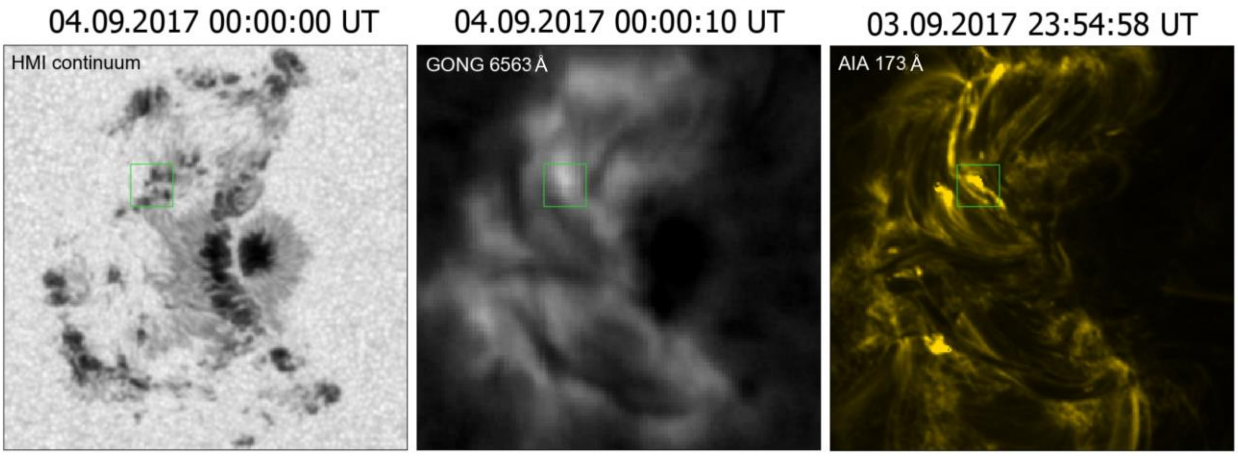

Figure 2. Small flare on September 4, 2017 (00:00:10 UT) in the active region NOAA 12673

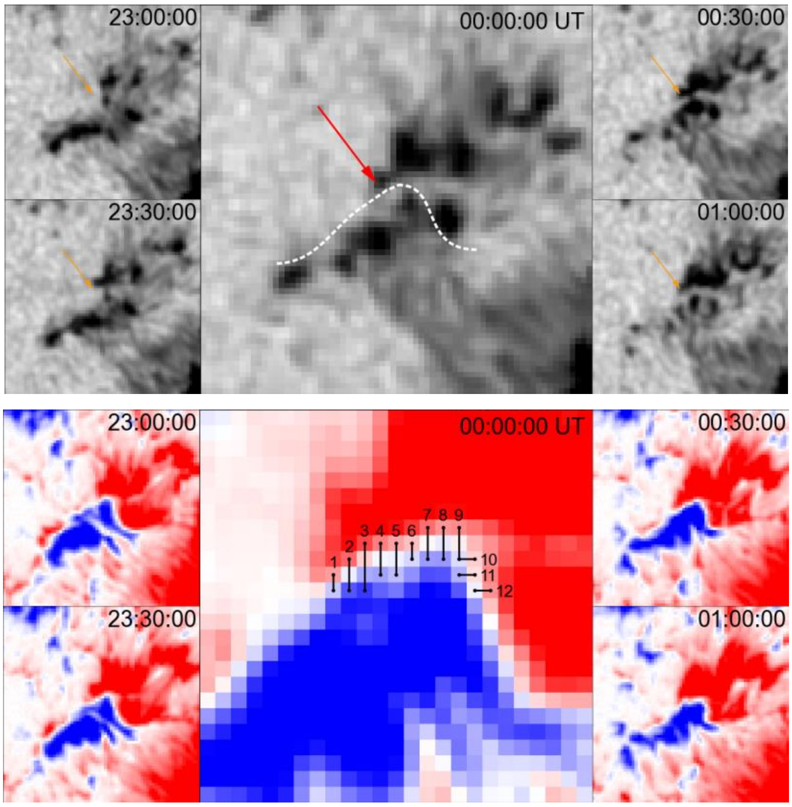

Figure 3. Sunspot activity and variations in the longitudinal magnetic field in the SF region for two hours

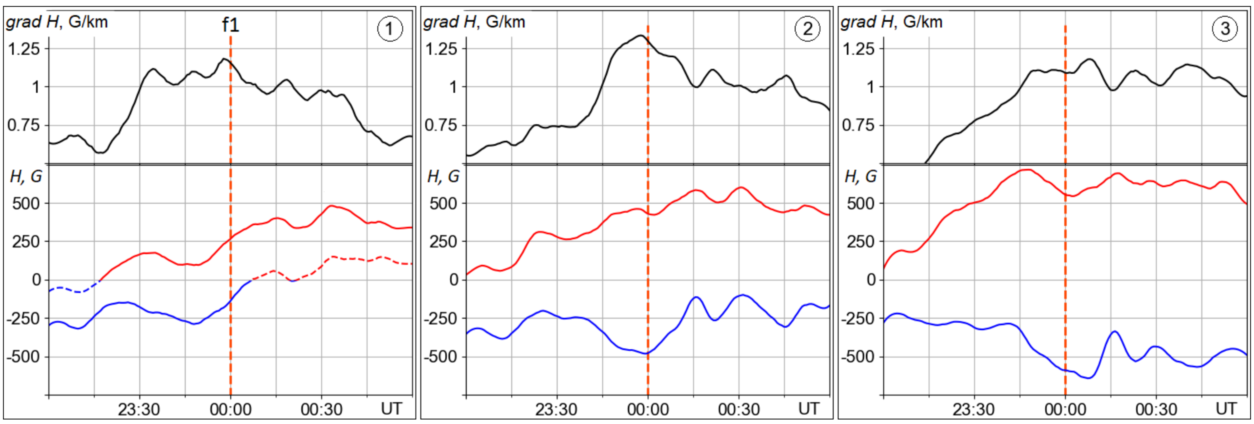

Figure 4. Variations in the magnetic field gradient and strength near LPIL in the flare region. Red and blue colors, as in the following Figures, mark variations in the magnetic field strength of south and north polarities respectively

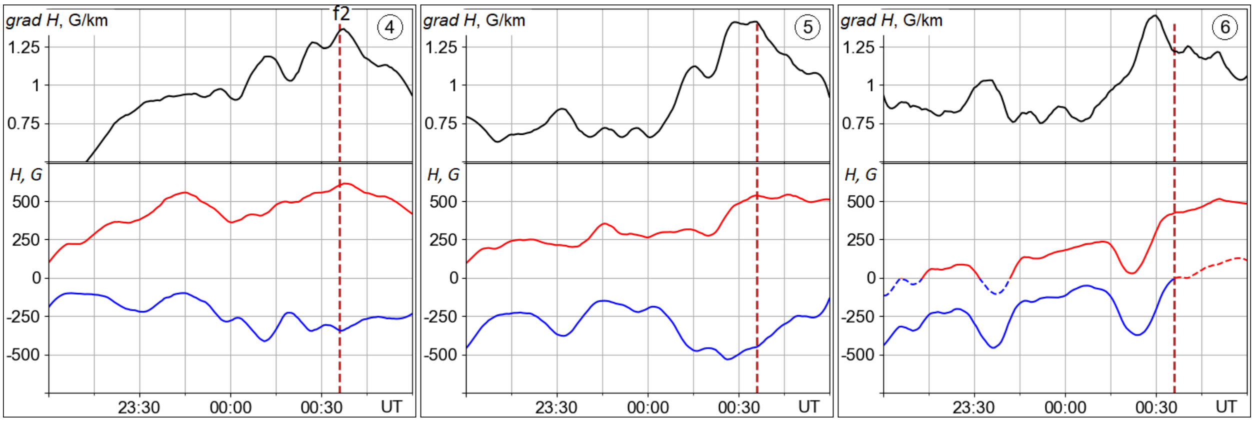

Figure 5. Variations in the magnetic field gradient and strength along LPIL in the f2 region (00:36:10) in segments 4–6

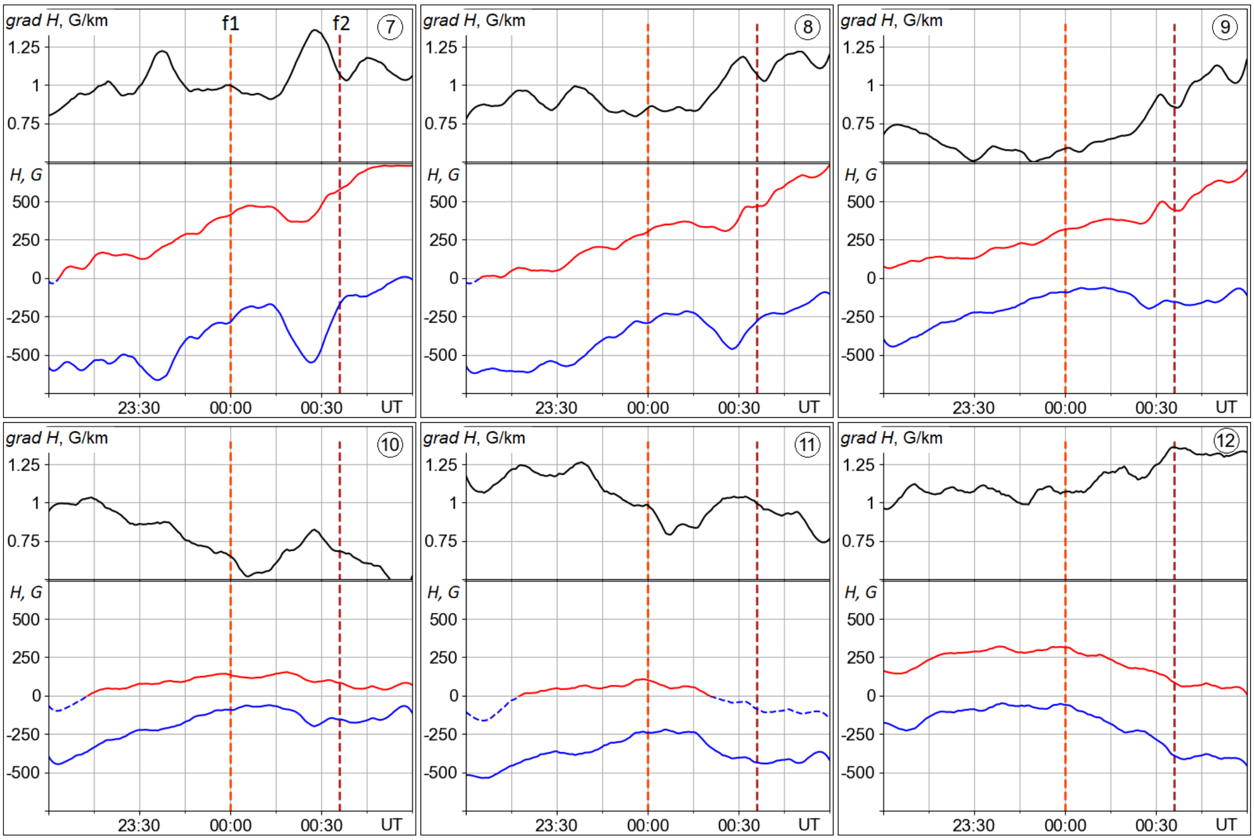

Figure 6. Variations in the magnetic field strength and gradient along LPIL in segments 7–12

CONCLUSION

Preliminary results of studying the dynamics of magnetic fields near small flares show that small flares are accompanied by clear-cut changes in the structure of the active region's magnetic field. The flares occur in local polarity inversion lines that arise in an active region due to convergence of magnetic fluxes of opposite polarity. One of the important and, possibly, the main conditions for the occurrence of small flares is the increase in the magnetic field gradient in some segments of LPIL to some maximum values (in our case, 1.3–1.5 G/km).

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