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Photospheric magnetic field variation during solar flares and their implication for the generation of sunquakes

S. Vargas Domínguez[1], W. Caicedo Tez[1] and J. C. Buitrago Casas[2]

[1]Universidad Nacional de Colombia, Observatorio Astronómico Nacional

[2]Space Sciences Laboratory, University of California, Berkeley

Abstract. Solar flares are an explosive manifestation of the complex magnetic structuring of active regions in the solar atmosphere. The photospheric magnetic field is found to change rapidly, abruptly, and significantly during flaring events. Previous studies are mainly based on line-of-sight or low-cadence data. In this work, we focus on the temporal and spatial evolution of the permanent changes in the magnetic field of solar flares from high-cadence vector data (135 seconds) of the imaging system (dopplergrams and magnetograms) of the SDO/HMI instrument. The highly energetic events under analysis occurred during the solar cycle 24, covering low and high energy ranges, according to GOES classification. This investigation also stands as a crucial input for the characterization and understanding of sunquakes.

Keywords. Sun: activity, Sun: flares, Sun: photosphere

1. Introduction

During a flaring event, the magnetic field topology changes rapidly, abruptly, and significantly. Some of these eruptive events inject enough energy into the photosphere and sub-photosphere to generate acoustic responses observed as sunquakes. The precise physical mechanism causing the acoustic source of a sunquake is still a topic of debate. Most authors agree that magnetic field restructuring must play a fundamental role in causing such acoustic drivers. Previous studies have mainly probed the line-of-sight component of the magnetic field in such scenarios. In this work, we investigate the temporal and spatial evolution of permanent changes in the magnetic field geometry.

2. Data

We use a sample of six acoustically active flaring events selected from Buitrago-Casas et al. (2015); Sharykin and Kosovichev (2020), as listed in Table 1. We used vector magnetograms acquired with the Solar Dynamics Observatory (SDO) with the Helioseismic and Magnetic Imager (HMI) instrument. The highly energetic events under study occurred during the past solar cycle 24, and cover a range of high and low GOES classes.

3. Analysis and Results

In order to probe the geometry of the magnetic field, we applied a procedure starting with choosing an appropriate interval covering the impulsive phase of each flaring event and identifying the region of interest. Maps of magnetic inclination differences are then constructed. Figure 1 shows an example of a region with the map of inclination with

Table 1. List of the studied flaring events.

Number	Flare	Heliospheric position	AR
1	SOL20130217T15:50-M1.2	[-338,307]	11675
2	SOL20131106T13:49-M3.8	[-549,267]	11890
3	SOL20131107T03:40-M2.3	[-450,-272]	11890
4	SOL20120509T14:02-M1.8	[-351,159]	11476
5	SOL20170904T15:11-M1.5	[-490,252]	12673
6	SOL20110213T17:28-M6.6	[-37,-132]	12297

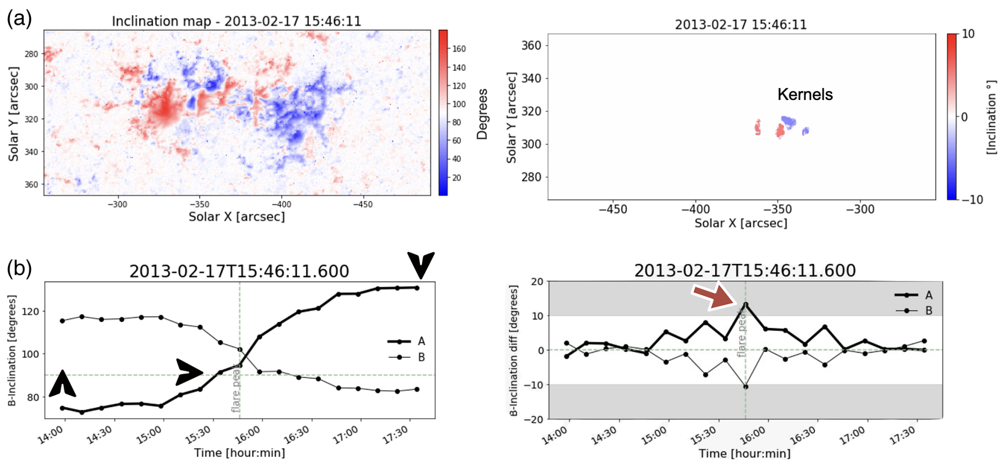

Figure 1. Example of maps and plots constructed to study the evolution of the magnetic field inclination for active region number 1 in Table 1. See text for details. This research used the SunPy 4.0.5 package (Mumford et al. 2020).

identified kernels (top panels) and plots for the time evolution of magnetic field inclination and inclination differences (bottom panels). Changes of tens of degrees in the magnetic field inclination are present in the flaring events displaying sunquakes. The acoustic wave is produced in the lower atmosphere by the ponderomotive force in the Alfvénic front associated with the magnetic variation.

4. Take-away ideas

Below we summarize some of the main ideas extracted from this work:

• Permanent changes in the magnetic field inclination with values greater than 10° in a kernel are likely to induce sunquake signatures, as stated in Russell et al. (2016).

• Results are in agreement with theoretical approaches.

• Injection of particles can not take place if the field lines do not display the correct direction (downwards).

• Sunquakes offer an opportunity to study the interaction of acoustic waves with magnetic fields and flows in flaring regions.

Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S1743921322005026.

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