Spatial distribution of magnetic helicity flux in a flare site

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Abstract

We use HMI/SDO line-of-sight magnetograms to analize the spatial distribution of the magnetic helicity flux in the active region NOAA 11283. Applying an algorithm to identify areas characterized by similar magnetic helicity flux, we determine how fragmented was the helicity flux in the active region. The results clearly show that areas characterized by the lower difference in the number of patches with helicity flux of opposite sign are the most favourable for eruptive events occurrence. We also show that flares and CMEs occurrence are linked to the interaction between magnetic systems characterized by opposite sign of magnetic helicity flux.

Observations and analysis

We analyzed the full-disk line-of-sight magnetograms acquired by **HMI/SDO** (Schou et al, 2012) at 6173 Å from Sept. 5, 2011 at 00:00 UT to Sept. 8, 2011 at 22:24 UT with a pixel size of 0.51 arcsec and a time cadence of 96 min in order to study the AR NOAA 11283. We also used 171 Å images taken by **AIA/SDO** (Lemen et al., 2012) during the same observation time interval, when four GOES M and X-class flares occurred, as reported in Table 1. All these events occurred at the same time of CMEs observed by LASCO/SOHO and reported in the LASCO catalogue.

Table 1 List of flares occurred in AR NOAA 11283 during the analyzed observation time interval

Date	Start (UT)	Peak (UT)	End (UT)	GOES class
Sept 6, 2011	01:35	01:50	02:05	M5.3
Sept 6, 2011	22:12	22:20	22:24	X2.1
Sept 7, 2011	22:32	22:38	22:44	X1.8
Sept 8, 2011	13:32	15:46	15:42	M6.7

All the subfields were aligned by applying a standard differential rotation rate (Howard et al. 1990). We determined the mean magnetogram corresponding to the average between two consecutive magnetograms and we measured the horizontal velocity fields by means of the Differential Affine Velocity Estimator (**DAVE**) method (Schuck, 2005) using a full width at half maximum of the apodization window of 19.80 arcsec. Then we used these measurements to compute the magnetic helicity flux using the **method of Pariat et al. (2005)**.

At the beginning of the selected time interval (on Sept. 5 at 00:00 UT) the AR NOAA 11283 was characterized by a preceding main sunspot and by several following pores as shown in the HMI/SDO continuum image of Fig. 1 (a).
The preceding sunspot corresponds to a more concentrated negative magnetic flux, while the more diffused positive magnetic field was located in the Eastern part of the AR (Fig. 1 (b)). The most interesting aspect of the AR evolution during the selected time interval is the **emergence** of new magnetic flux in the northern part of the main sunspot (see the arrows in Fig. 1 (b) and (c)). Probably, this new emerging flux played an important role in the storage of magnetic energy released in corona above that site (see the arrow in Fig. 1 (d)) during the events reported in Table 1.

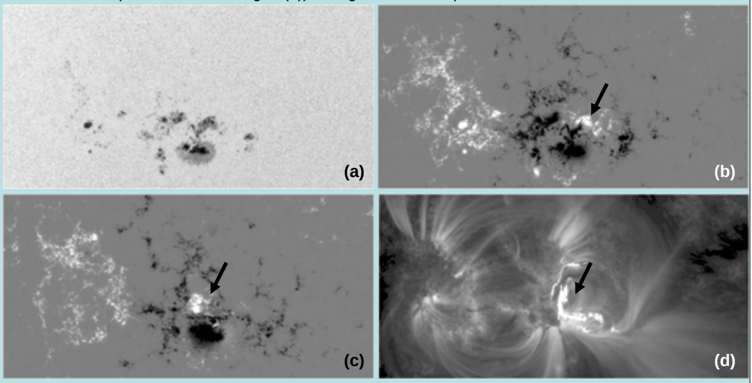

Fig. 1 *(a) Continuum image of AR NOAA 11238 taken by HMI/SDO on Sept. 5 at 00:00 UT; (b) and (c) line of sight magnetograms taken by HMI/SDO on Sept. 5 at 00:00 UT and on Sept. 6 at 22:24 UT, respectively; (d) 171 Å image taken by AIA/SDO on Sept. 6 at 22:17 UT. The field of view is of about 290 x 145 Mm. North is at the top, west is on the right.*

Velocity fields

In order to understand the possible connection between the shear of the magnetic field lines in the emergence site and the flare events, we studied the horizontal displacements of the photospheric magnetic features. In Fig. 2 we reported the most significant maps of the horizontal velocity fields. We note that the new positive feature moves eastwards while the negative one moves in the opposite direction with velocities of about 1 km s^{-1} (see the blue circle in Fig. 2 (a)). A **shear** motion along the Polarity Inversion Line (PIL) between the new positive feature and the main negative sunspot of the AR persists during the whole observation time interval (see Fig. 2 (b), (c) and (d)).

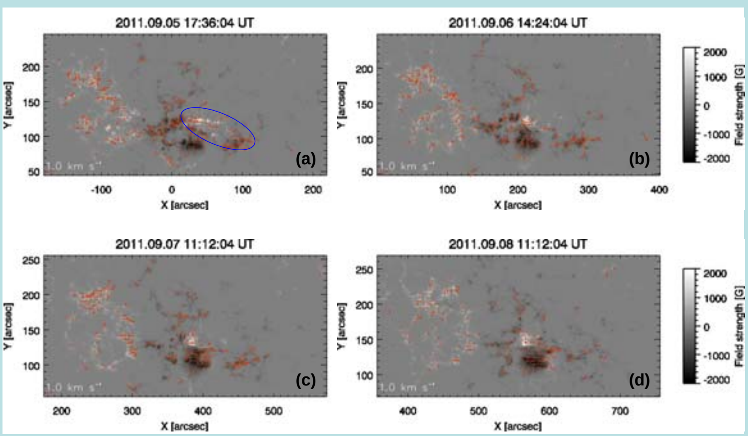

Fig. 2 Sequence of the horizonthal velocity fields overplotted on the HMI/SDO magnetograms.

Acknowledgements

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Spatial distribution of the magnetic helicity flux

The main sunspot of the AR is characterized by positive magnetic helicity flux since the beginning of the observation time interval. Its flux and size increases with time as we can see from the sequence in Fig. 3. Probably, we can ascribe this increase to the global **clockwise** rotation of the sunspot (see in particular Fig. 3 (c)).
However, the most important variation in the magnetic helicity flux distribution is the appearance and increases of some patches characterized by negative magnetic helicity flux near the PIL. This effect can be ascribed to the shear motions along the PIL. It is also worth of note that these patches of negative helicity flux tend to become a single negative one between two regions of strong positive helicity flux (Fig. 3 (c) and (d)).

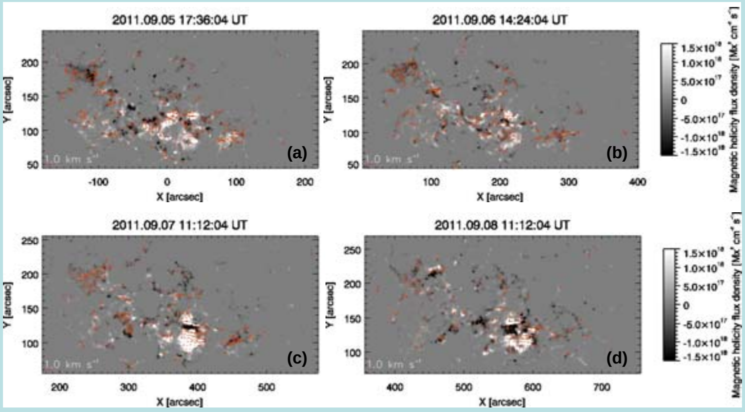

Fig. 3 Sequence of the horizonthal velocity fields overplotted on the maps of magnetic helicity flux.

Spatial distribution of the magnetic helicity flux

We investigated the temporal evolution of the magnetic helicity accumulated over the whole AR. In Fig. 4 (a) we show the accumulation of the positive, negative and total magnetic helicity in corona in time. The magnetic helicity accumulated in the AR in about 4 days is 1.8 x 10^{42} Mx^2. The positive flux of helicity is ever greater than the negative one due to the clockwise rotation of the main sunpot of the AR and the lower strength of the emerging magnetic flux. However, the contribution of the negative helicity flux becomes more and more significant while the new magnetic flux emerges.
We applied the labeling algorithm **YAFTA** (a single-pass "flux-ranked uphill gradient" algorithm described in Welsch and Longcope, 2003) on each map of magnetic helicity flux to group contiguous pixels into features (patches). We used a threshold of the minimum intensity to group unipolar, contiguous pixels of 5 x 10^{17} Mx^2 cm^{-2} s^{-1} and we considered 4 different thresholds of the minimum size: 25, 50, 100 and 200 pixels. We computed for each map the difference between the number of patches of the two signs, $|N_+ - N\_|$, in order to estimate the coexistence of systems characterized by opposite sign of magnetic helicity flux in the AR during the observation time interval. We found that the flares (and CMEs) occurred in correspondence of the **minima** of $|N_+ - N\_|$ (Fig. 4 (b)), with the exception of the last event, when we consider patches greater than 25 or 50 pixels.

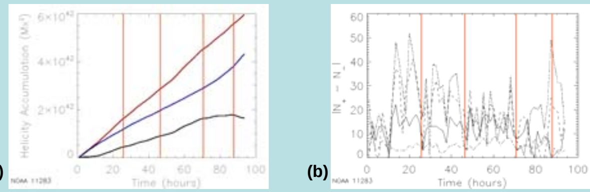

Fig. 4 *(a) Accumulation of the magnetic helicity vs time. The red, blue and black lines correspond to positive, negative and total magnetic helicity accumulation; (b) absolute value of the difference between the numbers of positive and negative patches vs time. The dotted, dashed, continuum and dash-dotted styles correspond to a threshold of the minimum size to identify a patch of 25, 50, 100 and 200 pixels. t=0 corresponds to 00:00 UT on Sept. 5, 2011. The red vertical lines indicate the flare/CME occurence. The thickness of the vertical lines is equal to 1 and 2 for flares of GOES M and X classes, respectively.*

Conclusions

- We observed four M and X GOES class flares occurred in AR NOAA 11283.

- This flare site is characterized by the emergence of new magnetic flux and by horizontal shear motions along the PIL.

- The emerging magnetic flux produce the appearance of some regions characterized by negative magnetic helicity flux.

- These regions tend to increase in size and to become a unique region of negative helicity flux between two regions of strong positive helicity flux.

- Most of the events occurr during the minima of the difference between the number of patches of the two signs of magnetic helicity flux.

All the above mentioned results seem to be in agreement with a scenario where the new emerging magnetic flux of negative helicity interacts with the pre-exisiting magnetic flux of positive helicity. The **interaction of magnetic fluxes with opposite helicity sign** supports the reconnection processes and the consequent release of free energy, as shown in numerical simulations of Linton et al. (2001), Mok et al. (2001) and Kusano et al. (2004).