

On the Dynamics of the Largest Active Region of the Solar Cycle 24

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Abstract. We have studied the dynamics of the solar active region (AR) NOAA 12192 using full-disc continuum images and the vector magnetograms observed by the Helioseismic and Magnetic Imager (HMI) onboard Solar Dynamics Observatory (SDO). AR 12192 is the largest region of the solar cycle 24. It underwent a noticeable growth and produced 6 X-class, 22 M-class and 53 C-class flares during its disc passage. But the most peculiar fact of this AR is that it was associated with only one CME in spite of producing several X-class flares. In this work, we present the area evolution of this giant sunspot group during the first three rotations when it appeared as AR 12172, AR 12192 and AR 12209, respectively. We have also attempted to make a comparative study of the flare-related photospheric magnetic field and Lorentz force changes for both the eruptive and non-eruptive flares produced by AR 12192.

Keywords. Photosphere, sunspots, flares, coronal mass ejections (CMEs).

1. Introduction

During the maximum phase of solar cycle 24, the largest solar active region of the cycle appeared on the solar disc as NOAA 12192 in October 2014. It completed its passage across the visible solar disc from October 17 to 30 and became the largest sunspot group in 24 years since NOAA 6368 in November 1990 (Thalmann *et al.* 2015). As the solar cycle 24 was a comparatively weak cycle (Jiang *et al.* 2015), the huge size of AR 12192 was quite unexpected.

Interestingly, the sunspot group AR 12192 was the return of AR 12172 from the previous rotation. It returned back to the next two rotations as NOAA 12209 and NOAA 12237, respectively, as shown in Figure 1. In the previous cycle also, it was non-eruptive in nature and produced 12 C-class and 1 M-class flares during its disc passage from September 21 to October 3. After disappearing behind the limb on October 3, it was seen in GONG farside images (Figure 2). From October 4 to October 16 it crossed the far side of the Sun and evolved to grow as a giant sunspot group and on October 17, it appeared as AR 12192 on the eastern limb of visible solar disc. However, it started showing pre-signatures of its appearance from October 14 when it was behind the eastern limb. Hinode flare catalog reveals two M-class flares on October 14 and 3 C-class and 1 M-class flare on October 16 at the location S14 E88. These strong flares behind the eastern limb and the appearance of a big spot in GONG far side image (Figure 2) on October 14, were the distinct signatures of an active region group approaching over the eastern limb.

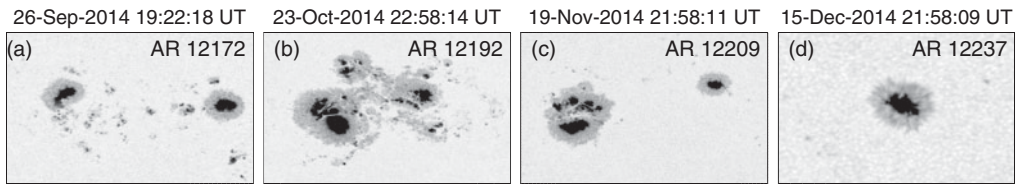


Figure 1. Images show the SDO continuum intensity map of AR 12192 (b) in its previous rotation (a), and subsequent rotations (c) and (d), respectively. The heliographic coordinates of the ARs illustrated in the above panels are S11W05, S12W08, S13W06 and S14E15 respectively from left to right.

From October 17 to 30, AR 12192 crossed the visible solar disc and produced 6 X-class flares, 22 M-class flares, and 53 C-class flares. On October 24, when it was close to the central meridian it produced one X3.1 class flare which set a record in flare energy for an event without a CME (RHESSI science nugget no.239, http://sprg.ssl.berkeley.edu/~tohban/wiki/index.php/A_Record-Setting_CMEless_Flare). At that time, the location of the AR was S16W21, which was an ideal location to produce an Earthward-directed halo CME event. However, no major CME was observed. Only one small CME was launched during an M4.0 class flare on October 24, which was the only CME produced by this active region during the disc passage.

On October 31, AR 12192 disappeared behind the western limb and returned back in the next rotation on November 13 as NOAA 12209 with a reduced size. From November 13 to November 26 NOAA 12209 was visible on the solar disc and produced 16 C class flares. After that, it went behind the visible solar disc and further reduced to a very small size and again became visible on the solar disc for the last time in the next rotation from December 10 to 22 as NOAA 12237.

In this work, we have studied the evolution of AR NOAA 12192 and its relation with the flare and CME productivity.

2. Data analysis

The evolution of AR 12192 during its disc passage was well captured by the observations from the Helioseismic and Magnetic Imager (HMI) (Schou *et al.* 2012) and the Atmospheric Imaging Assembly (AIA) (Lemen *et al.* 2012) onboard Solar Dynamics Observatory (SDO) (Pesnell *et al.* 2012). To study the umbral and penumbral area variation for all the three rotations of AR 12192 we have used the full-disc continuum images observed in the Fe I line at 6173 Å with a spatial scale of 0.5'' per pixel and temporal scale of 12 minutes. To study the photospheric magnetic field evolution of AR 12192, we have used the 12 minutes cadence HMI vector magnetogram series from the version of Space weather HMI Active Region Patches (SHARP; Turmon *et al.* 2010). For identifying the umbral-penumbral and penumbral-quiet Sun boundaries we have calculated the cumulative histogram (Pettauer & Brandt 1997, Mathew *et al.* 2007) of the intensity of each pixel's brightness within the cutout which encloses the whole active region as well as the immediately surrounding quiet Sun region. Before calculating the cumulative histogram, we have normalized all the pixels of the cutout region by the median of brightness value of a 10×10 pixel² quiet Sun region surrounding the active region. The cumulative histograms were computed for all the days during the disc passage of AR 12192 from 2014 October 21 to 2014 October 26 when its longitude was within ±75° from the central meridian. We have found the normalized intensity threshold for umbral-penumbral boundary is 0.53 and that of penumbral-quiet Sun boundary is 0.90. These

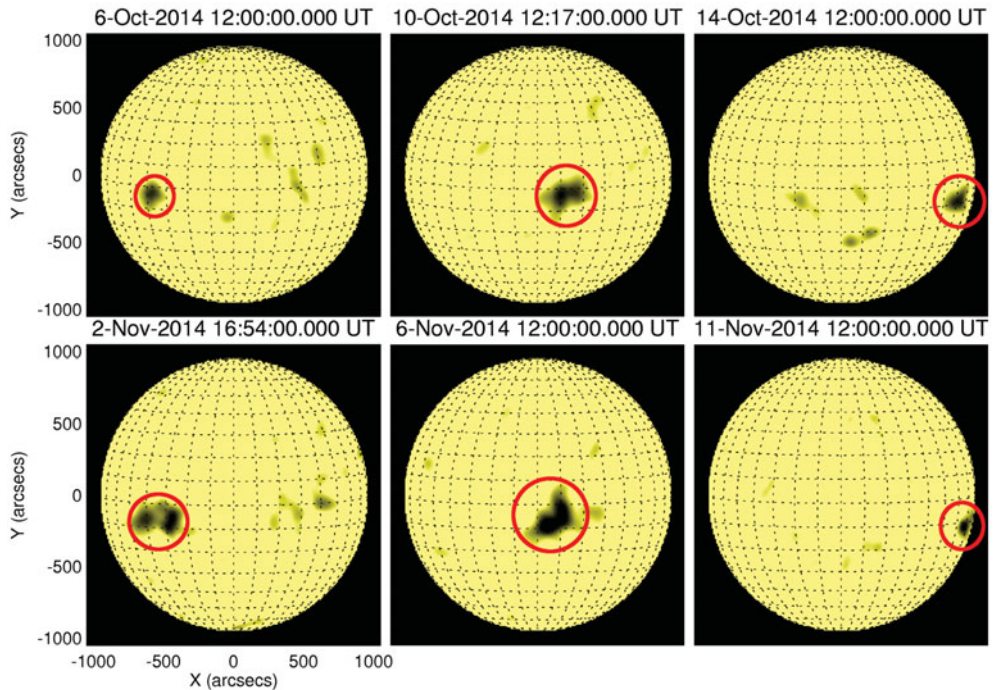


Figure 2. The upper panels show the appearance of AR 12192 (indicated by the red circles) in GONG far-side images in between the first and second rotation. The bottom panels show the same in between the second and third rotation.

values were then used to calculate the umbral and penumbral area evolution during the first three rotations of the AR. As the area during the 4th rotation was too small it was not included in the analysis. To calculate the true area of the sunspot groups, we have used the algorithm introduced by Cakmak (2014). The variation in area of AR 12192 for the first three rotations is illustrated in Figure 3.

3. Summary and Discussions

AR 12192 underwent a gradual growth starting from the previous disc passage during which the umbral and penumbral area increased from ~ 40 to ~ 85 MSH (Millionths of Solar Hemisphere) and ~ 300 to ~ 500 MSH respectively. The further growth of the AR occurred on the backside of the visible solar disc. Finally, when it appeared as AR 12192 in the second rotation, both the penumbral and umbral area became almost 6 times larger than the previous rotation. Also the major dynamics of this AR occurred during this rotation when the umbral area grew from ~ 500 to ~ 650 MSH and the penumbral area increased from ~ 3200 to ~ 4000 MSH. This noticeable growth in both the umbral and penumbral area reflected in the magnetic energy content of AR 12192, as it produced six high energetic X-class flares within an interval of one to two days during its disc passage. It implies that the huge size of AR 12192 may be the reason of its sufficient energy storage to trigger the recurrent high energetic flares. In the third rotation, the active region area decreased by almost ten times of that from the previous rotation. Notably, in all the three rotations the penumbral to umbral area ratio remained almost constant (approximately 5.5), implying that both the umbra and penumbra evolved almost in a similar fashion during the whole evolution period.

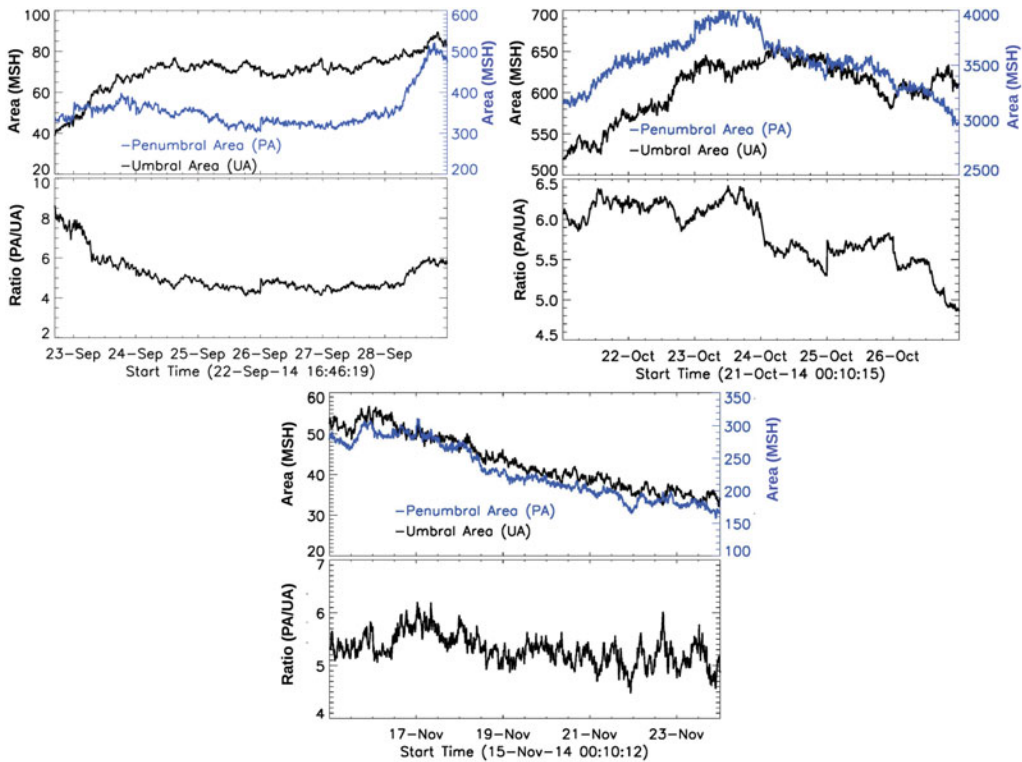


Figure 3. Area variation of the AR for the first three rotations

From the analysis of HMI vector magnetograms, we have studied the four non-eruptive major flares which occurred near the core region of AR 12192 and one eruptive flare that occurred away from the core region. We found abrupt and permanent changes in the horizontal magnetic field near the magnetic neutral line along with significant changes in the radial component of Lorentz force. Importantly, the above changes were significantly less in case of the four confined flares than the eruptive one. The distinct changes in the magnetic properties for both the eruptive and non-eruptive flares reveal that the large flares leave significant magnetic imprints on the solar photosphere which may carry the information of the nature of eruptions. A detail comparative study of the magnetic characteristics associated with both the eruptive and non-eruptive flares produced by AR 12192 is presented in Sarkar & Srivastava (2018).

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