EVIDENCE FOR COLLAPSING FIELDS IN THE CORONA AND PHOTOSPHERE DURING THE 2011 FEBRUARY 15 X2.2 FLARE: SDO/AIA AND HMI OBSERVATIONS

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ABSTRACT

We use high-resolution Solar Dynamics Observatory (SDO)/Atmospheric Imaging Assembly observations to study the evolution of the coronal loops in a flaring solar active region, NOAA 11158. We identify three distinct phases of the coronal loop dynamics during this event: (1) slow-rise phase: slow rising motion of the loop-tops prior to the flare in response to the slow rise of the underlying flux rope; (2) collapse phase: sudden contraction of the loop-tops, with the lower loops collapsing earlier than the higher loops; and (3) oscillation phase: the loops exhibit global kink oscillations after the collapse phase at different periods, with the period decreasing with the decreasing height of the loops. The period of these loop oscillations is used to estimate the field strength in the coronal loops. Furthermore, we also use SDO/Helioseismic and Magnetic Imager (HMI) observations to study the photospheric changes close to the polarity inversion line (PIL). The longitudinal magnetograms show a stepwise permanent decrease in the magnetic flux after the flare over a coherent patch along the PIL. Furthermore, we examine the HMI Stokes $I$, $Q$, $U$, $V$ profiles over this patch and find that the Stokes-$V$ signal systematically decreases while the Stokes-$Q$ and $U$ signals increase after the flare. These observations suggest that close to the PIL the field configuration became more horizontal after the flare. We also use HMI vector magnetic field observations to quantify the changes in the field inclination angle and find an inward collapse of the field lines toward the PIL by $\sim 10^\circ$. These observations are consistent with the “coronal implosion” scenario and its predictions about flare-related photospheric field changes.

Key words: Sun: corona – Sun: flares – Sun: oscillations – Sun: photosphere

Online-only material: animation, color figures

1. INTRODUCTION

Understanding the coupling between the photosphere and solar corona requires simultaneous observations of the Sun at different wavelengths. The observations from the recent Solar Dynamics Observatory (SDO) mission are best suited for such studies. The continuous high-resolution observations of the full disk of the Sun at a rapid cadence in multiple wavelengths allow us for the first time to study the evolution of solar active regions from the photosphere to the corona on a regular basis. The evolution of the photosphere as well as the corona above the flaring active regions can give us important clues about the development of non-potentiality, which fuels the flares. It was hitherto believed that the flare was predominantly a coronal phenomenon and that most of the flare-related changes would be observed in the corona with no visible changes at the photospheric boundary (Priest & Forbes 2002). However, contemporary observations have shown that during large flares abrupt changes are clearly visible at the photosphere (Kosovichev & Zharkova 2001; Sudol & Harvey 2005; Deng et al. 2005; Gosain et al. 2009b; Gosain & Venkatakrishnan 2010; Petrie & Sudol 2010).

Hudson (2000) suggested that the buildup of free energy in an active region must lead to an inflation of the overlying coronal structure due to enhanced magnetic pressure. Furthermore, Hudson (2000) conjectured that the release of this free energy during flare and coronal mass ejections (CMEs) must consequently lead to a deflation of the magnetic field in the active region. This phenomenon was termed as “coronal implosion.” Furthermore, Hudson et al. (2008) predicted the consequences of the “coronal implosion” at the photospheric boundary and suggested that the field inclination should change such that the final configuration is more horizontal. Recently, Wang & Liu (2010) studied the vector field of 11 active regions during X-class flares and found that the post-flare field configuration is in agreement with the prediction of Hudson et al. (2008). Furthermore, a similar pattern of magnetic field evolution was observed at the lower boundary in the three-dimensional numerical MHD simulations of an erupting flux rope (Gibson & Fan 2006; Fan 2010; Li et al. 2011). The observational signatures of coronal loop implosion or contraction were reported during an erupting filament (Liu & Wang 2009), a C-class flare (Liu et al. 2009), and an M-class flare (Liu & Wang 2010). However, these studies have been done in isolation, and a combined study of simultaneous flare-related coronal and photospheric changes during a flaring event has not been done due to a lack of complete observations. Co-temporal Helioseismic and Magnetic Imager (HMI) and Atmospheric Imaging Assembly (AIA) observations offer a unique opportunity to detect such changes at an unprecedented temporal coverage. Using recently released preliminary test vector magnetogram data for this active region, Liu et al. (2012) performed a nonlinear force-free field (NLFFF) computation for this active region and found that the mean horizontal field near the flaring polarity inversion line (PIL) increased by about 28% and the strong horizontal current system above this region collapsed downward after the flare. Sun et al. (2012) also used these NLFFF computations and found that magnetic free energy reached about $2.6 \times 10^{32}$ erg before the flare and about $0.3 \times 10^{32}$ erg was released within one hour of the X-class flare. Schrijver et al. (2011) used multi-wavelength coronal observations in AIA channels and studied the extreme-ultraviolet (EUV) wave during the X-class flare in this region and found that the sections of propagating coronal front running over the quiet Sun were consistent with adiabatic warming, while for other sections additional heating by Joule dissipation may be required.
Figure 1. Inverted color map of active region NOAA 11158 observed in Fe\textit{x} \textit{i} 171 Å wavelength by the SDO/AIA instrument during 02:29 UT on 2011 February 15. The loops marked 1–4 are studied for temporal evolution and are highlighted by blue curved line segments. The line contours at 500 and 1000 G levels of the longitudinal magnetic field observed by the SDO/HMI instrument are overlaid in blue (red) colors, representing negative (positive) polarity, respectively. The yellow line marks the position of the artificial slit that is placed to sample the dynamics of the apex of the loops. The spacetime diagram corresponding to the slit is shown in Figure 2.

Here we report on the observations of the coronal implosion as observed in NOAA 11158 during the X2.2-class flare event during 2011 February 15. The detailed coverage of the event by the AIA instrument on board SDO allowed us to capture the evolution of coronal loops over this active region before, during, and after the flare. We derive magnetic field strength estimates using the observed loop oscillations. Also, the photospheric observations by HMI allowed us to study the evolution of the photospheric line-of-sight (LOS) magnetic field component, field inclination angle, as well as the direct observable, i.e., Stokes profiles themselves in relation to this flare. Furthermore, we use SDO/AIA images in EUV and detect a bright front emanating from this active region during the flare. We report here a combined study of the coronal and photospheric changes during the flare, which are in agreement with the predictions by Hudson (2000) and Hudson et al. (2008) and corroborate previous such observations carried out with limited spatial and/or temporal resolution.

In Section 2 we describe the observational data and methods of analysis. Then, in Section 3 we present the evidence for coronal implosion as deduced from the present analysis and the observed changes of the LOS magnetic field and the Stokes profiles at the photospheric boundary during the flare interval. We discuss these results in the light of previous reports as well as theoretical arguments.

2. OBSERVATIONS AND DATA ANALYSIS

2.1. SDO/AIA Fe\textit{x} \textit{i} 171 Å Observations

The first X-class flare of the current solar cycle (cycle 24) occurred during 01:48 UT on 2011 February 15 in a $\beta\gamma\delta$ sunspot complex, NOAA 11158. This event was observed in great detail by the instruments on board SDO (Pesnell et al. 2011). The photospheric observations were obtained by the HMI instrument (Schou et al. 2011a) in the Fe\textit{i} 6173 Å line (Norton et al. 2006) and the coronal observations were taken by the AIA instrument in as many as eight EUV wavelength passbands (Lemen et al. 2011; Boerner et al. 2011). The coronal images analyzed here correspond to Fe\textit{x} 171 Å passband. The level-1 SDO/AIA images are obtained through the Joint Science Operations Center (JSOC) Web server. The region of interest (ROI) used for the analysis is extracted from the level-1 full disk AIA images and is shown in Figure 1, in the inverted color map. The time interval chosen for the analysis is between 00:30 UT and 02:30 UT on 2011 February 15. The ROI is tracked in time using a cross-correlation technique. Furthermore, the intensity counts in the images are normalized for the variable exposure time (SDO/AIA has a variable exposure time during flare events). The loops (or bundle of loops) of interest are outlined by blue line segments and are marked 1–4. An artificial slit is placed along the yellow line such that the slit is normal...
Figure 2. Top panel shows the spacetime diagram corresponding to the slit marked in Figure 1. The positions corresponding to loops 1–4 are marked on the right side. The three phases of evolution discussed in the text are marked in the figure and indicated by arrows. The bottom panel shows the soft X-ray light curve observed by the GOES satellite during the same time interval.

(A color version of this figure is available in the online journal.)

to the loop apex. This facilitates the detection of any implosive motion in the loops. The spacetime diagram corresponding to this slit is shown in the top panel of Figure 2, while the GOES X-ray flux in the two energy channels (1–8 Å and 0.5–4 Å) during the same time interval is shown in the bottom panel. The loops 1–4 are marked in the top panel of Figure 2 for identification. The three phases of loop dynamics discussed in the following section are marked by orange colored arrows. The red dotted line marks the slow-rise phase and the portion between the two slanted yellow lines mark the implosion phase. The oscillation phase is visible toward the right portion of the spacetime diagram. The dynamics of these loops is best viewed in the animation of this event, which is provided in the online journal (movie1.mpg). The animation was created by using a Jhelioviewer software application (Mueller et al. 2010), provided by ESA/NASA.

2.2. SDO/HMI Fe i 6173 Å Observations

The photospheric observations by HMI on board SDO are used for the present analysis. These observations are (1) longitudinal magnetograms and (2) Stokes profiles, $S(\lambda) = [I(\lambda),Q(\lambda),U(\lambda),V(\lambda)]$, normalized to the continuum intensity $I_c$. These are full disk level-1 data obtained from the JSOC Web server. The HMI observations are taken in the imaging spectropolarimetric mode using the Fe i 6173 Å line. The Stokes profiles are obtained by tuning the filter across this line at six wavelength positions. The details of the HMI filter characteristics and calibration are described in Couvidat et al. (2011). The polarization calibration of the HMI Stokes level-1 data is described in Schou et al. (2011b). The time interval of the observations used here is the same as for the SDO/AIA images, i.e., 00:30-02:30 UT. The cadence of the longitudinal magnetograms is 45 s while that of the Stokes profiles is 12 minutes.

The longitudinal field corresponding to the ROI extracted from the level-1 full disk LOS magnetogram data for our analysis is shown in Figure 3. The same ROI is extracted from the full disk Stokes images. For the registration of the longitudinal magnetograms and Stokes images ($I, Q, U, V$ images), we perform cross-correlation of the HMI continuum intensity images (which are co-temporal with full disk LOS magnetograms) and Stokes-$I$ (continuum) images and apply the derived shifts to these maps. This registration allows us to study the evolution of the Stokes profiles over the region of the LOS field changes during the flare interval. Furthermore,
we use the HMI vector magnetograms released by the HMI team (Hoeksema et al. 2012) for studying the changes in the field inclination angle near the flaring PIL. These vector magnetograms are available at a cadence of 12 minutes. We register the HMI vector magnetograms with the high cadence LOS magnetograms by a cross-correlation method.

3. RESULTS

3.1. The Evolution of the Coronal Loops

The four prominent loops (or bundle of loops) that show clear evidence for loop implosion (from the visual inspection of the animation) are selected for analysis and are marked as 1, 2, 3, and 4 in Figure 1. The apparent height of the loop apex ($H$) in the image plane is measured from the bright core of the active region and is estimated to be $\approx 175, 155, 115,$ and $85$ Mm for loops 1, 2, 3, and 4, respectively. The approximate loop length is then given by $L \approx \pi H,$ as 550, 485, 360, and 267 Mm, respectively, for loops 1, 2, 3, and 4, assuming a semicircular loop geometry. The spacetime diagram corresponding to the artificial slit placed across the top (flat) part of the four loops is shown in Figure 2. The dynamics of these loops shows three distinct phases of evolution. These phases are described below.

3.1.1. Slow-rise Phase

During this phase we observe that the height of the apex of loop 4 is increasing before the onset of the flare. This increase in the loop height is perhaps present in all four loops but is distinctly visible for loop 4 owing to its higher intensity contrast. The increase in the apex height suggests that the loops...
are stretched vertically upward due to an increase in magnetic pressure in the core of the active region as a result of free energy buildup. We call it the slow-rise phase and it is marked by a red dotted line in the spacetime diagram in Figure 2. This slow-rise phase can be traced back up to 00:40 UT, i.e., about one hour before the onset of the flare. The slow-rise phase is gradual from 00:40 up to 01:25 UT and becomes rapid from 01:25 up to the onset of the flare at \(01:48\) UT. The overall inflation of the loop height during the period 00:40–01:48 UT is about \(10^6\), which corresponds to \(\sim 7\) Mm.

3.1.2. Collapse Phase

During this phase all four loops show a sudden implosive decrease in their apex height. Such possible change in the apex height of loops could also be attributed to the change of the tilt angle of the loop’s plane to the LOS, due to the flare impulse. However, in that case we would expect the loops to return to their original apex heights once the flare impulse has passed the loops. In the spacetime diagram (Figure 2), however, we note that the change in apex height is permanent and the loops oscillate (oscillation phase described below) about the new mean apex height (blue arrows) of the loops, which is lower than the pre-flare apex height of the loops (i.e., the height at the beginning of the implosion phase, the first yellow line). Thus, we can safely believe the loop dynamics to be essentially polarized in the loop’s plane. The observed implosion phase is marked by the two yellow lines. The first yellow line joins the epochs when the first signature of implosion can be traced for loops 1–4, while the second yellow line joins the epochs when the maximum contraction for loops 1–4 is reached. It may be noticed that there is a time delay between the onset of the implosion phase of the loops, with lower loops imploping earlier than the higher ones. This is discussed further in Section 4 where we present a possible scenario for the observed delay in the contraction of the loops.

Moreover, it may be noticed that loops 1–4 continue to rise for few minutes after the flare onset. A plausible explanation for these observations may be as follows. The flare onset suggests the onset of magnetic reconnection beneath the rising flux rope, while the continued expansion of the observed overlying loops for the minutes after the flare onset suggests that the part of the flux rope underneath loops 1–4 is still expanding. It may be noted that the footpoint of an eruptive flux rope remains anchored in the photosphere. Since observed loops 1–4 are not exactly over the central portion of eruptive flux rope but over the peripheral part of flux rope, they probably continue to rise for some time as part of the evolution of the footpoints of an eruptive CME flux rope.

3.1.3. Oscillation Phase

After the implosion phase the loops begin to oscillate about their new contracted position, which we call the oscillation phase. It may be noticed that the periods of the oscillations are not the same for loops 1–4. By inspecting the spacetime diagram, we deduce that the oscillation period is in the range of \(660\) s for loops 1 and 2, and about \(450\) and \(180\) s for loops 3 and 4, respectively. Since these oscillations show transverse displacement of the entire loop with respect to loop position, we believe these are the fundamental (first harmonic) fast kink mode MHD oscillations. The phase speed of this mode, \(C_K\), in the low plasma \(\beta\) limit and the assumption that the loop width is much smaller than the loop length, is given as

\[
C_K \approx \left( \frac{2}{1 + \rho_e/\rho_i} \right)^{1/2} C_A,
\]

where \(C_A\) is the Alfvén speed in the loop and \(\rho_e/\rho_i\) is the ratio of densities outside and inside of the loop. The value of \(C_K \approx 2L/P\) for loops 1–4 can be determined from the observations as \(1670, 1470, 1600,\) and \(2966\) km s\(^{-1}\). The parameter \(\rho_e/\rho_i\) is unknown and can typically take values from 0 to 0.3. Following Nakariakov et al. (1999) we take \(\rho_e/\rho_i\) to be 0.1 and compute the Alfvén speed using the relation above as \(1238, 1090, 1186,\) and \(2199\) km s\(^{-1}\) for loops 1–4, respectively. Then using relation \(V_A = 2.18 \times 10^{11} B/\sqrt{n}\) we estimate the field strength inside loops 1–4 to be in the range of \(15–43, 13–38, 15–41,\) and \(28–77\) G for loops 1–4, respectively. Here, the upper and lower limits correspond to the upper and lower limits of the estimated loop density \(n \approx 10^{9.33\pm0.44}\) cm\(^{-3}\) by Aschwand et al. (2011) for a sample of 570 loop segments in this active region using automated DEM (differential emission measure) analysis of AIA observations. These values of the magnetic field strength are consistent (by an order of magnitude) with the previous seismological estimations using TRACE observations (Nakariakov & Ofman 2001). It may be noted that the field strength in loop 4, which is lower in height, is typically higher than the field strength derived for higher loops 1–3, which is expected as the magnetic field strength decreases with height due to expansion of the magnetic field in the coronal volume above the photosphere. A more detailed investigation of these oscillations along with their damping times is deferred to another paper, where we plan to compare the field strengths deduced here with the results of force-free field (FFF) extrapolation.

3.2. The Evolution of the Photospheric Magnetic Field

In this section, we analyze the evolution of the photospheric magnetic field for this active region using the longitudinal magnetograms obtained from SDO/HMI. In addition to the evolution of the LOS field we also show the evolution of the Stokes \(I, Q, U,\) and \(V\) profiles themselves at the locations where we detect longitudinal field changes, together with the evolution in a region away from the flaring region, which serves as a control region for comparison.

3.3. Evolution of Longitudinal Field during the Flare

The high-resolution longitudinal magnetograms available from HMI at a cadence of 45 s are used to study the evolution of the field during the flare interval.

The magnetograms of the field of view are shown in the top panel of Figure 3. The changes in the absolute value of the LOS magnetic flux are obtained by taking the running difference of the magnetograms (absolute value) observed between 01:45 and 02:00 UT. The difference image is shown in the bottom panel of Figure 3. The positive changes (white areas) correspond to the decrease in the LOS flux, while the negative changes (black areas) correspond to the increase in the LOS flux. It may be noticed that in the periphery of the active region, the random black and white differences dominate due to the small-scale evolution and convective drift. While near the PIL there is a coherent patch showing a decrease of the LOS flux. Overall it may be noticed that the areas of the LOS flux decrease dominate over the LOS flux increase. Furthermore, we study the nature of the evolution of the LOS magnetic flux in two regions,
marked by boxes 1 and 2 in Figure 3. The time profile of the one located near the PIL and one away from the flaring region, labeled 1 and 2, displayed in the panels of Figure 3. Box 1 is located in a quiet magnetic region away from the flaring region, while box 2 is located over the coherent patch where the LOS flux decreased during the flare interval and is close to the PIL.

The bottom panel shows the evolution of the LOS flux in box 1 (the quiet region) and the top panel shows the evolution in box 2 (the flaring region). An abrupt change in the LOS flux can be noticed near the flaring region, which is permanent and distinct from the gradual evolution of the LOS flux in the control region (box 1). The earlier studies of the LOS flux changes during strong X-class flares using low-resolution observations obtained from ground-based GONG and space-based SOHO/MDI instruments have shown such behavior of the LOS flux during strong flares (Kosovichev & Zharkova 2001; Sudol & Harvey 2005; Petrie & Sudol 2010). The dominance of the regions of decreasing flux over increasing flux is consistent with earlier results (Petrie & Sudol 2010).

3.4. Evolution of the Stokes Profiles during the Flare

For the 2011 February 15 X2.2 flare, there are other photospheric changes that have been reported, for example: (1) Kosovichev (2011) reported the detection of a powerful "sunquake," (2) Maurya et al. (2012) reported the detection of transient Doppler and magnetic signatures associated with flare ribbons, and (3) Wang et al. (2011) reported a permanent enhancement of the linear polarization signals near the PIL, which was interpreted as an enhancement of the transverse magnetic field. To add to these photospheric observations, we study the evolution of the spatially averaged full Stokes profiles observed by the HMI instrument over the rectangular boxes (2′5 × 2′5), one located near the PIL and one away from the flaring region far away from the flaring location. The earlier results (Petrie & Sudol 2010). The dominance of the regions of decreasing flux over increasing flux is consistent with earlier results (Petrie & Sudol 2010).

3.5. Evolution of the Field Inclination during the Flare

A recent study of the HMI vector field and its NLFFF extrapolation reveals an increase in the horizontal field component by about ∼28% near the PIL (Liu et al. 2012). While the horizontal field component is comprised of field strength and inclination (B_θ = B \sin \gamma), here we examine how the field inclination that is indicative of the field topology changes during the flare interval across the PIL. Using these data sets in a statistical sense, Sun et al. (2012) show that in a box near the PIL the distribution of inclination angles shifts toward more inclined fields. Similarly, Wang et al. (2012) studied the temporal evolution of inclination near the PIL and found a permanent change in the inclination of the fields toward horizontal. In Figure 6, we show maps of the magnetic field inclination angle from HMI vector field data and their running difference corresponding to times 01:48 and 02:00 UT. A coherent patch of changing inclination can be seen near the PIL. The patch has opposite signs on either side of the PIL, which means that the field on either side of the PIL becomes more horizontal since the inclination angle is measured in the 0°–180° range, where 90° corresponds to the horizontal field and 0° and 180° correspond to the field pointing upward (positive polarity) and downward (negative polarity), respectively. We select a rectangular box over this region where we see coherent change in the inclination angle and plot its profile averaged in the x-direction so that a mean variation across the PIL can be estimated. The profile is shown in the right panel of Figure 6. It may be noted that the change of ∼10° toward the
horizontal direction is seen on either side of the PIL, suggesting an inward collapse (toward the PIL) of the field configuration. This is consistent with the predictions about the possible changes in field topology after a major flare by Hudson et al. (2008).

4. DISCUSSION AND CONCLUSIONS

The observations from SDO provide the best spatial and temporal coverage to study the evolution of flaring active regions. In the present work, we studied the evolution of coronal
loops as well as the photospheric magnetic field and Stokes profiles in relation to an X2.2-class flare. The flare-related changes in the active region corona and the photospheric field are found to be in agreement with the predictions made by Hudson (2000) and Hudson et al. (2008) using free energy arguments. The two main predictions, namely the implosion in the corona and the changes in the magnetic field configuration at the photospheric boundary, are tied to the argument that the post-flare state must correspond to a lower energy state compared to the pre-flare state, irrespective of the detailed mechanism by which the excess energy is released. These predictions have been tested in the past using either coronal or photospheric observations separately. In the present case we were able to observe both of these predictions in a single active region during an X-class flare, thanks to excellent spatial, temporal, and spectral coverage by the SDO mission.

The three phases of the evolution of the coronal loops above the active region during the flare interval could be resolved in great detail in the present case. The slow-rise phase during which the loop height is observed to increase prior to the flare/CME onset has been studied earlier by Liu et al. (2010a) in another event. Such an expansion could happen due to the slow rising of a flux rope as seen in Liu et al. (2010b), which is often invisible unless being traced by filament material as in Gosain et al. (2009a). Schrijver et al. (2011) studied this active region in detail and identified an erupting flux rope structure during the flare. They detected an EUV wave associated with the eruption. The expanding overlying loop system in response to the rising and expanding flux rope in the core of eruptive active regions is a common phenomenon, and in the present case, with high spatial and temporal resolution, we can observe this phenomenon in great detail. A plausible explanation for the observation of the successive collapse of loops with increasing height in Figure 2 can be as follows. According to the flare model given by Hirayama (1974, see Figure 1(b)), reconnection occurs in the current sheet formed below the rising flux rope and the compression region is formed causing the surrounding field to collapse inward. As the flux rope moves forward, the centroid of the compression region will also move upward and therefore, one would expect the collapse of surrounding fields successively at greater heights. This may explain our observation of a systematic delay in the onset of the collapse of the loops with height. The EUV bright fronts are a signature of expanding flux rope (Schrijver et al. 2011). In Figure 7, we show a running difference of EUV AIA 171Å images during a flare interval. In Figure 7(a), we mark the EUV bright front observed in its early phase. During this time the implosion in loops (1–4) has not started. Furthermore, Figure 7(b) shows the location of the
EUV bright front at an instant when the first signature of the collapse of the loops (the lower loop system, 4 in Figure 1) can be traced in the running difference. The collapse of higher loops (loops 1–2) appears later in time, as shown in Figure 7(c), when the flux rope rises to greater height. Such a scenario should be tested with more observations of powerful flares as well as with numerical MHD simulations of solar eruptions.

The slow-rise phase of overlying active region loops, which lasts several minutes before the flare occurrence, could be a precursor to major flares and therefore has a potential for flare detection. Real-time image processing and analysis tools could be used for detecting such precursors in flares. The implosive phase is clearly visible in a hierarchy of loops during the flare interval. Similar observations of implosive phenomena for other flares observed by SDO/AIA would be useful to establish the phenomena further. The spatial variation of the implosion over the active region could be analyzed in detail to investigate the locations of energy storage in active regions. Furthermore, the oscillation phase seen in loops analyzed here as well as other loops that are not analyzed here but can clearly be seen in the animation (in the online journal) can be exploited in detail by the methods of coronal seismology to probe the properties of coronal loops (for example, the magnetic field) over active regions. We plan to carry out a detailed study of the oscillation period and damping times of various loops for this active region in a future work.

Furthermore, the evolution of the LOS magnetic field as well as the observed behavior of the Stokes profiles themselves firmly establish the prediction (Hudson et al. 2008) that the field lines in the aftermath of a flare become more horizontal. Such changes of the photospheric field, i.e., the field becoming more horizontal after the flare, were also found to be statistically significant in a recent study of 11 X-class flares by Wang & Liu (2010), where they found in most of the cases a transverse field near the PIL, the peak X-ray output of the flare, the kinetic energy of the accompanied CMEs, and the helioseismic response of a flare. Such comprehensive studies have not been undertaken in the past due to limited coverage of flaring events, but with SDO, STEREO, and Hinode observatories, there is a good scope for performing these studies that would eventually help in testing theoretical ideas about the dynamics of the solar flares (Hudson et al. 2011).

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