RELATIONSHIP BETWEEN MAGNETIC FIELD EVOLUTION AND
FLARING SITES IN AR 6659 IN JUNE 1991

B. SCHMIEDER
Observatoire de Paris, URA 326 (CNRS), F 92195 Meudon, Cedex, France

M. J. HAGYARD
MSFC, NASA, AL 35812, U.S.A.

AI GUOXIANG, ZHANG HONGQI
Beijing Observatory, 100080, Beijing, China

B. KALMÁN, L. GYŐRI
Heliophysical Observatory of the Hungarian Academy of Sciences, H-4010 Debrecen, P.O. Box 30, Hungary

B. ROMPOLT
Astronomical Institute of the Wroclaw University, Wroclaw, PL 51–622, Poland

P. DÉMOULIN
Observatoire de Paris, URA 326 (CNRS), F 92195 Meudon, Cedex, France

and

M. E. MACHADO
UAH, Huntsville, AL 35899, U.S.A.

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Abstract. During the international campaign of June 1991, the active region AR 6659 produced six very large, long-duration flares (X10/12) during its passage across the solar disk. We present the characteristics of four of them (June 4, 6, 9, 15). Precise measurements of the spot motions from Debrecen and Tokyo white-light pictures are used to understand the fragmentation of the main sunspot group with time. This fragmentation leads to a continuous restructuring of the magnetic field pattern while rapid changes are evidenced due to fast new flux emergence (magnetograms of MFSC, Huairou). The first process leads to a shearing of the field lines along which there is energy storage; the second one is the trigger which causes the release of energy by creating a complex topology. We conjecture that these two processes with different time scales are relevant to the production of flares.

1. Introduction

Two key questions about solar flares are: (1) where is the energy stored, and (2) why and where is it suddenly released? It is now generally believed that the energy is stored in the magnetic fields by field-aligned currents. This energy may be suddenly released when the magnetic field configuration reaches a global ideal instability. The high coronal conductivity and the spatial scale lengths involved allow the use of ideal MHD equations except where discontinuities appear in the field. These discontinuities favor the release of the energy in the corona. Conductive fronts or particle transport drive this energy to the chromospheric level where bright flare ribbons are formed. The ribbons are thus a secondary consequence of the processes involved in flares.

While it is commonly accepted that energy is stored along field lines in non-potential magnetic configurations, many questions still remain unsolved. Why and when does the configuration become nonpotential? Is the nonpotential field due to currents generated deep in the convection zone or to motions of magnetic field line footpoints; is it due to a long-term evolution between two large opposite-polarity regions (Martres et al., 1968) or movements with new emerging flux? The problem of the time scale of the deformation is unknown. The way in which the magnetic field is deformed can be investigated using two observational signatures: the proper motion of the sunspots and magnetograms with good spatial and temporal resolution.

Active region AR 6659 (N31°), the target of a Flares22/Max91 campaign, gave us the opportunity to study the temporal evolution of an active region's magnetic structure during its disk passage in June 1991 (Figure 1). Thirty flares occurred in this AR, and six of them were of class X10/12 (Table I). This activity prompted extensive observing programs so that large amounts of observations from all over the world were obtained in different wavelengths and with different kinds of instruments. The region had a typical δ configuration with a large negative preceding (p) sunspot group surrounded by a 'crown' of small following (f) positive spots or faculae. The activity of this region was comparable to the activity observed in similar delta spots of the super-active regions that have been extensively studied in recent years (Wang et al., 1991; Wang and Shi, 1993; Tang and Wang, 1993; Wang and Tang, 1993). Thus this region provided a further example to study how this level of activity is related to the evolution of a region's magnetic field.

This paper is organized in the following manner. In Section 2, the motions of the identifiable sunspots are discussed in terms of a long-term process; in the third section, the large-scale evolution of the region's magnetic field over its disk passage is shown. We describe in Section 4 the characteristics of four of the six major flares. In the fifth section we analyze the signatures of the short-term processes which trigger the flares. After a discussion we conclude that two separate processes are involved in producing flares, each having a distinctly different time scale.

2. Evolution of the Spots in AR 6659

2.1. Fragmentation of the Main p Spot Group

AR 6659 was formed two rotations earlier (labeled AR 6580 in April and 6619 in May), and even in the previous rotation it was a compact δ group, with an unusual north–south orientation and the principal p and f spots already in place. After producing the extensive flare activity in June 1991, the region decayed during the following rotation and two rotations later no traces of the complex were observable in the magnetic maps.

The appearance of AR 6659 was preceded by an X12 flare on June 1, when the group was behind the east limb. The evolution of the sunspots can be followed by looking at the Tokyo white-light pictures (courtesy of E. Hiei, Figure 1) and from the
Fig. 1. White-light observations of AR 6659 from Tokyo on June 8, 11, 12, 14 (courtesy of E. Hiei) and from Debrecen on June 15.
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drawings made at Debrecen (Figure 2), derived from the Tokyo pictures and from the Debrecen observations (see Dezsö, Gerlei, and Csepu,
1988). Identification of the spots was done by using magnetograms obtained from different observatories (see Table II). The active region became visible as a large, compact group with a
Fig. 2. Spots of AR 6659 from white-light observations from Debrecen and Tokyo. Numbers and letters denote preceding (negative) and following (positive) polarity, respectively.

large preceding umbra of negative polarity (1–2), a medium-sized following umbra of positive polarity (A) to the NE and some small umbras, of mainly p polarity around the large umbra: on the north (e.g., B on June 4–5, D on June 5–7), on the east side (e.g., C, E, G), on the west (e.g., K, L, M, N, R after June 9). The p polarity satellite spots outside the common large penumbra are denoted by numbers above 90 in Figure 2.

The first important evolutionary mechanism in this region is the continuous fragmentation of the main p polarity. The second is the flux emergence which occurred mainly along the inversion line between A and the p group.

Between June 7 and 9 the northern part of umbra 2 was fragmented into two distinct spots, 3 and 4 (Figure 2). The formation of new umbras was the result of an important evolution of penumbral fine structure. For example, if we look carefully at the penumbra between the A and p group on June 8 between 01:05 and 23:47 UT (Figure 1), darker parts (t1 and t2) appeared on the southeast and southwest sides of A as formed by a coalescence of dark penumbra fibrils. The part t1 becomes spot 4. Such a formation of umbra from penumbra has previously been observed by Wang et al. (1991). To the northwest of A, many small spots of
negative polarity (e.g., 92, 93 on June 8, see Figures 1 and 2 for details) appeared just two hours before one of the major flares to be discussed later. The restructuring of the magnetic field and this new flux played a role in the onset of the big June 9 flare (Section 5).

On the days following June 8, the breaking up of the central $p$ polarity proceeded rapidly. It was possible to follow all fragments of umbra 2; only the largest parts were designated as spots: 20, 21, and 22. Spot 4 was fragmented into 40, 41, 42. New flux emerging between 20 and A deformed 3 and 4, maintaining the high gradient in this active part of the neutral line of the longitudinal field.

2.2. PROPER MOTION OF UBRAE

A study of the proper motions of the spots was performed, taking into account different corrections (Kalmán, 1980; Gyori, 1989; Gyori, Gerlei, and Csepurá, 1992). At the high latitude of the group (N31°) the effects of solar differential rotation are significant, so a correction for this rotation was introduced according to the method of Newton and Nunn (1951). All coordinates are given in this corrected system, which coincided with the Carrington system on June 9 at 12:00 UT, when the group was at central meridian. Trajectories of the more persistent umbrae are shown in Figure 3.

We can form five groups of spots according to their proper motions as follows: $p_1$, the main group (spots 1, 2, 21, 22); $f_1$, the following polarity (spot A); $p_2$, the group formed from the fragmentation of the preceding polarity (spots 20, 30, 40); $f_2$, the group on the east side (C, E, G); and $f_2\',$ on the west side (K, L, M, N). The small satellite spots (91, 93, 94, 95, B, D, R) moved irregularly and were visible for only a few days; they did not participate in the large-scale evolution. Thus the region can be simplified into the $f_2$, $f_1$, $p_2$, $p_1$, and $f_2\'$ groups (Figure 3). The groups $p_2$ and $f_2\'$ moved in opposite directions due to the constant emergence of new flux. Their respective motions maintained a continuous and strong shear between them and the stable groups $f_1$ and $p_1$, as seen in the magnetic maps (see Section 3).

The group $p_2$ was pushed against $f_1$ and $f_2$ polarity and squeezed. A tongue of $p$ polarity (umbra 42 on June 10) was squeezed next to A and a new spot $f$ spot, E, moved very fast in the same direction as spot 20. Following this period of fragmentation and movements by the different fragments, a white light, X12 flare erupted on June 11 at 01:56 UT.

Spots like 40 were observed to pass over the former corridor of the neutral line and appear on the east side of A on June 14–15; the June 15 flare occurred following these movements.

3. GLOBAL MAGNETIC FIELD EVOLUTION

The magnetic field of the active region was extensively observed during this Flares22/Max91 campaign with vector magnetographs from observatories around
Fig. 3. Proper motions of the spots referenced in Figure 2. Arrowheads represent the positions at 12:00 UT. Polarity is indicated by the convention given in Figure 2. Contours indicate groups of spots having the same polarity and similar displacements ($f_2$, $f_1$, $p_2$, $p_1$, $f'2$).

**TABLE II**

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the globe (Table II). To describe the global evolution of AR 6659 we have used vector magnetograms from the Marshall Space Flight Center Solar Observatory (Hagyard et al., 1982; Hagyard, Cumings, and West, 1985) and the Huairou Solar Observing Station (Ai and Hu, 1986; Ming et al., 1988). The Marshall vector
magnetograph provides magnetograms with a pixel size of $2.8''$ in a field of view of $6' \times 6'$ with a cadence of one vector magnetogram every 6 min. Series of photospheric vector magnetograms and chromospheric longitudinal magnetograms are obtained at Huairou Solar Observing Station at Beijing; the temporal resolution of such a series can be as high as 10 min. The observations are made with a vector video magnetograph, similar to the one that operates at Big Bear Solar Observatory (Ai, 1987). The two working spectral lines used for AR 6659 observations were Fe I $\lambda 5324.19$ Å and H$\beta$ $\lambda 4861.34$ Å. The field of view of the magnetograph is $\approx 4' \times 6'$ and the scale of each pixel on the CCD is $\approx 0.4'' \times 0.7''$. Stokes’ parameters ($U$, $V$, $Q$) are measured by using the technique developed by Ai (1987). Chromospheric magnetograms are also obtained through the data processing described by Zhang and Song (1992).

As in the majority of flare-productive regions, the significant magnetic signature of this region was a $\delta$-configuration. Mt. Wilson sunspot observations indicate that both the negative umbrae and the embedded positive polarity were associated with intense magnetic fields on the order of 3000 G throughout the disk passage of AR 6659. Very steep gradients were observed along the magnetic neutral line between these polarities (Figure 4).

### 3.1. Longitudinal Magnetic Field

Magnetograms covering the interval June 6–15 (with the exception of June 11) are shown in Figure 4. Because the maximum magnetic field was normalized to 2500 G for the Marshall data and to 3000 G for the Huairou data, isocontours having the same value do not superpose. However, a general agreement between the two series of magnetograms is noticed, and a qualitative comparison can be made using the data of both observatories for June 9 (Figure 4). An analysis of the morphology shows that changes were taking place at a number of locations in concert with emerging flux, internal motions, and fragmentation of umbrae. The major flares were seen to erupt at these locations.

The evolution of the ridge of positive polarity connecting spots A and C is evident from June 6–7. Although some of this may be projection effects, there does seem to be an emergence of positive flux between A and C ($F3$ in Figure 8) associated with the X12 flare at 00:54 UT on June 6. While not evident minutes before flare onset, a small positive polarity is seen in the Huairou magnetogram at 02:34 UT, 15 min after the end of this major flare (Figure 8). This area increased in strength over the next few days, forming a major concentration of positive flux just to the south of A (Figure 4).

Several changes in the line-of-sight field are seen over the time period June 6–10. There is a notable development of negative polarity in the northern part of the active region, particularly from June 7 to June 8; this is associated with the development of spot 92 in Figure 4. Emergence of negative flux in the central area (moving eastward against the positive region A–C) increased the field gradients along the magnetic neutral line there, particularly on June 8 and 9. The X12 flare
Fig. 4. Longitudinal magnetic field maps for June 6–10 and June 12–15 (labels are in pixel units). The first series, marked $M$, corresponds to Marshall magnetograms taken around 12:30 UT each day; they are calibrated to a maximum field of 2500 G in the strongest negative polarity. The contour levels of the longitudinal magnetic field are 100, 1000, and 2000 G, the pixel unit is 2.8"; the significance of the symbols * and + are explained in Section 3.2. The second series marked by $H$ correspond to Huairou magnetograms calibrated to 3000 G. The contour levels of the longitudinal magnetic field are 200, 640, and 1920 G, the pixel unit is 0.25". The two magnetograms of June 9 are presented for comparison of Marshall and Huairou observations. The kernels of the large flares (dark heavy lines) are referenced by letters a, b, e, f.

of June 9 occurred during this period of evolution. Subsequently, between June 9 and 10 the positive polarity connecting A and C is broken into two parts. These changes take place during the time that the central negative umbrae are undergoing fragmentation. In the western part of the region we see the emergence of the positive polarities M and L on June 9, an unusual evolution of $f$ polarity appearing in front of $p$ polarity and moving forward.
On June 11, the inversion line lies in the middle of penumbral concentrations as suggested by the variety of directions of the fibrils inside (below A in Figure 1). The evolution of the longitudinal field from June 12 to June 15 shows that the negative polarity is progressing toward the southeast of A (Figure 4). This corresponds to the global motion of the negative polarity $p2$ described in Section 2.2 and Figure 3. Thus we conjecture that perspective effects are not the main reason for the observed evolution of the magnetic field in this region (but parasitic polarities that seem to be present near A and 1 are probably just artifacts due to perspective effects).

3.2. TRANSVERSE MAGNETIC FIELD

The evolution of the transverse field is most notable in the same areas where the line-of-sight field was changing. In the north, where the negative spot develops from June 7 to June 8, the transverse field reconfigures with the azimuth of the field rotating almost $90^\circ$. The transverse fields in the eastern area between A and C weaken and change direction from June 9 to June 10, in step with the breaking up of the positive fields and the intrusion of negative polarity there. In the western part of the region from June 9 to June 10, the field grows and rotates direction along the neutral line near the intrusion of the positive polarities M and L.

The global fields of AR 6659 exhibited several persistent areas of sheared magnetic fields as evidenced by the alignment of the transverse field with respect to the magnetic neutral line. These areas of sheared fields are a signature of nonpotential fields and have been associated with sites of flare activity in previous studies (Hagyard and Rabin, 1986; Hagyard, 1990). To quantitatively evaluate the nonpotential characteristics of the field, we compared the transverse component of the observed field with that of the potential field calculated from the distribution of the observed line-of-sight component using the method of Teuber, Tandberg-Hanssen, and Hagyard (1977). Selecting observed points along the main eastern and western magnetic neutral lines, we computed the angular shear $\Delta \phi$, the difference between the directions of the observed and potential transverse fields, at those points where the magnitude of the field was greater than one-half the maximum value along the selected neutral line (but at least 300 G). We then designated fields to be moderately stressed at points where

$$70^\circ \leq \Delta \phi < 80^\circ$$

and highly stressed were

$$80^\circ \leq \Delta \phi < 90^\circ .$$

Maps of areas of stress were made using symbols for the two different ranges of $\Delta \phi$: + and * for the moderately and highly stressed fields, respectively. These areas have been indicated on the magnetograms for June 6–10 in Figure 4. Several interesting features can be seen from these maps. First, there is a segment of the neutral line adjacent to spot A that was persistently sheared from June 6 to June 10;
this was the site of the eruption of all the X-class flares listed in Table I. Also, the neutral line in the area of emerging positive flux on June 6 was highly sheared on June 6 and 7. The emergence of M and L and their subsequent forward movement seem to be associated with the large increase in shear on June 9 and 10 along the western neutral line, the site of an M6 flare on June 10.

Other areas of stressed fields can be identified but these were not associated with any major flares. Thus the magnetic shear does not seem to be a sufficient condition for producing flares (Hagyard and Heyvaerts, 1991; van Driel et al., 1993) but nevertheless it seems a favorable condition.

4. Hα Flaring Sites

A great number of flares registered in soft X-rays by the GOES satellite were observed in different observatories (see Table I). Six of them were of X10/12 class, occurred relatively regularly, and were observed in Hα and Hβ as well as in white light (Sakurai et al., 1992). They all occurred along the same stressed section of the neutral line, to the south of the positive polarity A (Figures 4–6). We will describe four of these X-class flares, as well observed in white light, Hα and Hβ on June 4, 6, 9, and 15.

4.1. The Flares of June 4 and June 6

Huairou Hβ pictures allow us to accurately locate the ribbons of these two flares with respect to the inversion line, which lies in the north–south direction. On June 4 at 03:37 UT, a southern ribbon covered the eastern side of spots 1–2 and a northern ribbon was over the A–B spots (see Figure 2 for the location of these spots). On June 6 at 00:05 UT, there was a similar morphology for the main ribbons of that flare: a northern ribbon at (a) and a southern one at (b) in Figure 4). Large systems of post-flare loops were seen to develop between the ribbons which were moving away from each other.

4.2. The Flare of June 9 at 01:36 UT

The Hα flare was already visible at 01:36 UT at the Yunnan Observatory (Kunming) with its two main ribbons at (a) and (b) (Figures 4 and 5). By 01:38:22 UT, the northern ribbon (a) became thick with an extension (e) towards the west which correspond spatially to the bright network. By superimposing the magnetic field map and the Hα pictures (Figures 9 and 5) and by studying the post-flare loops (systems I, II, and III in Figure 5), we deduce that a secondary system of two ribbons had appeared: one ribbon (f) is located in the north of spot A, probably over a negative facula or small spots (92 in Figure 2), the other one (e) along the boundary of the network. The thin connection between them may also be a loop (Figure 4).
Fig. 5. Kunming Hα observations of the flare on June 9. The filter bandpass was 0.24 Å (0.46 Å at 01:51:42 UT).
Fig. 6. Wrocław observations of the flare of June 15. (1) Bright kernels and low bright loops seen at 07:49 UT. (2) The two ribbons \(a\), \(b\) and the extension \(e\) at 08:49 UT. (3) The remnant ribbon brightenings \(a'\) and \(b'\) or feet of the post-flare loops observed with the horizontal telescope at 11:43 UT (filter bandpass of 0.5 Å). (4) Post-flare loops at 11:58 UT reaching 100 000 km observed with the coronagraph (filter bandpass of 3 Å).

4.3. THE FLARE OF JUNE 15 AT 08:15 UT

The flare of June 15 was observed with the horizontal telescope and large coronagraph in Wrocław (Figure 6) and in Debrecen/Gyula station. At 07:49 UT two regions of flare-like brightness were visible with a compact loop seen in emission connecting them. Many other small bright loops were also detectable in the western part of the region. With the large coronagraph, a large circularly shaped arch was observed before the flare, with material being ejected from one leg and flowing towards the other. By 08:07 UT this loop was fading. Beginning at 08:11 UT the large two-ribbon flare was observed and was followed until 08:50 UT. We observe two ribbons: one ribbon, (a), overlaid A and the other, (b), had a reversed U-shape over spot 40. The first manifestations of the formation of post-flare loops were loops lying between (a) and (b) named (I) and over (b) named (II) in Figure 6. The system II disappeared rapidly. The system I reached an altitude of 37 000 km at its maximum brightness (11:38 UT) and 100 000 km later at 15:31 UT (Figures 6). The flare and its loop system lasted more than seven hours, much longer than the other flares (Table I).
In summary, these large X12 flares consisted of several ribbons, but there were always the two main ribbons, one on the northern spot of positive magnetic polarity A and one on the southern group of sunspots of negative polarity, spanning a region of high magnetic shear (Section 3).

5. Observational Evidence of Rapid Evolution of the Magnetic Field

Under good seeing conditions, the Huairou longitudinal maps can be obtained every 10 min with good spatial resolution ($\sim 2^{"}$). For June 4 and 6 we can use such observations to demonstrate that rapid changes in the magnetic field may have triggered the large flares.

5.1. Magnetic Field on June 4

Examination of the longitudinal magnetograms in Figure 7 clearly shows the development of two positive polarities. The first one, $F1$, grew to the northwest of A, the second, $F2$, to the southwest (Figure 7). The longitudinal field intensities of $F1$ and $F2$ reached $\sim 160$ and $100$ G, respectively. The change of positive flux in this region is estimated to be $\sim 6 \times 10^{19}$ Mx during those two hours (Zhang et al., 1993). Because the region was located at E70, part of the effect of this new magnetic flux may be to increase the transverse field strength and thus also increase the magnetic shear. These positive polarities appeared at the time of the white-light flare (WLF), between 02:24 and 04:05 UT. The location of the two northern bright kernels of the WLF was close to these two positive polarities. It suggests that the presence of these new polarities may have triggered the flare starting at 03:37 UT.

5.2. Magnetic Field on June 6

A series of vector magnetograms in Figure 8 shows a rapid variation of the magnetic field during the flare starting at 00:54 UT while there was no evident evolution from 23:57 UT on June 5 to 00:50 UT on June 6 (see Zhang et al., 1993). We see

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Fig. 8. Huairou vector magnetograms on June 6 of a part of AR 6659 (field of view limited by a box in Figure 4(a)). (a) Longitudinal magnetograms before, during, and after the flare. F3 is a new polarity just appearing. Black structures mark the position of the WLF kernels. (b) Transverse components of the field (pixel unit= 4”). Note the rotation of the transverse field bars from nearly potential at 00:50 UT (continuous lines) to a nonpotential character after the flare time at 05:13 UT (dashed lines) in the region between the kernels (represented in the box which is magnified by a factor 2).
different changes along the neutral line between the position of the flare kernels (black dots in Figure 8) in the longitudinal magnetic maps between 00:50 and 02:34 UT. These occur primarily in three specific regions: the first at F3 where a positive polarity progressively appears as previously mentioned in Section 3, because it participated in the long-term evolution of the group; the other two are the parasitic opposite polarities, one on each side of the neutral line, visible only at 01:27 UT. These produce a shift of the neutral line in a westward direction at a speed of about 2–3 km s\(^{-1}\) and a change of flux of about \(6 \times 10^{19}\) Mx. This speed is much larger than the usual motion of magnetic structures (0.4 km s\(^{-1}\)). After the flare, by 02:34 UT, the longitudinal neutral line returned to its pre-flare position (except that F3 stays). There are different interpretations of this ephemeral phenomenon. New emerging flux could cause this change through emergence of positive polarity in the southwest part and negative polarity in the northeast. But in this case both new polarities have to emerge and disappear in one hour! This can also be interpreted by large blueshifts of the line profile due to ejection of material during the flares. An ejection with an upward velocity of \(\sim 8\) km s\(^{-1}\) could invert the sign of the magnetic field polarity and produce such an observed effect. While this last interpretation appears more credible, in any case, great care should be taken when inferring rapid magnetic changes during a flare.

The orientation of the transverse component of the magnetic field also changed during the flare interval. The largest measured rotations were about 30–40 deg in 30 min during the flare. These were located between the two kernels of the WLF (Figure 8). The transverse field was nearly potential at 00:50 UT, 4 min before the beginning of the flare, then the angle with the neutral line was decreasing through the flare time and afterwards. At 05:13 UT the transverse field was aligned along the neutral line as it was observed at Marshall between the flares, so the total rotation was approximately 90 deg (see the enlarged bars in the box of Figure 8). It should be noted that this rotation is a mixing of an increase of the magnetic shear and a change of the vertical field component due to the northern position of the active region.

Such variation of shear angle has been detected prior to the flare of June 11, 1991 by analyzing the rotation of H\(\alpha\) fibrils which are taken to be the tracers of the chromospheric magnetic field (Rausaria et al., 1993).

5.3. JUNE 9, 1991

For this flare, we have one magnetogram from Marshall about 10 hours after the flare and two magnetograms from Huairou 2 and 5 hours after the flare (Figure 9). These time intervals are too long to detect any fast evolution of the magnetic field. In order to see evolutionary changes that might have led to the June 9 flare, we can thus only refer to the sunspot observations (see Section 2), where we see the fragmentation, motions, and flux emergence that occurred near the flare site.
6. Discussion

The active region NOAA 6659 was complex, with its principal negative polarity surrounded by many positive polarity concentrations. The original main spots \( p1 \) (1 and A), were relatively stable during the region's passage across the disk (Figures 1 and 2), but inside the leader group there was an 'explosion' of sunspot groups (\( p2 \)), which was presumably governed by strong, divergent, subphotospheric flows. The study of proper motions showed that two of these new groups, \( p2 \) and \( f'2 \), moved in opposite directions. As they were close to the stable groups \( f1 \) and \( p1 \), respectively, such persistent stretching drifts induced and maintained large shear between stable and moving features, as shown in the vector magnetogram observations.

We showed that the six major flares observed in this region all occurred along the same site of high shear, between \( f1 \) and \( p2 \), had similar strength (X10/12 and white-light emission), and their ribbons had nearly the same location, indicating that the same magnetic structure was involved. On the other hand, in the other locations of shear between \( p1 \) and \( f'2 \) there were flares of lesser importance (see Table I), or just surges, in spite of the fact that the shear level was similar. The main difference between the two sites seems to be the field strengths (over 3000 G at \( f1/p2 \)) and field gradients, which were substantially larger at the \( f1/p2 \) site.

The next issue that needs to be addressed is what triggered the flares. There
is no indication in the data pointing towards the scenario that the flares were triggered by a global ideal instability, after, e.g., exceeding some limiting shear value (cf. Section 3), although this may be due to intrinsic limitations in the data. On the other hand, there is substantial evidence of magnetic changes occurring at the site of the flares. Besides the continuous stretching, we have also detected sunspot changes in white-light data occurring two hours before the flare of June 9. The Huairou magnetograms give indications of possible magnetic flux changes up to \(6 \times 10^{19}\) Mx from two hours to 30 min before the onset of two other flares (June 4 and 6). We have cautioned against a straightforward interpretation of these observed variations, showing that they could also be due to flows. However, in either case, the observations show that dynamic phenomena occurred before and during the flare. Also, just before the June 6 flare, the magnetic configuration was nearly potential in the flaring site; then, during the flare the transverse field turned to a nonpotential configuration which was reached five hours later.

Wang and Shi (1993) studied the association of flares with observed magnetic changes in an active region and concluded that it comes from a coupling of slow reconnection in the lower atmosphere (cancelling flux) with fast reconnection in the corona. In this study we have shown two types of photospheric processes that follow the time scale of Wang and Shi. During the slow process subphotospheric stream continuously drive the sunspots in two opposite directions leading to shear of the magnetic field lines along which energy can be stored in the corona. The fast process is due to new flux or fragmentation. It can also store some magnetic energy in the corona but its main effect is to increase the topological complexity of the region.

Several recent studies have shown that the magnetic topology of an active region is a determining parameter in its flare productivity (Mandrini et al., 1991, 1993; Démoïlin, Hénoux, and Mandrini, 1992; Démoïlin et al., 1993; Poletto, Gary, and Machado, 1993; van Driel et al., 1993). In a 3-D configuration, the magnetic field of active regions is separated by separatrices, surfaces that divide topologically distinct magnetic fluxes. When the magnetic configuration is deformed, either by motions or by flux emergence or submergence, current sheets can be created at the separatrices (Vekstein, Priest, and Amari, 1991, and references therein), where reconnection can lead to the release of the magnetic free energy stored there. Only through this topological model is one able to explain the simultaneous brightening of different flare loops and the presence of widely separated \(H\alpha\) brightenings located in widespread regions of different magnetic polarity. For the flares in AR 6659, the patterns of \(H\alpha\) kernels on the magnetic polarities, as well as the observation of ‘post-flare’ loop systems (see, e.g., Figures 5 and 6), are consistent with this topological scenario. If we look in particular at the June 15 flare observations, we notice the circular shape of the flaring region which, coupled with the shape delineated by the other kernels, definitely suggests the presence of two intersecting separatrices as described in the topological models (cf. references above).
Unfortunately, the construction of a topological model of this complex group encounters three main difficulties. First, the evolving small polarities must be carefully followed and the number of field configurations implies a complex topology from which the basic process needs to be extracted. Secondly, the ambiguity in the azimuth of the transverse field must be resolved in order to transform the magnetic field into heliographic coordinates and follow the magnetic evolution during the transit of the region across the solar disk. Finally, a nonlinear force-free field model is required because the observed magnetic shear is both strong and localized. These problems must be solved before a topological model can be tested quantitatively on such a complex flaring region.

In spite of these limitations, as well as some possible ambiguities in the interpretation of the magnetic field data, we can conclude that the unusual level of activity observed in AR 6659 was due to the combination of two effects, both driven by the highly dynamic changes that occurred through its disk transit. First, the observed breakup and motions of different polarity regions maintained a high shear level (continuous energy storage) in two rather extended activity sites. Second, rapid motions and changes in the magnetic sources led to a continuous evolution in the topological complexity of the region, which triggered the release of stored energy.

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