PREFLARE STATE *

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Abstract. Discussion on the preflare state held at the Ottawa Flares 22 Workshop focused on the interpretation of solar magnetograms and of \( \text{H} \alpha \) filament activity. Magnetograms from several observatories provided evidence of significant build up of electric currents in flaring regions. Images of X-ray emitting structures provided a clear example of magnetic relaxation in the course of a flare. Emerging and cancelling magnetic fields appear to be important for triggering flares and for the formation of filaments, which are associated with eruptive flares. Filaments may become unstable by the build up of electric current helicity. Examples of heliform eruptive filaments were presented at the Workshop. Theoretical models linking filaments and flares are briefly reviewed.

1. Introduction

The emphasis in the ‘Preflare Team’ was on the interpretation of magnetograms and of \( \text{H} \alpha \) filaments as indicators of the build-up of magnetic energy and a tendency to instability. There could be two scenarios to relate energy supply and energy release. In the ‘storage followed by release’ model, energy is stored more or less continuously but it is released suddenly and catastrophically. In the ‘driven’ model, the time profile of energy release closely follows that of the energy injection. The consensus at the workshop was that flares are due to a storage-and-release process. ‘Driven’ models might be adequate for activity in emerging flux regions.


It is frequently claimed that filaments have a close relationship with flares. Flares with filament eruptions are called ‘eruptive flares’. Physically, filaments are cool material supported in the hot corona on a sheared magnetic arcade or trapped in a floating magnetic flux rope. Such magnetic field configurations are more fundamental than the presence of cool material. Therefore, even in the absence of cool material, flares can still be eruptive. Any flare that involves topological changes from closed to open magnetic fields is called eruptive. In many cases, filaments are useful indicators of energy storage.

Flux emergence usually accompanies continuous chromospheric activity and, under certain circumstances, it may trigger a flare. Complex magnetic field configurations are most closely related with the production of flares, and active regions become complex in various ways, for example by shear motions, collision of sunspots, emerging flux, etc. In the following sections we will discuss these topics in more detail.

2. Magnetic Shear, Electric Currents, and Flares

Flares are believed to be powered by the magnetic energy stored in the non-potential component of magnetic fields. This non-potential component can be deduced from the difference between the observed vector magnetic field and the inferred potential field, which is calculated form the observed line-of-sight magnetic field. For an accurate comparison, the vector magnetograms must be well calibrated and have the 180°-ambiguity of the observed field azimuth removed. This non-potential component is also known as the source field (Hagyard, Low, and Tandberg-Hanssen, 1981), and it has been characterized by the shear angles of the vector magnetic field and their projections onto the photosphere (Hagyard et al., 1984; Hagyard, Venkatakrishnan, and Smith, 1990; Li, Chen, and Ai, 1999), by vertical currents (Moreton and Severny, 1968), and by the force-free factor $\alpha$ (Wang, 1993). Mapping of the non-potential component in 2-D is a necessary first step in specifying flare-associated changes.

2.1. Vector-Magnetographic Observations at Huairou

Wang (1993) presented time sequences of Huairou vector magnetograms with the ambiguity in observed field azimuth removed. His data showed a great enhancement in the non-potential field several hours before a 1M flare. Some decrease in the non-potential field was found during and after the flare.

In localized areas above sunspots, chromospheric magnetic fields with polarity opposite to that of the underlying photospheric field have been found (Chen et al., 1989; Wang and Shi, 1992; Li, Chen, and Ai, 1994). Wang found that the polarity reversals are not caused by emission in the sampled spectral line and not by a simple Doppler effect corrupting the Zeeman measurements. The polarity reversals were quite closely correlated with flare activity. Many examples of polarity reversal can be found in Huairou H$\beta$ magnetograms.
2.2. MAGNETIC OBSERVATIONS COMPARED WITH YOHKOH X-RAY DATA

Sakurai presented work that aims at identifying possible magnetic changes in the photosphere associated with coronal activity observed by the Yohkoh soft X-ray telescope. He used magnetic data from the vector magnetograph at Okayama and a new video vector magnetograph at Mitaka.

Sakurai et al. (1992) detected a clear example of relaxation of magnetic shear in the course of a flare. In that case, the Yohkoh soft X-ray images showed a coronal loop which had an S-shaped configuration before the flare. After the flare the loop relaxed to a simple magnetic configuration connecting the two polarities. Vector magnetograms revealed vertical electric currents before the flare. These currents disappeared after the flare.

Sakurai is attempting to detect magnetic changes associated with small-scale activity in coronal loops. An active region for which continuous magnetic and X-ray observations are available was studied. The X-ray light curve of the region showed several peaks that corresponded to brightenings in sheared coronal loops, and the Hα emission was enhanced at the footpoints of the brightened loops. A magnetic field change of about 40 G in the longitudinal component was detected at the footpoints. The region studied was 50° from the disk center, and the magnetic field change was interpreted as a change of field orientation, namely, an initially low-lying loop rose slightly during these brightening events. The magnetic change was rather gradual, and it is not clear whether this magnetic field change was the cause or the result of the X-ray brightenings.

2.3. SUNSPOT MOTIONS AND DEVELOPMENT OF MAGNETIC SHEAR

Gaizauskas presented a case study (Gaizauskas et al., 1994) of shear-related flare activity created by the sudden disruption of the f-polarity umbral component of a δ-spot. The δ-spot formed by the slow convergence of adjoining active regions inside a nest of sunspots. The convergence went on for 5 days without significant flare activity. Four days after the δ-spot formed; its f-umbra swelled by 30% in a 6-hr interval and displayed prominent internal brightenings. Penumbral matter extruded from the umbra to form an unusual tangential penumbral band. Gaizauskas, Harvey, and Proulx (1994) argue that these changes are part of a chain of processes initiated when the converging p- and f-umbrae in the δ-spot reach a critical separation estimated at 3200 km. The sequence ends with the splitting and flying apart of the f-umbra and with the eruption of a string of homologous flares, of which the strongest is classified as 1B/X1 (Figure 1).

Gaizauskas, Harvey, and Proulx further argue that the transverse component of the reconnected photospheric fields in the originally stable δ-spot becomes strong enough to block vertical transport of heat into the gap between the approaching sunspots. They hypothesize that blocked heat is diverted at a shallow sub-surface level into the colliding umbrae where it sets up a new regime of fluid flows. These new flows quench the downdrafts that constrain the flux tubes forming the f-umbra
Fig. 1. Close-up view of rapidly developing flare kernels on 28 May, 1978 in a δ-spot formed by colliding sunspot umbrae of opposite polarity belonging to adjoining active regions. Left panel: the time refers to the underlying half-tone; the contours mark the position of the same two spots 24 hr earlier to the same origin of coordinates. Perspective effects have been removed; all displacements are real proper motions. It is estimates that the f-umbra began to split into two major fragments ~5 hr earlier. Right panel: the same half-tone image as the one of the left forms the background. The time refers to the overlay of flare kernels which are extracted from a filtergram of a class X1 flare taken 4 min later at Hα + 1.0 Å and registered to the same set of coordinates. The brightest flare kernels in this display appear as white, the faintest as dark grey. The kernels coincide in time with the ‘toe’ of the impulsive rise in 10.7-cm flux. Digitally processed photographs from the Ottawa River Solar Observatory.

(Parker, 1979). The umbra then becomes dynamically unstable. The sudden change of motion at the polarity inversion inside the δ-spot might promote reconnection among the rapidly reconfiguring field lines. Because chromospheric ejecta and radio spectral bursts of Types II, III, IV, or V are all absent at the time of the 1B/X1 flare, this event can be called a ‘confined’ flare and might be explained by a current-interruption model. In that case, according to Gaizauskas, currents induced in the separator by the rapid sunspot motions could exceed the current-carrying capacity of the local plasma and so promote the growth of instabilities on the separator inside the δ-spot.

2.4. VECTOR-MAGNETOGRAPHIC OBSERVATIONS AT POTSDAM

With the Potsdam vector magnetograph (Staude, Hofmann, and Bachmann, 1991), Hofmann observed two active regions (NOAA 5680 and 5698, 1989 September) with moderate spatial resolution (2.5″ was the limit determined by seeing conditions) and temporal 0.5 s pixel⁻¹ resolution but a relatively high polarimetric sensitivity (<0.1%). Vertical electric currents were derived by using Ampère’s law.

There were about 45 flares during the disk passage of AR 5680. Ten of them had an X-ray importance ranging between C3.8 and X1.5. In three cases highly energetic γ-ray bursts were reported (Rieger, 1991). All the energetic flares occurred just at the location of a small spot of opposite polarity inside the leader polarity. Some of
the flares (especially those with $\gamma$-ray bursts) showed a circular ribbon surrounding the intrusion of opposite polarity and a dot-like ribbon in the center. These, too, may have been confined flares rather than eruptive ones.

During the period of energetic flaring (~4 days) the intrusion moved eastward at $\sim 6500$ km day$^{-1}$ relative to the leader field. In the flaring region there was no signature of shear in the photospheric field. It is possible that shear was spread widely over areas of weak field so that the transverse field component was lower than the sensitivity threshold of the magnetograph. Also, any vertical shear of the field would have been undetectable.

AR 5698 produced 25 C-class and 8 M- and X-class flares with the largest being the X9.8 of 29 September, 1989. It was one of the strongest proton events of the last cycle. Hofmann found two $\delta$-configurations there ($D1$ and $D2$ in Figure 2) with highly sheared field and strong currents. The two deltas were distinctly different in flare activity. All the energetic flares occurred in $D2$; none occurred in $D1$.

$H\alpha$ observations show that the fibrils in $D1$ did not connect the two spots but extended from them in different directions. Hofmann concludes that the spots are not magnetically connected to each other. The currents flow in different directions in the spots, as drawn in the current map. The map suggests to Hofmann that $D1$ was a result of spot collision between the leader and follower parts of two separate bipolar groups. Such deltas produce low flare activity (Zirin and Liggett, 1987; Gaizauskas, 1993).

Opposite to $D1$, the two large umbrae in $D2$ were connected by highly sheared penumbral and chromospheric fibrils indicating that electric currents flowed from one $\delta$-spot to the other. Such $\delta$-configurations produce large flares, especially if the shear is caused by opposite tangential motions of the two spots or if flux emerges. In the case of $D2$, strong growth of the follower (southern) polarity was observed and led to an intense energy build-up and flaring lasting over a long period.

3. Emerging/Cancelling Magnetic Fields and Flares

3.1. CANCELLING MAGNETIC FIELDS

Cancelling magnetic fields are defined by the disappearance of magnetic flux of both polarities at the boundaries between closely spaced magnetic features of opposite polarity. The association of flares and cancelling magnetic fields was first noted by Martin, Livi, and Wang (1985) and was discussed in relation to other pre-flare changes by Livi et al. (1989). The initial brightenings of flares straddle sites of cancelling magnetic fields but the flare emission then often spreads into other areas where there are no cancelling magnetic fields. According to Livi et al., no flares occur in the absence of cancelling magnetic fields.

Martin and Livi (1991) suggested a physical link between cancelling magnetic fields and eruptive flares. They propose that the filament magnetic field is a principal site of flare energy storage and that cancelling magnetic fields represent the direct transfer of magnetic flux, and therefore energy, from the photosphere into the
Fig. 2. *Top*: intensity-map and directions of the transverse field in AR 5698. The length of the line segments corresponds to the field strength in a nonlinear scale. *Middle*: map of longitudinal field. The two circles mark the two $\delta$-configurations $D_1$ and $D_2$. *Bottom*: vertical current density. The arrows mark the currents flowing in the $\delta$-configurations.
filament. According to Martin (1990), filament formation does not cease as long as cancelling magnetic fields are present. Even the eruption of the magnetic field and initiation of a flare in the upper part of a filament channel does not interrupt the continued formation of additional new filaments in the lower parts of the same channel.

3.2. Models of cancelling magnetic fields

Interpretations of disappearing magnetic fields (cancelling magnetic fields) published to date, are illustrated in (A) through (D) of Figure 3. The sketches show how magnetic flux might disappear by either upward or downward transport of magnetic flux through the atmosphere. The horizontal line represents the photosphere. The first four interpretations are: (A) simple submergence of an inverted U-shaped loop; (B) upward retraction of a U-shaped loop; (C) submergence immediately following magnetic reconnection above the photosphere and between separate loops; and (D) upward retraction immediately following magnetic reconnection below the photosphere and between separate loops.

There is little or no evidence for simple submergence (A) except possibly in the case of cancellation between strong sunspot magnetic fields as proposed by Gaizauskas (this report). Martin’s view was that simple submergence is inconsistent with observations because cancelling magnetic features are not connected by fibrils. Instead they are often separated by filaments. The presence of filaments in active-region magnetic fields is evidence against both simple submergence and submergence following magnetic reconnection as depicted in Figures 3(A) and 3(C) in or above the chromosphere. This is because the magnetic field within and beneath active region filaments lies predominately along and parallel to the long axis of the filament, as found by Foukal (1971), LeRoy (1988), and Martin (1990). Interpretations B and C might be similarly incompatible with these observations.

Martin et al. (1991) propose a 3-D model of filament channels (Figures 3(E–G)). The top view (F) of this configuration was already illustrated as a possibility by Rompolt and Bogdan (1986). (E)–(G) show a horizontal magnetic field in the channel (perpendicular to the page in E) and along the polarity inversion (parallel to the page in F and G). With increasing distance from the channel, the magnetic field becomes more vertical: upward on one side and downward on the other.

The arrows in (F) represent the motions of the magnetic field elements during filament formation. Magnetic reconnection might occur as opposite polarity fields migrate together or are brought together by convective motions. Martin proposed that the reconnection associated with filament formation occurs close to the photosphere. In the configuration shown in Figures 3(E–G), reconnection low in the solar atmosphere might result in nearly horizontal loops or threads joining and springing upward (dashed line) into the low corona to form the longer threads of the filament field.
Fig. 3. A, B, C, and D are possible 2-D representations of the disappearance of magnetic field from the photosphere (represented by the horizontal line). A, C, and D are after Zwaan (1985, 1987). B is suggested by Spruit, Title, and Van Ballegooijen (1987). E, F, and G are the end, top, and side views of Martin's 3-D interpretation of the magnetic field configuration associated with the disappearance of magnetic field in filament channels. G depicts magnetic field reconnection close to the photosphere and the consequent upward-moving field line.
3.3. FILAMENTS AND FLUX DISAPPEARANCE: HUAIROU OBSERVATIONS

Wang found that flux disappearance in small-scale cancelling magnetic features underneath part of a filament is the only obvious change in the filament environment in the course of filament activation. In Figure 4, the magnetic environment of a filament activation is shown by a Huairou vector magnetogram. A drawing of the filament is superposed. The line-of-sight component of the magnetic field is shown by isogauss contours with solid (dashed) lines for positive (negative) polarity; the transverse component is shown by short line segments whose length is proportional to the field strength. There are no arrowheads on the lines because of the $180^\circ$ ambiguity in the transverse field measurements. Beneath the central part of the filament, there are two cancelling magnetic features consisting of positive components from ephemeral regions and negative components from the old magnetic network fields in the north. After a flux loss of $2 \times 10^{20}$ Mx in the cancelling magnetic features, vigorous untwisting motions of the filament took place. By 23:00 UT, the untwisting part of the filament had disappeared. This may indicate that the small-scale cancelling magnetic features are sites where parts of magnetic lines of force which stabilize the filament are anchored. The pre-eruption disturbance of a filament seems to be characterized by strong untwisting, upward motions (Wang and Shi, 1993b). At the sites of flux cancellation the filament appeared broken and bifurcated, with brightening points appearing nearby.

3.4. EMERGING FLUX: HUAIROU OBSERVATIONS

According to Wang, emerging flux regions (EFRs) play a central role in almost all aspects of the pre-flare phase. The vigorous footpoint motions caused by fast flux emergence and the collision of an EFR with old flux often result in strong magnetic shear in the interface between newly emerged and old flux loops. Gradual reconnection in the lower atmosphere between EFRs and old flux has been identified with flux cancellation. When this type of reconnection takes place under the photosphere, an EFR may show up in only one polarity but with a bundle of very strong transverse field segments in between apparent and hidden polarities (Wang and Shi, 1993a). In many cases Wang observed an EFR and its driven flux cancellation before flares. It often continued during and after the flare. EFRs not only introduced new magnetic energy into the atmosphere, but also added further complexity to the magnetic configuration, which, in turn, increased the level of flare activity.

3.5. HEATING OF BRIGHT POINTS AND MICROFLEARES

At the opposite end of the scale from large two-ribbon eruptive flares are the tiny microflares, e.g., X-ray bright points. Webb et al. (1993) found that most bright points in the corona occur above cancelling magnetic features. The standard model for bright points as being due to emerging flux (Heyvaerts, Priest, and Rust, 1977), therefore, is inappropriate and a new cancelling flux model was proposed.
Fig. 4. Huairou magnetogram showing the magnetic environment of a filament activation. A drawing of the filament is superposed. The line-of-sight component of the magnetic field is shown by isogauss contours with solid (dashed) lines for positive (negative) polarity; the transverse component is shown by short, line segments with length proportional to the field strength and direction parallel to the field direction.

by Priest, Parnell, and Martin (1993). The model envisages a pre-interaction phase (Figure 5) in which the opposite polarity fragments are unconnected and approach one another. Then there is an interaction phase in which reconnection in the corona creates the bright point, sometimes together with jets of hot plasma and long hot loops. Finally, in a cancellation phase, reconnection in the photosphere creates the cancelling magnetic feature.
4. Helical Fields in Filaments

4.1. INJECTION OF HELICITY

Martin, Bilimoria, and Tracadas’ (1993) discovery that right-hand heliform filaments are most frequently found in the northern hemisphere while left-hand
filaments dominate in the south prompted Rust to re-examine existing literature on helicity in the Sun. In discussing the problem of coronal heating, Choudhuri (1986) assumed that rotational footpoint motions are completely random. The same assumption seems to be implicit in most magnetic field studies. But, suppose helicity accumulates in active regions. Then, even in a plasma with a small, but finite, resistivity, the current helicity,

\[ K = \int \mathbf{B} \cdot \text{rot}\mathbf{B} \, dv, \]

where \( \mathbf{B} \) is the magnetic field, is conserved. Thus, the plasma in a filament, for example, may relax to the lowest possible force-free energy state but it will preserve its helicity. And, unless the helicity of active regions is random on some scale, or there is a way to shed helicity from the Sun, the helicity will accumulate. Although it is usually assumed that the helicity in emerging fields is random, both the new filament observations and much older sunspot observations (Richardson, 1941; Ding, Hong, and Wang, 1987) show that this assumption is probably incorrect.

Helical structure is most obvious in eruptive prominences. Usually the whole body of the prominence participates, but sometimes individual strands twist, too. Many active region prominences also show obvious twisting motion and a helical shape. In quiescent prominences, the twisted structure is usually barely discernible, but some observations reveal it clearly (Rompolt, 1990). Doppler images, made by subtracting red- and blue-wing H\( \alpha \) filtergrams, show rotational motion in quiescent prominences on a very large scale (Liggett and Zirin, 1984).

4.2. SPECIFIC EXAMPLES

Many eruptions reveal increasing twist, or at least, show a more clearly twisted structure during eruption than before. For example, Figure 6 shows the Doppler shifts in an erupting filament photographed at Sacramento Peak on January 19, 1972. The eruption, which occurred in the southern hemisphere near the center of the disk, initiated a 1B flare. The event was unusual in that it occurred in an area where two active regions were colliding. The filament looked like a left-hand screw, as is predominate in the souther hemisphere. But Rust suggested that, since the dark filament matter would be supported by fields that are concave upward, the threads that make the filament appear heliform outline lines of force on the underside of the helix. This makes a right-hand screw look left-handed.

In the January 19 case, a right-hand helix would unwind with upward motion on the eastern flank. Thus, if the filament were unwinding, one would expect the eastern side (left in the figure) to be blue-shifted. Instead, Figure 6 shows a red-shift on the east, consistent with its identification as a right-hand helix that increases its twist upon eruption. At flare onset, the filament resembled a barber pole with alternating blue- and red-shifted stripes intertwined. This is the signature of an expanding helix. The explanation is consistent with observations of eruptive prominences where the diameter of the helix increases during the eruption and ejection from the Sun.
Fig. 6. An Hα Doppler subtraction showing eruption of a southern-hemisphere filament on January 19, 1972. The Dopplergram, obtained at flare onset, shows the characteristic ‘barber pole’ signature of an erupting, expanding helix. Black indicates rising material, white denotes falling material (Sacramento Peak Observatory photo).

Wang and Shi (1992) observed the Doppler shifts and photospheric magnetic context for an eruptive filament on July 8, 1989 in AR 5572. Starting at about 06:07 UT motion increased in the filament and at 08:04 UT there is a very strong ‘barber pole’ pattern, which Wang and Shi identify as untwisting rotation. However, Rust compared the images of 06:51 and 08:04 UT and suggested that the pitch increased during that interval from no detectable pitch to approximately three full turns. The filament expanded to become an open helix with twice its previous thickness. As it expanded, it erupted upward. Expansion, twisting and upward motion together make the blue-shifted parts most apparent. The contrast of the red-shifted parts is low because the downward rotating parts of the helix also participated in the general upward motion.

4.3. Evolution of Twists as Filaments Erupt

Although the pitch of the helices in eruptive events discussed here increased with time, this result may not hold for all events. Rompolt (1990) interprets the activity in a prominence photographed on January 29, 1957, as an untwisting. However, the prominence was not erupting, and one might say that the twist moved laterally.
along the prominence, all the while conserving the helicity. From one end to the other, Rompolt's prominence appears to twist through an angle of about $180^\circ$. Rompolt has offered several examples of erupting prominences which, he writes, are untwisting. He may be correct in this, and in each case, he is careful to point out that a large-scale, twisted structure was transformed into a series of distinct loops (not post-flare loops). It may be possible to maintain that the loops were really fragments of an exploded helix.

If the pitch of the helical fields in a prominence increases or remains the same during eruption, it may mean that when the total twist of the field exceeds a little over one turn, or about $2.5\pi$, according to Vršnak, Ruždjak, and Rompolt (1991) and Hood (1991), the filament becomes unstable, and the twist is transferred into larger and larger structures. Rust suggested that helicity could accumulate in a filament through flux emergence. Thus, as each flux loop emerges and coalesces with a filament, any twist in it would add to the twist in the filament until the net twist exceeded $2.5\pi$ and it erupted. Perhaps the observed association of 'flux cancellation events' and filament activation is evidence of this process.

If we grant there are twisted horizontal fields in filaments and that these fields become unstable and produce eruptive flares, how then does the twist increase? To gain a general understanding consistent with the observations and that does not rely on shearing motion along the filament channel, we refer the reader the general theoretical arguments of Wang (1992), who emphasized the many ways to develop magnetic shear. He shows that shearing motion, flux emergence, flux cancellation or submergence, collisions and other sunspot motions can all produce magnetic shear. Rust (1994) proposed that, because of the hemispherical preferences in helicity, all of these processes would act in a way that accumulates twist in filaments.

5. Theory of Pre-Flare State

5.1. Conditions for Eruptive Flare Occurrence

Priest (1992) pointed out that, to describe pre-flare phenomena theoretically, one just needs to solve the MHD equations for a slow evolution through a series of equilibria and wait for the onset of a dynamic eruption. It would not occur at a pitchfork bifurcation when the state becomes linearly unstable with a nearby new stable equilibrium, but it would occur at either a subcritical bifurcation or a nonequilibrium or catastrophe state (Priest, 1992). However, so far no numerical experiments have given a convincing demonstration of such an onset.

A new ‘catastrophe model for solar flares’ by Priest and Forbes (1990) is, however, able to produce an eruption of the kind required. In the model the inward motion of flux from the sides builds up a magnetic arcade containing an island where a prominence forms. As the flux is built up, the prominence slowly rises through a series of equilibria until eventually they cease to exist. An eruption of the prominence and arcade then gives reconnection in a current sheet below the
prominence. The model has been developed further and demonstrated numerically by Forbes (1991) and Forbes, Priest, and Isenberg (1994).

5.2. BALD PATCH INVERSION LINES

Titov, Priest, and Démoulin (1993) have considered the criteria for the occurrence in 3-D fields of regions of the polarity inversion line where the overlying magnetic polarity is inverse, so that the overlying field is oppositely directed from what one would expect from a simple magnetic arcade. Such regions they called 'bald patches'. For example, they considered the field with a contorted inversion line (Figure 7) due to four sources that are either potential or force-free and found how the existence and extent of the bald patch changed with the locations of the sources. In particular, they found it is much easier to create bald patches for force-free fields of high twist – such patches may be important both for prominence formation
since they create a dip to support plasma) and for flares (because the field is more likely to become unstable).

Priest stressed that shear and complexity are both important for flare occurrence—shear because it gives storage of energy in excess of potential, and complexity because it allows the release of that energy (Priest, 1992).

6. Concluding Remarks

Based on the discussions in the Workshop it is apparent that studies of the pre-flare state have progressed considerably in the past few years. X-ray observations by the Yohkoh satellite, magnetographic observations, radio observations, and theoretical studies all contributed to this progress. Soft X-ray images have literally revolutionized solar physics, and similar X-ray imaging observations in the future are highly desirable. The importance of radio observations with respect to pre-flare activity was stressed by Enome and Urbarz. Classical Hα observations still give useful and valuable information. What is perhaps most needed are more quantitative results from the vector magnetographs. Consistent and proper calibrations of magnetographs are crucial in carrying out quantitative analyses of pre-flare energy build-up. Campaigns aiming at cross-calibrating magnetographs have been made within the U.S.A., and such efforts should be pursued further by involving more magnetographic stations worldwide.

References


