Magnetic field, helicity and the 2000 July 14 flare in solar active region 9077

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ABSTRACT
In this paper we analyse the non-potential magnetic field and the relationship with current (helicity) in the active region NOAA 9077 in 2000 July, using photospheric vector magnetograms obtained at different solar observatories and also coronal extreme-ultraviolet 171-Å images from the TRACE satellite.

We note that the shear and squeeze of magnetic field are two important indices for some flare-producing regions and can be confirmed by a sequence of photospheric vector magnetograms and EUV 171-Å features in the solar active region NOAA 9077. Evidence on the release of magnetic field near the photospheric magnetic neutral line is provided by the change of magnetic shear, electric current and current helicity in the lower solar atmosphere. It is found that the ‘Bastille Day’ 3B/5.7X flare on 2000 July 14 was triggered by the interaction of the different magnetic loop systems, which is relevant to the ejection of helical magnetic field from the lower solar atmosphere. The eruption of the large-scale coronal magnetic field occurs later than the decay of the highly sheared photospheric magnetic field and also current in the active region.

Key words: Sun: activity – Sun: flares – Sun: magnetic fields.

1 INTRODUCTION
An important topic in the study of the solar active regions is the relationship between the configuration of the magnetic field and solar activity, such as solar flares. It is known that solar flares are normally associated with abnormal magnetic configurations relative to the Hale–Nicholson law, especially in the δ-magnetic regions in which umbras of opposite magnetic polarity are close together (e.g. Zirin & Liggett 1987). The formation of such a magnetic configuration normally is caused by an amount of newly emerging flux with opposite polarity relative to the existing magnetic field. The δ-magnetic configuration normally consists of an intense electric current system in the photosphere of active regions (e.g. Zhang 1995). This means that the magnetic field in these active regions departs significantly from the potential field. The non-potentiality of the magnetic field with photospheric electric current in the solar active regions has been analysed by several solar groups (e.g. Krall et al. 1982; Canfield et al. 1993; Wang, Xu & Zhang 1994b). The large-scale electric current probably plays an important role in the energy release in solar flares (Melrose 1997). Thus analysis of the evolution of the electric current (the magnetic chirality) in the flare-producing regions becomes an interesting topic. The chirality (or handedness) of the magnetic field can also be inferred via the force-free factor of the magnetic field in the active regions (Pevtsov, Canfield & Metcalf 1994), even if the distribution of the photospheric electric current in the active regions is more complex (Zhang 1997, 2001a). The evolution of the electric current in active regions can be inferred from photospheric vector magnetograms (e.g. Wang et al. 1994b). Information on the change of magnetic helicity can also be inferred from the photospheric vector magnetic field (Pevtsov et al. 1994) and the morphological evolution of the coronal configurations (Priest 1999). The formation of the current helicity density with the emergence of magnetic flux in the photosphere and its possible transport into the solar corona were discussed by Zhang (2001b). It was found that the formation of the large-scale helical magnetic field in the corona occurs later than the large-scale photospheric non-potential (or twisted) magnetic field, which was accompanied by reconnection of the magnetic field inferred from a series of vector magnetograms and corresponding soft X-ray images. This has provided a candidate for the formation of the highly sheared magnetic field in the photosphere and the relationship with the electric current above the photosphere. Although the formation of helical magnetic field in the corona above the active regions has been proposed by some authors (e.g. Low 1992; van Ballegooijen 1999), finding real evidence of the possible transport of helical magnetic lines of force from the subatmosphere in active regions still is a basic problem, because it concerns solar eruptive phenomena, such as flares, coronal mass ejections, etc. Moreover, the analysis of the sample active regions is probably useful in understanding basic information on the non-potential magnetic field in active regions.

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The 3B/5.7X flare on 2000 July 14 is a well-known ‘Bastille Day’ one with intense coronal mass ejection (CME). The influence of this flare is seen not only in the fine observational results by the TRACE and SOHO satellites, but also in the significant solar–terrestrial effects in solar cycle 23, etc. (e.g. Bothmer 2001, and private communication). This flare formed in active region NOAA 9077 and also has a obvious relationship with the evolution of the photospheric vector magnetic field discussed by some authors (e.g. Liu & Zhang 2001) and some rapid changes of the field during the period of the flare on 2000 July 14 (Kosovichev & Zharkova 2001). The analysis of the magnetic field in active region NOAA 9077 is probably the key to understanding the trigger process of the ‘Bastille Day’ flare.

In this paper, we will analyse the formation and release of the non-potentiality of the magnetic field and current (helicity) in the solar \( \delta \)-active region NOAA 9077 in 2000 July. In the following sections we describe how we infer the photospheric current helicity parameter from photospheric vector magnetograms (in Section 2), and the relationship with configurations of TRACE 171-Å images for analysing the possible spatial configuration of the magnetic field in active region NOAA 9077 (in Section 3). We also discuss a possible model of the current helicity in solar active regions (in Section 4) and present some results (in Section 5).

2 CONFIGURATION OF THE VECTOR MAGNETIC FIELD

2.1 Observations of the photospheric vector magnetic field

To analyse the basic magnetic handedness of solar active regions, we used vector magnetograms from the Video Vector Magnetograph at the Huairou Solar Observing Station of National Astronomical Observatories of China. The working line of the Huairou Vector Magnetograph is FeI \( \lambda 5324.19 \) Å for the measurement of the photospheric vector magnetic field. This line is a normal triplet in the magnetic field and the Lande factor \( g = 1.5 \); the excitation potential of the low-energy level of this line is 3.197 eV. The transverse and longitudinal magnetograms for the Huairou Vector Magnetograph are normally observed at 0.0 and \(-0.075 \) Å from the line centre respectively, even if the observational wavelength of the filter can be shifted at different positions of the line. It is normally possible to get high spatial resolution magnetograms via the CCD camera in good seeing conditions at Huairou Solar Observing Station (Zhang 2000). After smoothing over 2 \( \times \) 3 pixels, the spatial resolution of the vector magnetograms is about \( 2 \times 2 \) arcsec\(^2\). The vector magnetograms can also be observed with the Haleakala Stokes Polarimeter at Mees Solar Observatory and with the Solar Flare Telescope at the National Astronomical Observatory of Japan. The instrument of the Haleakala Stokes Polarimeter normally has a 6-arcsec circular aperture with Fe I \( \lambda 6301.5 \) Å (Lande factor \( g = 1.667 \)) and Fe I \( \lambda 6302.5 \) Å (Lande factor \( g = 2.5 \)) lines, and scans the solar image to build up a vector magnetogram (Ronan, Mickey & Orrall 1987). The Solar Flare Telescope is used with a birefringent filter and the transmission peak of the filter is set at the blue wing of the Fe I \( \lambda 6302.5 \) Å line (Sakurai et al. 1992).

2.2 Configuration of the vector magnetic field and chirality

Fig. 1 shows a longitudinal magnetogram overlaid on the white-light image observed by the TRACE satellite on 2000 July 14. It is found that the magnetic poles of opposite polarity close together in the middle of the active region NOAA 9077 to form the \( \delta \)-magnetic configuration, which is marked by a square in Fig. 1. The evolution of the magnetic features and the relationship with the 2000 July 14 flare have been analysed by Liu & Zhang (2001) in detail.

For photospheric vector magnetograms we resolved the 180° azimuthal ambiguity of the transverse magnetic field following Wang et al. (1994b). Fig. 2 shows a series of daily vector magnetograms obtained at the Huairou Solar Observing Station on 2000 July 12–15 in the heliographic plane. The prospective effect of these vector magnetograms has been removed. We find that in this \( \delta \)-active region the field changes significantly. The magnetic main pole N of positive polarity is separated gradually into two parts, \( N_1 \) and \( N_2 \), and the shear of the transverse field forms near the magnetic neutral line between the magnetic main poles \( N_1, N_2 \) and

Figure 1. The white-light image in the active region NOAA 9077 at 10:09:33 UT on 2000 July 14 observed by the TRACE satellite, is overlaid with the longitudinal magnetogram observed at 09:42 UT. The contours indicate the longitudinal magnetic field distribution, \( \pm 50, 200, 500, 1000, 1800, 3000 \) G.
$S_{21}, S_{22}$ of opposite polarity in the active region on 2000 July 12 and 13. We also note that the magnetic poles $S_{21}$ and $S_{22}$ separate away and magnetic pole $S_{22}$ moves toward the northern direction and squeezes the magnetic field of positive polarity between $N_1$ and $N_2$. These findings provide basic information on the evolution of the photospheric footpoints of the magnetic field bundles, i.e. quantities of magnetic flux with opposite polarity emerge, and magnetic features move into the middle of this active region to form a highly sheared magnetic configuration. It is also found that on about July 15 this active region gradually became a slack one and the flux of the magnetic pole $S_{22}$ decreased significantly.

The magnetic lines of force are normally anchored at the photosphere, where the magnetic field normally departs from a force-free field. The electric current in the active region can be separated into two parts by the formula (Zhang 2001a)

$$J = \frac{B}{\mu_0} \nabla \times b + \frac{1}{\mu_0} (\nabla B) \times b,$$

where $B = B b$ and $b$ is the unit vector along the direction of magnetic field. It is found that the electric current in solar active regions is related to the properties of chirality and gradient of the magnetic field. The first term in equation (1) denotes the twist of unit magnetic lines of force and intensity of the field. It is found that part of them represents the force-free field. The second term in equation (1) denotes the heterogeneity and orientation of the magnetic field, which represent the current and the shear of the vector magnetic field. It can also be seen that the current in the second term in equation (1) is perpendicular to the magnetic field, i.e. it contains the current of the non-force-free field and reflects the interaction of different magnetic lines of force or with extra forces, even if this part of the current can be partly cancelled by the first term in equation (1). As one analyses both parts of the electric current in the active region and their evolution, one can understand the possible contribution of both components of the current to the triggering of the powerful flare on 2000 July 14. In Fig. 3, we show the evolution of the photospheric vertical current corresponding to the vector magnetograms in Fig. 2 in active region NOAA 9077 in the heliographic plane. Fig. 3(a) shows the vertical current inferred from the first term of equation (1). It reflects the twist of large-scale transverse magnetic field in the active region. This large-scale electric current flows downward and is broken gradually near the magnetic neutral line between magnetic poles $N$ and $S_{21}, S_{22}$ of opposite polarity in the period July 12–14. Fig. 3(b) shows the vertical current inferred from the second term of equation (1). In contrast with Fig. 3(a), we do not find large-scale structures of shear current formed in the active region.

Fig. 4(a) shows the distribution of the photospheric current helicity parameter $B_y (\nabla \times B)_\parallel$ in the active region NOAA 9077 in

\begin{figure}[h]
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\includegraphics[width=0.8\textwidth]{figure2.png}
\caption{A series of photospheric vector magnetograms with the 180° ambiguity of the transverse magnetic field resolved in active region NOAA 9077 on 2000 July 12–15 in the heliographic plane. The contours indicate the longitudinal magnetic field distribution, $\pm 50, 200, 500, 1000, 1800, 3000$ G. The arrows mark the transverse field. The size of the magnetograms is $3.0 \times 3.0$ arcmin$^2$. North is at the top; west is at the right.}
\end{figure}
2000 July inferred from the vector magnetograms in Fig. 2. The photospheric current helicity density is calculated by the formula

\[ h_{\text{obs}} = B_{\|} \cdot (\nabla \times B)_{\|} = B_z \left( \frac{\partial B_x}{\partial y} - \frac{\partial B_y}{\partial x} \right). \]  

(2)

It is found that the mean helicity in the active region in the heliographic plane has negative sign. The mean value of the current helicity density reached a maximum on July 13 (Fig. 4b). This provides information on the transport of current helicity from the subatmosphere with magnetic shear and squeeze in the active region. We also note that the amplitude of the current helicity decreased significantly on July 14. This is consistent with the evolutionary process of the photospheric vector magnetic field in the period of July 12–15.

Fig. 5 shows the photospheric vector magnetograms with the 180° ambiguity of the transverse magnetic field resolved in active region NOAA 9077 on 2000 July 14, obtained by the Haleakala Stokes Polarimeter at Mees Solar Observatory, by the Solar Flare Telescope at the National Astronomical Observatory of Japan, and by the Video Vector Magnetograph at Huairou, and also the current helicity parameter \( B_{\|} \cdot (\nabla \times B)_{\|} \) inferred from the corresponding vector magnetograms in the image plane. Because the active region was just located near the middle of the solar disc on July 14, the projection effect of the magnetic field is not significant. Evidence of this can be found in the distribution of the current helicity parameter \( B_{\|} \cdot (\nabla \times B)_{\|} \) calculated by the Huairou vector magnetogram in the image and heliographic planes on July 14 in Figs 4(a) and 5(b). It is found that the distributions of the photospheric current helicity density obtained by different magnetographs show the same tendency in the image plane, while differences can also be found. As an example, it is found that the distributions of current helicity near N1 of these vector magnetograms on July 14 in Fig. 5 show slightly different patterns. A comparison between the vector magnetograms and the corresponding current helicity obtained at Huairou and the Mees Solar Observatory was made by Bao et al. (2000), who found that the slight difference in the transverse magnetograms is probably caused by magneto-optical effects of the spectral lines. Bao et al. (2000) and Zhang (2000) found that the Huairou transverse magnetic field has a mean error angle of about 12° in the transverse magnetograms obtained at the Fe I λ5324.19-Å line centre. We note that the noise levels of the vector
magnetograms (especially the different components of transverse field in these vector magnetograms) and the resolution of the 180° ambiguity of the transverse field obtained at these observatories are different. These probably are additional reasons for the difference in the current helicity parameter $B_{\parallel} \cdot (\nabla \times B)$ maps obtained at different observatories. Such influences can be confirmed near the magnetic neutral line in the active region, where the magnetic field is almost perpendicular to the line of sight and the magneto-optical effects on the calculation of current helicity are negligible. The time difference for these vector magnetograms obtained at different observatories is also a possible candidate. Even if a difference in the determination of the photospheric current helicity density exists, one can also find that the mean helicity in the active region retains the negative sign implied by the vector magnetograms observed at different observatories, which is consistent with Seehafer’s rule of current helicity (Seehafer 1990). The similarity on the distribution of the photospheric current helicity density reflects the basic information on the chirality of magnetic field in active regions (Bao et al. 2000; Zhang 2000). Moreover, comparison of the vector magnetograms obtained at different observatories is a requirement for understanding the basic properties of the solar magnetic field. This problem will be discussed in a future paper.

3 THE 3B/5.7X FLARE ON JULY 14 AND MAGNETIC FIELD

3.1 Change of the magnetic field in the pre-flare

The Transition Region And Coronal Explorer, TRACE (described by Handy et al. 1999), offers an unprecedented opportunity to observe the solar corona and the chromospheric–coronal transition region. Fig. 6 shows the TRACE 171-Å (Fe IX/X) images of the active region NOAA 9077 on 2000 July 14. It is found that the change of the 171-Å morphological configuration occurred above the magnetic neutral line between magnetic main poles $N_1, N_2$ and $S_1, S_2$ in the period 08:43:06 to 09:22:16 UT before the eruption of the dark filament at 10:11:09 UT. As it is believed that the distribution of the 171-Å features reflects information on the magnetic lines of force, it is easy to infer the possible evolution of the magnetic field above the photosphere in the active region. The TRACE 171-Å filament feature f was located almost along the magnetic neutral line between the magnetic main poles $N_1, N_2$ and $S_1, S_2$ of opposite polarity, and changed with time near the magnetic neutral line in the active region. It probably reflects the change of magnetic field above the photosphere, i.e. reconnection of the magnetic field occurs. This change of magnetic field just
Figure 4. (a) The current helicity parameter $B_\| \cdot (\nabla \times B)_\| \cdot$ in the active region inferred from the vector magnetogram of Fig. 2. The contours indicate the distribution of the current helicity parameter $B_\| \cdot (\nabla \times B)_\| \cdot \leq 0.1, 0.4, 1.0, 2.0, 3.2, 6.0$ (units of $10^{-2} \text{ G}^2 \text{ M}^{-1}$). The arrows mark the transverse field. The size of the magnetograms is $3.0 \times 3.0 \text{ arcmin}^2$. North is at the top, west is at the right. (b) The corresponding amplitude of the mean current $B_\| \cdot (\nabla \times B)_\| \cdot$ with error bars (units of $10^{-4} \text{ G}^2 \text{ M}^{-1}$).
Figure 5. Left-hand panels: the photospheric vector magnetograms with the 180° ambiguity of the transverse magnetic field resolved in active region NOAA 9077 on 2000 July 14, obtained by the Solar Flare Telescope at the National Astronomical Observatory of Japan (a), by the Video Vector Magnetograph at Huairou Solar Observing Station (b), and by the Haleakala Stokes Polarimeter at Mees Solar Observatory (c). The contours indicate the longitudinal magnetic field distribution, ±50, 200, 500, 1000, 1800, 3000 G. Right-hand panels: the corresponding photospheric current helicity parameter $B_i \cdot (\mathbf{V} \times \mathbf{B})$ in the active region inferred from the vector magnetogram. The contours indicate the distribution of the current helicity parameter $B_i \cdot (\mathbf{V} \times \mathbf{B})$, ±0.1, 0.4, 1.0, 2.0, 3.2, 6.0 (units of $10^{-3} \, G^2 \, M^{-1}$). The arrows mark the transverse field. North is at the top; west is at the right.
occurred where the highly sheared transverse field formed on July 12 and 13 in Fig. 3. It is found that at 09:22:16 UT a significant change of the filament feature in the pre-flare connects with emerging flux near the magnetic neutral line in the active region. By comparing the \textit{TRACE} 171-Å image in Fig. 6 with vector magnetograms, it is found that at about 10:11 UT on July 14 the dark filament erupted near the magnetic neutral line in the active region to trigger the 3B/5.7X flare. Fig. 7 shows a soft X-ray image at 04:35 UT on July 14 in the active region NOAA 9077 obtained by the \textit{YOHKOH} satellite. Owing to the loss of spatial resolution in the soft X-ray image which cannot be adjusted well, only a rough relationship is visible between the soft X-rays loops and the photospheric vector magnetic field. It is found that the enhancement of the soft X-rays was almost along the photospheric magnetic neutral line in the active region. This also means that the local reconnection of the magnetic field near the magnetic neutral line triggered the instability of the large-scale magnetic field for the powerful flare. This is consistent with the results obtained by Zhang et al. (2000). From the \textit{TRACE} 171-Å image in Fig. 6, it is found that the extreme-ultraviolet filamentary feature between the magnetic main poles N1 and S2, S22 of opposite polarity ran almost along the magnetic neutral line and did not twist significantly.

3.2 Change of the electric current and powerful flare

The distribution of the photospheric vector magnetic field provides a basic key for understanding the evolution and reconnection of magnetic field in the solar atmosphere. From the daily vector magnetograms, it is found that the shear of the transverse magnetic

\begin{figure}[h]
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\caption{A series of extreme-ultraviolet 171-Å images of the active region NOAA 9077 on 2000 July 14 at the pre-flare (left), and the corresponding photospheric vector magnetograms with the 180° ambiguity of the transverse magnetic field resolved (right). f marks the dark filament, the configuration of which changes with time. The contours indicate the longitudinal magnetic field distribution, ±50, 200, 500, 1000, 1800, 3000 G. The arrows mark the transverse field. The size of the images is $2.5 \times 2.1$ arcmin$^2$. North is at the top; west is at the right.}
\end{figure}
field is connected with the shear motion of the photospheric magnetic poles which are the footpoints of the magnetic lines of force in the photosphere. The evolution of magnetic bundles above the photosphere can be confirmed by the photospheric vector magnetogram and the extreme-ultraviolet images.

The relationship between the change of the vector magnetic field and flares has been analysed by Chen et al. (1989, 1994), Wang et al. (1994a) and Zhang et al. (1994). Fig. 8 shows the distribution of the vertical current inferred from both parts of the electric current in equation (1) in the active region. It is seen that the decrease of the electric current relative to the magnetic shear and gradient [the second term in equation (1)] occurs near the magnetic neutral line between the magnetic main poles N1, N2 and S2 of opposite polarity. This change is consistent with that in the TRACE 171-Å images. This provides evidence of the change of magnetic field in the lower solar atmosphere before the 3B/5.7X flare in the active region. In contrast, it is found that the current inferred from the first term in equation (1) did not show a significant change with time.

As it is believed that the large-scale magnetic field bridges over the photospheric magnetic neutral line aligned with the TRACE 171-Å features to connect the photospheric magnetic poles N1, N2 and S1, S2 of opposite polarity in the active region NOAA 9077 at the post-flare phase, the possible model of the large-scale magnetic field above the photosphere can be extrapolated by the photospheric magnetic field with linear force-free field shown in Fig. 9, where the force-free factor \( \alpha = -0.15 \) (units of \( 10^{-4} \) km). It is almost consistent with the distribution of 171-Å features of the post-flare loops. This means that, after a powerful flare, the magnetic field in the active region probably does not completely become a potential one, and this is consistent with the residual current helicity after the 3B/5.7X flare, such as on July 15.

Fig. 10 shows a possible trigger process for the eruption of the dark filament in active region NOAA 9077 in the pre-flare. A sequence of reconstructions of the magnetic field occurred near the magnetic neutral line above the photosphere in the active region. The reconnected magnetic lines of force erupted up and pushed the large-scale magnetic field that connects the magnetic poles N1, N2 and S1, S2 of opposite polarity in the active region. A possible process for the reconnection of the magnetic field in this active region is as follows. (i) The initial reconnection of the magnetic field occurred in the local area near the magnetic neutral line (Fig. 10b), which probably was triggered by the emergence of new magnetic flux of opposite polarity (Fig. 10a). (ii) The local reconnection of magnetic lines of force caused instability of the magnetic field and the continuous reconnection of the field in the active region. The reconnection was also accompanied by activity of the dark filament (Fig. 10c). (iii) The reconnection of the large-scale magnetic field occurred in the higher atmosphere and the dark filament erupted from the active region, which was accompanied by escape of magnetic (current) helicity from the solar atmosphere. Similar models of the magnetic field in the solar flare-producing regions have been proposed by other authors (e.g. Antiochos & DeVore 1999; van Ballegooijen 1999; Zhang et al. 2000). The basic information on the current helicity with the reconnection of the magnetic field in the active region was discussed by (Zhang 2001b).

4 DISCUSSION

From the spatial configuration of the magnetic field in the active regions inferred from the photospheric vector magnetograms and the morphological configuration in active region NOAA 9077 in the lower solar atmosphere, a possible evolution of the magnetic field and the relationship with the solar flare can be deduced. The analysis of the photospheric vector magnetic field and electric current also provides information on the non-potentiality of the energy in the picture of the magnetic field or electric current. Fig. 11 shows a possible basic evolution process of the magnetic lines of force in the active region NOAA 9077. A growing magnetic dipole formed in the active region, and the positive polarity N of this dipole separated into two parts N1 and N2. The magnetic main pole N2 moved eastward, and S2 separated from S2 and squeezed in between magnetic poles N1 and N2 of opposite polarity. A highly sheared transverse magnetic field occurred near the magnetic neutral line between the magnetic main poles N1, N2 and S21, S22 of opposite polarity. This non-potential magnetic field was also connected with the local high intense current or current helicity density in the active region. The reconnection of the large-scale magnetic field formed between the magnetic main poles N1, N2 and S21, S22 of opposite polarity.

Although the current helicity is similar to the magnetic helicity which is not a local quantity (because the current helicity is determined by the magnetic field in all space), the local change of
current helicity density can be provided by the local magnetic field. The change of current helicity density in the photosphere is important and relates to solar flares in the active regions (Bao et al. 1999). The evolution of current helicity inferred by the force-free factor was discussed by Pevtsov et al. (1994), who found that the characteristic decay time of the photospheric current helicity elements is about 27 h. There are probably two basic processes for the change of current helicity, if one distinguishes the morphological evolution of the current helicity relative to the reconnection of magnetic field in the solar atmosphere. One is the small-scale change of current helicity density in the solar atmosphere with the reconnection of the magnetic field in the solar atmosphere. The change of helicity density does not connect with the sudden variation of large-scale topology in the chromosphere and corona, even if the topological change of the active regions occurs gradually. Another basic process probably is the large-scale process in the solar corona and chromosphere which is connected with the violent change of solar morphology of active regions in the solar atmosphere. This process is normally associated with the reconnection of large-scale coronal magnetic field above the photosphere. The magnetic flux of opposite polarity emerges from the subatmosphere and reconnects in the lower atmosphere near the magnetic neutral line to form the non-potential magnetic field. This probably causes instability of the large-scale magnetic field in the solar corona to trigger solar flares and CMEs. The magnetic lines of force in the solar atmosphere probably tend to a lower energy state as the twisted (or partly twisted) magnetic field is ejected out from the solar atmosphere. The corresponding characteristic decay time of

**Figure 8.** The vertical electric current in active region NOAA 9077 on 2000 July 14, inferred from the photospheric vector magnetograms in Fig. 6: electric current corresponding to the first term of equation (1) (left) and the second term of equation (1) (right). The solid (dashed) contours correspond to the upward (downward) flows of vertical current of $\pm 0.002, 0.008, 0.02, 0.04, 0.075, 0.12$ A m$^{-2}$. The size of the current maps is $2.5 \times 2.1$ arcmin$^2$. North is at the top; west is at the right.
the magnetic (current) helicity density in the corona is about (or more than) a few hours, if the topological change of the coronal configuration reflects that of the magnetic field and also the current helicity density in the corona. By comparing the evolution of the photospheric current helicity parameter $B^\parallel (\nabla \times B)_\parallel$ in the active region NOAA 9077 on 2000 July in Fig. 4, it is found that significant decay of the photospheric current helicity density occurred in the period July 13–14 before the powerful 3B/5.7X flare on 2000 July 14. This is consistent with the response of the large-scale magnetic field in the high atmosphere being later than the photospheric one owing to the transfer process of magnetic field in the active regions (Zhang 2001b).

A possible model of the current helicity in solar active regions is therefore as follows. The emergence of abnormal magnetic flux in the active regions causes highly sheared transverse magnetic field near the magnetic neutral line and instability of the magnetic field above the photosphere, which represents the shear and squeeze motion of the photospheric footpoints of these magnetic lines of force. The current helicity density is also transported from the subatmosphere with magnetic flux bundles which probably twist and/or link each other. Part of the current helicity density with non-potential magnetic field escapes from the lower solar atmosphere into the corona and the distribution of current helicity density near the lower atmosphere assumes a simple form. This means that a quantity of free magnetic energy has been stored above the photosphere in the active region before the powerful flare. The reconnection of the magnetic field occurs near the magnetic neutral line to trigger large-scale reconnection of the magnetic field in the active regions. Even though a powerful flare in the active region, the magnetic field above the photosphere probably does not release all of the force-free energy (and helicity) to become a potential one.

5 CONCLUSIONS

The main results of this analysis are as follows.

By comparing vector magnetograms, TRACE 171-Å and white light images in the δ-active region NOAA 9077, a basic form of the configuration of the current helicity in the active regions can be inferred. The shear motion and squeeze of the footpoints of magnetic bundles cause the apparent non-potential photospheric magnetic field in active regions. It is found that the eruption of the coronal magnetic field in the powerful 3B/5.7X flare on 2000 July 14 was delayed with respect to the decay of photospheric electric current and current helicity. Evidence for the change of magnetic field and corresponding shear current can be found in the photospheric vector magnetograms and TRACE 171-Å images.
during the powerful pre-flare. This provides information that the 3B/5.7X flare on 2000 July 14 was caused by a series of magnetic reconnections near the magnetic neutral line above the photosphere.

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