

Formation of Solar Delta Active Regions: Twist and Writhe of Magnetic Ropes *

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Abstract We analyze the process of formation of delta configuration in some well-known super active regions based on photospheric vector magnetogram observations. It is found that the magnetic field in the initial developing stage of some delta active regions shows a potential-like configuration in the solar atmosphere, the magnetic shear develops mainly near the magnetic neutral line with magnetic islands of opposite polarities, and the large-scale photospheric twisted field forming gradually later. Some results are obtained: (1) The analysis of magnetic writhe of whole active regions cannot be limited in the strong field of sunspots, because the contribution of the fraction of decayed magnetic field is non-negligible. (2) The magnetic model of kink magnetic ropes, supposed to be generated in the subatmosphere, is not consistent with the evolution of large-scale twisted photospheric transverse magnetic field and not entirely consistent with the relationship with magnetic shear in some delta active regions. (3) The proposition is that the large-scale delta active regions are formed from contribution by small-scale non-potential magnetic flux bundles generated in the subatmosphere.

Key words: Sun: activity — Sun: flares — Sun: magnetic fields

1 INTRODUCTION

Non-potentiality of magnetic field in solar active regions normally relates to solar flares and coronal mass ejections (CMEs), as can be inferred from the observed magnetic field and the morphological configuration of active regions. It is generally believed that the evolution of photospheric vector magnetograms provides indication that magnetic energy is transferred from the subatmosphere into the corona. By following the evolution, one probably can construct a basic model of the formation of magnetic field and the relationship between the evolution of magnetic field and solar activities. It is generally believed that newly emerging magnetic flux of opposite polarities and shear in the transverse magnetic field near the magnetic neutral line in active regions are important parameters for the analysis of the non-potential magnetic field (Hagyard 1984). There are some possibilities in the generation of non-potential magnetic energy in the solar atmosphere. One is that a twisted magnetic field that has existed at the subatmosphere emerges to form the observed twisted magnetic ropes or knots in delta active

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regions (Tanaka 1991). Another is that a large-scale magnetic shear or electric current of active regions in the solar atmosphere is formed from contributions by emerging small-scale magnetic flux tubes with opposite arrangements (Zhang 1995a). As one believes that the magnetic field consists of flux tubes in the solar atmosphere (Parker 2001), the formation of large-scale twisted magnetic ropes in the solar atmosphere is probably a complex problem. For example, the delta active regions show unusual morphology and highly sheared transverse magnetic field with opposite magnetic polarities jammed together – sunspot umbrae of opposite magnetic polarity are frequently contained within a single penumbra (Zirin 1988; Lites et al. 1995; Fisher et al. 2000). It can be found that the life time of some super delta active regions is of the order of several months. This means the non-potential magnetic field in the active regions is probably contributed by amounts of magnetic flux which emerged at different times from the convection zone. The handedness distribution of magnetic flux also shows complex patterns in the active regions (Zhang 2001a). By following the evolution of photospheric vector magnetograms, we can determine possible conditions of formation and morphology of electric currents in the active regions and understand the correlation between the large-scale helical magnetic configuration and small-scale magnetic features.

For analyzing the magnetic field of active regions, the basic questions we should examine are, the general properties of the delta active region, the generation of the complex magnetic ropes in the subatmosphere, their emergence in the solar surface and the relaxation process. Even if some authors have suggested that the delta magnetic pattern in the active regions is caused by the emergence of kink magnetic ropes (Tanaka 1991; Linton et al. 1999), the possibility of kink magnetic configuration of active regions can be confirmed when we follow the evolution of the field to acquire observational evidence for the chirality of the field in the solar atmosphere.

The twist and tilt angle of the magnetic field in active regions are two basic physical quantities reflecting the field chirality. The twist of magnetic field can be inferred from the photospheric vector magnetograms, which relates to the handedness (helicity) along the magnetic ropes. It has been analyzed by the mean signs of photospheric current helicity density, α factor of force free field and handedness of soft X-ray loops, etc., due to the non-uniform of the twist degree of magnetic field in active regions (Seehafer 1990; Pevtsov et al. 1997; Bao & Zhang 1998). The writhe of magnetic field reflects the global deform of magnetic ropes. It is normally understood that the mean tilt angle and also the rotation direction of active regions provide some information of magnetic writhe (Linton et al. 1999; Tian et al. 2001; Lopez Fuentes et al. 2003). The tilt angle is normally defined as the angle between the equator and connecting line of weighted centers of positive and negative polarities in the active region. Figure 1a shows a scheme of tilt angle of magnetic bipole with the inverse “sigmoid” configuration in the northern atmosphere. The signs of tilt angle is the same as the normal definition (Tian et al. 2001). With the known complexity of the distribution of magnetic field in active regions, the mean tilt angle of magnetic field actually reflects the synthetic contribution of magnetic flux tubes, which includes the strong field areas and also enhanced network field in the vicinity of sunspot groups. Some of enhanced network magnetic field is the vestiges of decaying magnetic poles in the active region and reflects the historical development. The determination of magnetic writhe from the tilt angle of active region hides the connectivity of magnetic ropes in the solar atmosphere. By following the evolution of solar delta active regions, it has been found that some new magnetic ropes probably emerge from subatmosphere and some old ones have annihilated or became the enhanced network field gradually. So, it indicates that the weighting centers of magnetic polarities of active region evolve with time.

To analyze the properties of delta active regions, we demonstrate the configuration and evolution of some well-known super delta active regions in this paper. In Sect. 2, the observational properties of the active region NOAA 9026, 6818-6850-6891-6929 and 5354-5395-5441-5470 are presented. In Sects. 3, 4 and 5, we discuss the basic properties of these delta active regions and in Sect. 6 we show some results.

2 DELTA ACTIVE REGIONS

2.1 NOAA 9026

Active region NOAA 9026 was a fast developing region in 2000 June, and it was noticeable in the northern hemisphere in the 23rd solar cycle, which produced a series of powerful flares and the corresponding geophysical effects (Kurokawa et al. 2002). Figure 1b shows the soft X-ray configuration of this active region overlaid with the magnetic lines of force above the photosphere. The lines of force are extrapolated by the constant force free field based on the MDI full disk magnetogram obtained by SOHO satellite. The α factor is $-3.83 \times 10^{-8} \text{ m}^{-1}$, which is relevant to the value of α_{best} calculated in the following. We can find that the magnetic field of active regions actually includes the strong magnetic field in the vicinity of spots and also the enhanced network one. The latter spreads into a large area near the active region. The powerful soft X-ray flare occurred above the active region and the past loops connected both polarities of photospheric magnetic field.

The mean tilt angle of the photospheric magnetic field of active region is about 14° in the MDI synoptic magnetogram on June 7, inferred from the weighted centers of positive and negative magnetic field of the active region. It is roughly consistent with the estimation (about 20°) from the connecting line of the footpoints of the extrapolated magnetic lines of force of opposite polarities, where the lines of force mainly connected the large-scale photospheric enhanced network magnetic field of opposite polarities and are almost consistent with the morphology of soft X-ray features near the middle of the active region in Fig. 1b. It is found that on July 5 the magnetic field of active region became the enhanced network field and the tendency of the tilt angle of magnetic field is almost the same. Due to the choice of different coordinate systems between the MDI full disk magnetograms in Fig. 1b and synoptic ones, the tilt angles in both systems are slight different, but their tendencies are the same. In the following discussion, this difference will be neglected.

Figure 2a shows the development of the photospheric vector magnetic field in the active region on June 4–8. It is found that the local polarity distribution of the sunspot field is complex and shows the delta configuration. The shear of the transverse field relates to the evolution of sunspots in the active region, i.e., the transverse field is almost parallel to the inversion line of opposite polarities in the middle of the active region. From the orientation of the transverse field, one probably can infer that the magnetic poles $p1$ and $f1$ consist of a pair of opposite polarities. The magnetic pole $p1$ moved westward relative to $f1$ in the development of the active region. It probably means that the magnetic pair $p1$ and $f1$ is independently relative to magnetic pole P in the formation process from the subatmosphere, in other words, the magnetic pair $p1$ and $f1$ probably was a magnetic rope in the subatmosphere and emerged from the solar surface to form a pair of magnetic poles of opposite polarities. The shear of transverse magnetic field between the magnetic poles P and $f1$ reflects the interaction of different magnetic systems. Figure 2b shows the vertical current and current helicity density h_{cz} in the active region NOAA 9026 inferred from the vector magnetograms of Fig. 2a. By

comparing Figs. 2a and 2b, we may find that the electric current normally flows from negative to positive polarity. The corresponding helicity picture in Fig. 2b shows that in most areas of the active region the photospheric current helicity density ($h_{cz} = B_z(\nabla \times \mathbf{B})_z$) has a negative sign. The values of α_{best} of the force-free field are -3.5 , -3.5 , -3.8 , -2.8 inferred from vector magnetograms on June 4, 6, 7 and 8 in Fig. 2, respectively (the unit is $\times 10^{-8} \text{ m}^{-1}$). It is consistent with the left handedness of the large-scale soft X-ray loops in Fig. 1b, the magnetic lines of force show basically the reversal sigmoid configuration above the photosphere in the active region. Although the configuration of the large-scale magnetic field, extrapolated from the photospheric magnetic field in the approximation of constant force free field, is relative simple, the existence of local photospheric reverse magnetic structures near the center of the active region actually means the magnetic ropes from the subatmosphere are very complex.

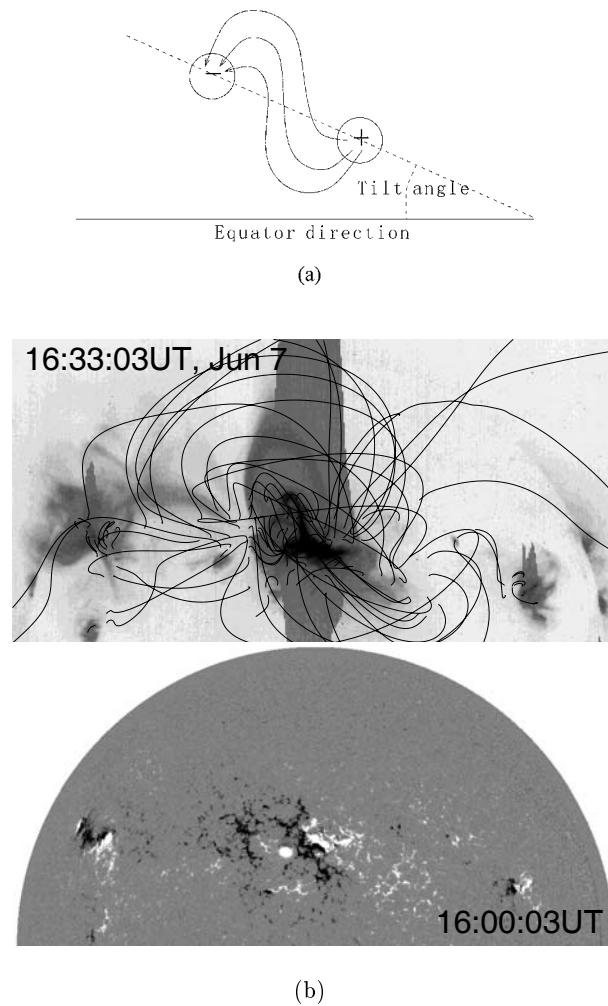


Fig. 1 (a) Schetch of tilt angles of the active regions in the northern hemisphere. (b) The soft X-ray image and the extrapolated magnetic field (top) inferred from the full disk MDI magnetogram (bottom) on 2000 June 7. The white (black) in the magnetogram indicates positive (negative) polarity. North is at the top, west is to the right.

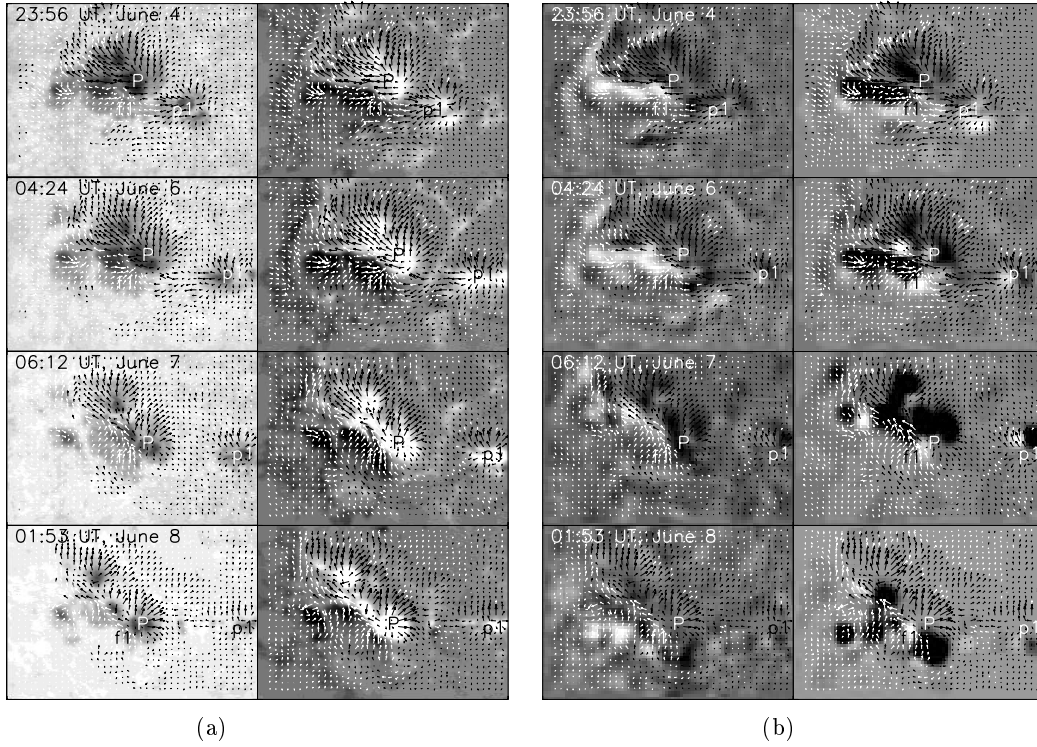


Fig. 2 (a) Photospheric images (left) and vector magnetograms (right) in active region NOAA 9026 in 2000. The white (black) in magnetograms indicates positive (negative) polarity. The arrows indicate the transverse components of field. (b) The vertical current (left) and current helicity density h_{cz} (right). The white (black) indicates the up (down) flow or positive (negative) sign. North is at the top, west is at the right. The size of images is $2.62' \times 1.82'$.

2.2 NOAA 6818-6850-6891-6929

The distribution of large-scale magnetic field near active region NOAA 6818-6850-6891-6929 can be found in the synoptic magnetograms inferred from the Kitt Peak full disk magnetograms. NOAA 6818-6850-6891-6929 was a super active region in the southern hemisphere, which produced a series of powerful flares. It was a new emerging flux region in the 1846 Corrigton rotation and became a complex delta active region gradually in 1847 and 1848 solar Corrigton rotations. In the 1849 Corrigton rotation, the magnetic field of active region weakened and the most part of magnetic field became the enhanced network field. The mean tilt angles of active region were about -18° on Sept. 5 and -11° on Oct. 3 obtained from Solar Geophysical Data. As a reference, the tilt angles of mean magnetic field in the active region were about -20° in 1847 and -16° in 1848 solar Corrigton rotations in the Kitt Peak synoptic magnetograms.

For comparing the basic configuration of magnetic field in delta active regions, the photospheric vector magnetograms in active region NOAA 6818-6850-6891-6929 in 1991 are shown in Fig. 3a, which were observed at the Huairou Solar Observing Station. Due to the limit of the field of view, some of enhanced network field in the vicinity of active region does not be included. By checking the distribution of photospheric vector magnetograms, the basic scheme of magnetic field in active region NOAA 6818-6850-6891-6929 can be inferred (Fig. 3b), as the

same with the sequence of Fig. 3a. *A* and *B* mark the basic magnetic structures in the active region.

We can image that the basic topological connectivity of the magnetic field changes significantly above the photosphere, as we examine the photospheric morphology of the sunspot group and corresponding vector magnetograms. This active region occurred in the solar surface about four months. It is found that the new magnetic flux emerged up to form a simple bipolar active region in September 1991. The delta magnetic configuration connected with the emergence of new magnetic flux in the local area of active region, where the shear of transverse field formed near the magnetic neutral line, such as on October 3 and 28. In the vector magnetogram on October 28, this active region became more complex. The major polarity of sunspots is positive and the α_{best} of force free field is $2.9 \times 10^{-8} \text{ m}^{-1}$ inferred from the photospheric vector magnetograms. Figure 3c shows the vertical current and current helicity density h_{cz} in active region NOAA 6818-6850-6891-6929 inferred from the vector magnetograms of Fig. 3a. In the most areas of active region, the photospheric current helicity density h_{cz} shows positive sign. It is consistent with the regular role of the magnetic helicity of active regions (Seehafer 1990). The shear of transverse field occurred in the vicinity of compact magnetic structures of opposite polarities, but it was not significant in the initial stage of the active region. The current in the active region in Fig. 3 increased with the development of active region. Some strong current occurred near the magnetic neutral line between the compact magnetic features of opposite polarities. This is consistent with that the magnetic field in the active region consisted of the separated magnetic features and did not show any simple large-scale compact current system like that of NOAA 6659 (Zhang 1996).

Now we study the initial stage in the formation of delta active region in the photosphere, to analyze the possible formation of delta active region. Figure 4 shows the evolution of active region NOAA 6818-6850-6891-6929 on Sept. 5 and 6, which was a typical emerging flux region. The footpoints of opposite magnetic polarities separated away in the active region. The dark arch filaments connected both footpoints of opposite polarities and some brightening features occurred near the magnetic footpoints in the $H\beta$ filtergrams. The chromospheric $H\beta$ material flowed downward near the footpoints and upward near the magnetic neutral line in the active region.

By analyzing the distribution of photospheric transverse field with chromospheric features, we infer that the tendency of twisted magnetic loop as a whole in Fig. 4 is insignificant. It is similar to the normal emerging flux regions, which is almost consistent with the observation in the initial stage of delta active region NOAA 7321 proposed by Zhang (1995a). The distribution of vertical current inferred from the photospheric vector magnetograms in the active region in Fig. 3c provides the similar evidence. There is no strong vertical current and helicity in the initial stage of the active region in the photosphere. The observational result probably excludes the evidence on that the delta configuration in active region NOAA 6818-6850-6891-6929 consisted of large-scale magnetic ropes as a whole pre-twisted in the subatmosphere, as one follows the evolution on the shear stage of transverse field in the active region. The delta configuration in active region NOAA 6818-6850-6891-6929 probably was contributed by different magnetic flux systems and these magnetic flux ropes emerged from the subatmosphere sequentially. The indication of interaction of different magnetic bundles is that the shear of transverse field occurred near magnetic neutral line between the magnetic polarities jammed together in the active region.

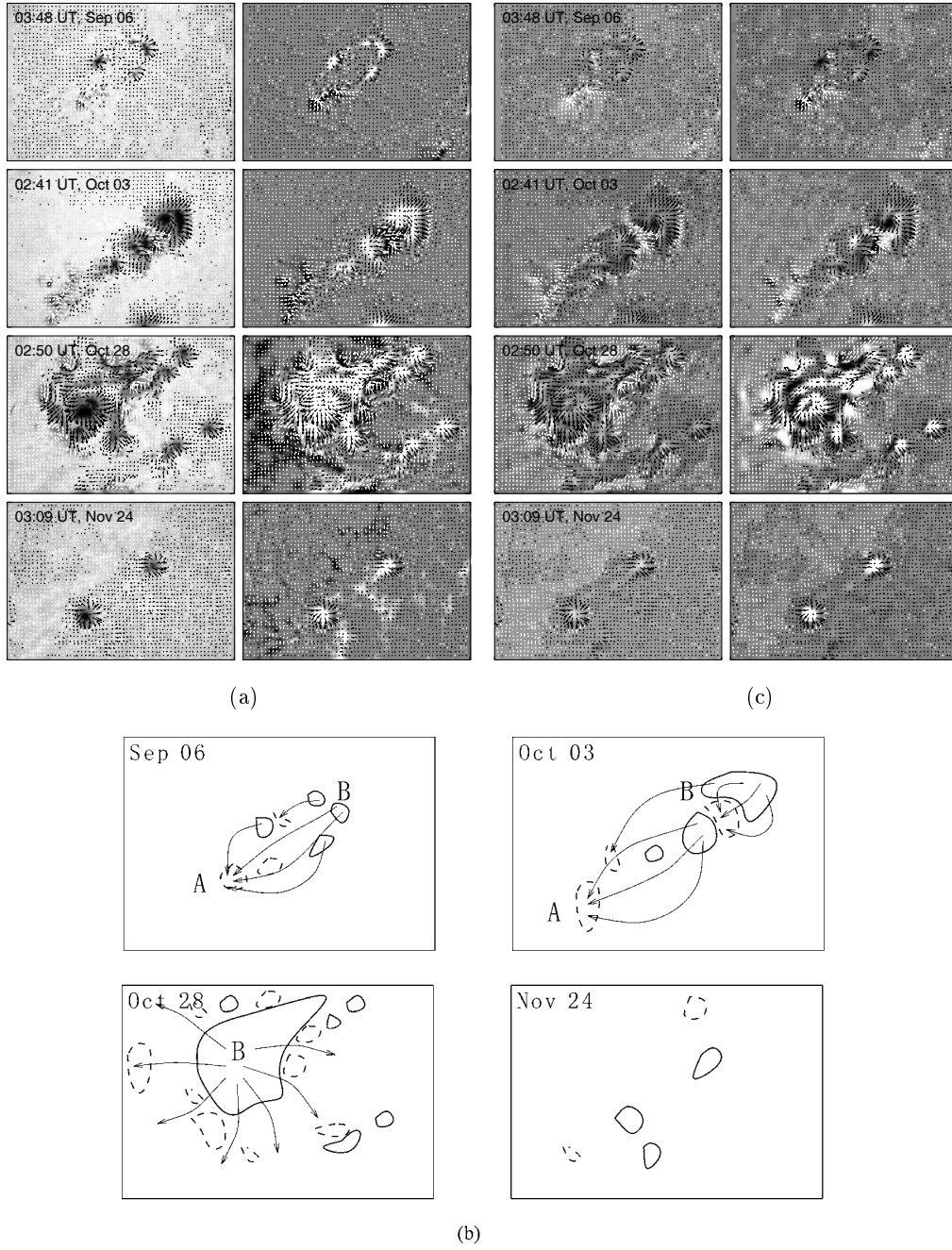


Fig. 3 (a) Photospheric images (left) and vector magnetograms (right) in active region NOAA 6818-6850-6891-6929 in 1991. The white (black) in the magnetograms indicates positive (negative) polarity. The arrows indicate the transverse components of field. (b) The basic morphological evolution of magnetic field of the active region in the top of view. (c) The vertical current (left) and current helicity density h_{cz} (right). The white (black) indicates the up (down) flow or positive (negative) sign. North is at the top, west is at the right. The size of images is $5.23' \times 3.63'$.

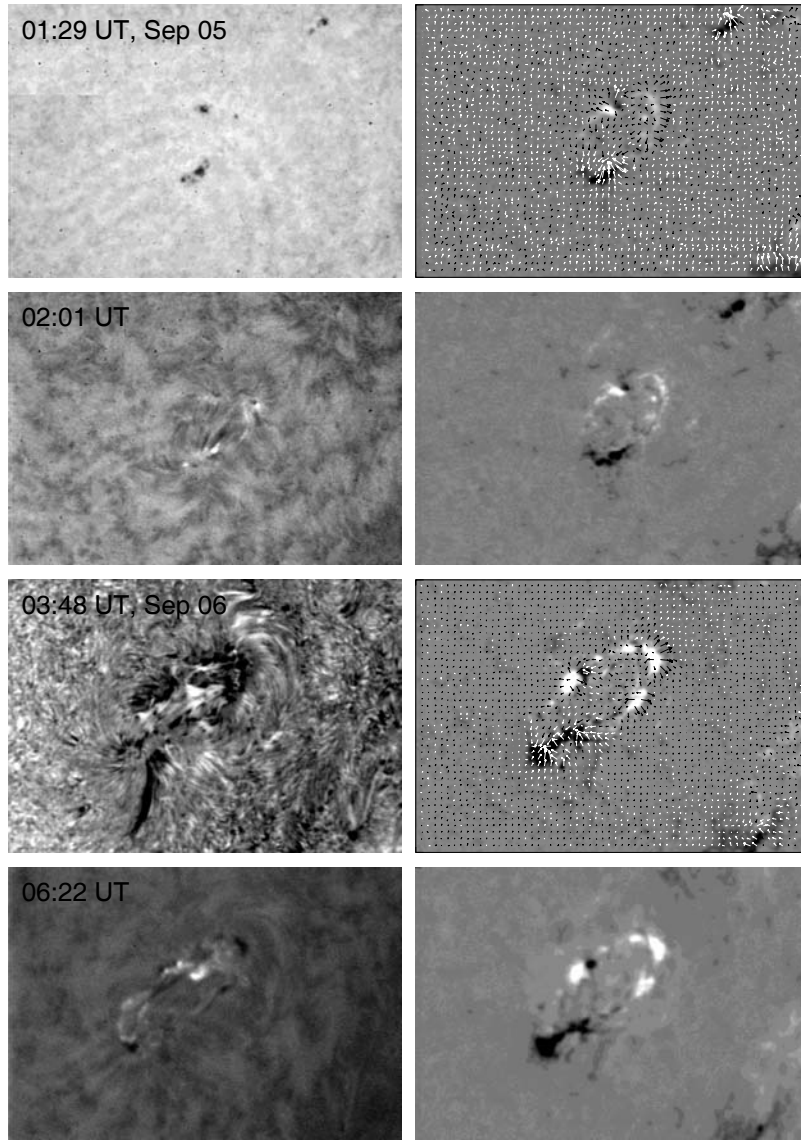


Fig. 4 Photospheric images, H β filtergrams (near 02:01 UT on Sep. 5 and near 06:22 UT on Sep. 6), H β Dopplergram (near 03:48 UT on Sep. 6) and photospheric vector magnetograms (right) in the active region NOAA 6818 on Sep. 5 and 6. The observational times of photospheric vector magnetograms are noted. The white (black) indicates the upward (downward) flow in Dopplergrams and positive (negative) polarity in magnetograms. The arrows indicate the transverse components of field. The size of images is $5.23' \times 3.63'$.

2.3 NOAA 5354-5395-5441-5470

Active region NOAA 5354-5395-5441-5470 was a super active region in the northern hemisphere and produced a series of powerful flares. The magnetic main poles of opposite polarities

in the active region separated gradually for several solar rotations. We can find that the preceding polarity broken fast than the following one. The active region became the enhanced network field almost through out 1815 Corrington rotation in Kitt Peak synoptic magnetograms, except the new reversal magnetic dipole. The mean tilt angles of the magnetic field in active region NOAA 5354-5395-5441-5470 were about 22° in 1812, 1813 and 1814 Corrington solar rotations inferred from the synoptic magnetograms.

The vector magnetograms in active region NOAA 5354-5395-5441-5470 in 1989 are shown in Fig. 5a, which were observed at the Huairou Solar Observing Station. It is found that a large dipole active region formed in February 1989 and the tilt angle of active region was about 11° on Feb. 10 obtained from Solar Geophysical Data. It was a regular magnetic configuration in the early stage of active region. The proceeding magnetic pole of negative polarity broken, as this region appeared again from the eastern limb of the Sun in March. In March it became a typical delta region (Wang et al. 1991; Zhang 1995b; Ishii et al. 1998). The main polarity of this region was positive and the magnetic shear of transverse field formed in the vicinity of magnetic neutral line in the eastern side of the magnetic main pole of positive polarity. The basic scheme of magnetic field in active region NOAA 5354-5395-5441-5470 is shown in Fig. 5b. It is found that the delta configurations only occurred in some evolution stages of the active region and the large-scale twisted magnetic field above the photosphere related to the highly sheared emerging magnetic flux in the active region.

Figure 5c shows the vertical current and current helicity density h_{cz} in the active region NOAA 5354-5395-5441-5470 inferred from the vector magnetograms of Fig. 5a. The electric current increased with the formation of magnetic shear in the active region. By investigating the evolution of magnetic field in the active region, it is found that the formation of local strong current in the eastern side of active region on March 11 was caused by the emergence of magnetic flux with opposite arrangement of magnetic polarities. In this active region flares tended to occur near the highly sheared magnetic neutral line, where the transverse field is almost parallel to it, and small scale magnetic features of opposite polarities moved out on either side of the magnetic main pole of positive polarity and curled around it in curved trajectories in the active region (Wang et al. 1991). This means that the magnetic shear and electric current in the solar atmosphere relate to the emergence of magnetic flux of opposite polarity. The flares near the highly sheared magnetic neutral line provide evidence on the reconnection between the emerging magnetic flux and overlying field.

In April and May the magnetic main pole of positive polarity broken and the total flux of the active region decreased gradually, while there was also the left handedness of helical magnetic configuration in the active region dominantly. The α_{best} of force free field is $-1.6 \times 10^{-8} \text{ m}^{-1}$ on Feb. 10, $-4.2 \times 10^{-8} \text{ m}^{-1}$ on Mar. 11, $-3.9 \times 10^{-10} \text{ m}^{-1}$ on Apr. 11 and $-3.0 \times 10^{-8} \text{ m}^{-1}$ on May 5, respectively. It is consistent with that the mean sign of current helicity density h_{cz} in the active is negative.

Figure 6 shows the magnetic lines of force in the solar atmosphere extrapolated by the linear force free field with $\alpha = -3.8 \times 10^{-8} \text{ m}^{-1}$. It is of a similar order of α_{best} inferred from photospheric vector magnetogram on Mar. 11. We can find that the most lines of force connect the magnetic main pole of positive polarity and the enhanced network of negative one in the active region. This means that, as the main pole of active region becomes the enhanced network field, the field of active region also keeps the basic bipolar topology obviously in the higher solar atmosphere, even if the field probably is force free, i.e., the current exists in the atmosphere.

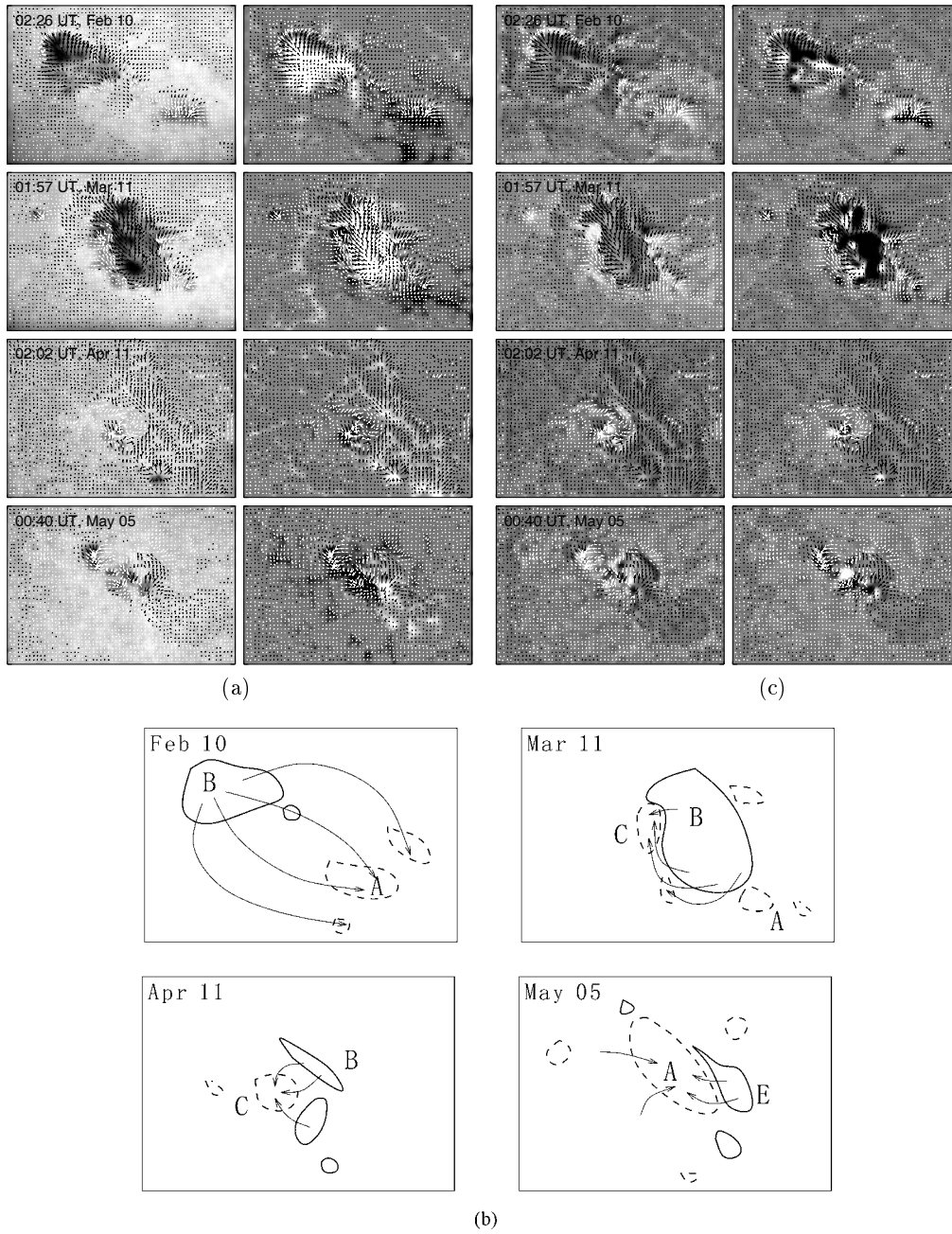


Fig. 5 (a) Photospheric images (left) and vector magnetograms (right) in active region NOAA 5354-5395-5441-5470 in 1989. The white (black) in the magnetograms indicates positive (negative) polarity. The arrows indicate the transverse components of field. (b) The basic morphological evolution of magnetic field of the active region in 1989 in the top of view. (c) The vertical current (left) and current helicity density h_{cz} (right). The white (black) indicates the up (down) flow or positive (negative) sign. North is at the top, west is at the right. The size of images is $5.23' \times 3.63'$.

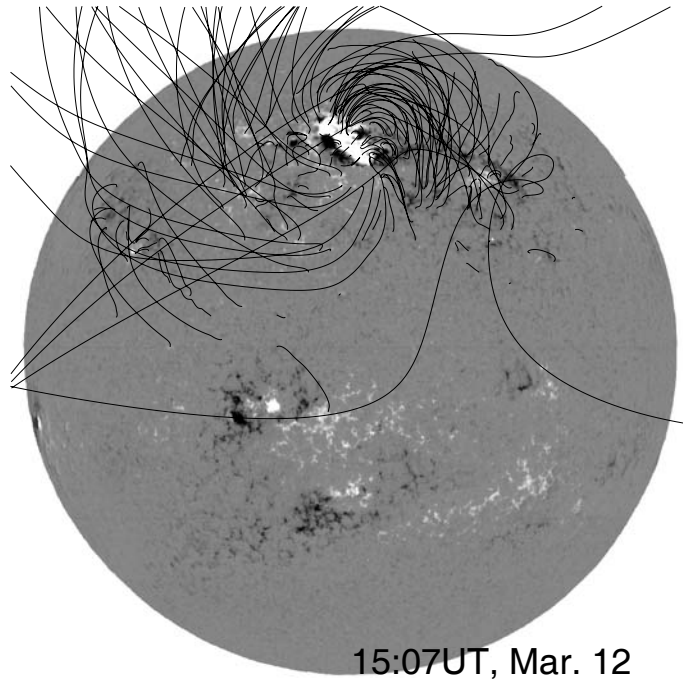


Fig. 6 Spatial configuration of magnetic field extrapolated from linear force free field in the north hemisphere based on the MDI full disk magnetogram on 1989 March 12.

3 THE RELATIONSHIP BETWEEN THE TWIST AND WRITHE OF MAGNETIC ROPES

The formation of delta active regions is a key process, because almost all of the great flares occur in the delta magnetic configuration and accompanied with intense coronal mass ejections. The magnetic fields of opposite polarities in delta active regions compact together to form the complex magnetic cluster or islands. It is noticed that except some fast developed delta active regions, such as NOAA 7321 (Zhang 1995, 2001b), 9026 (Kurokawa et al. 2002) and 9077 (Liu & Zhang 2001), some active regions became mature delta magnetic configuration after they underwent several solar rotations, such as NOAA 5354-5395-5441-5470 and 6818-6850-6891-6929. This means the formation of delta active regions is a complex process in the solar atmosphere. The highly sheared transverse field normally forms between compact poles of opposite polarities. The combination and interaction between the newly emerging magnetic flux and existing ones probably are dominant process in the formation of delta active regions. A series of photospheric vector magnetograms probably indicates that the emergence of highly sheared magnetic field near the magnetic neutral line contributes to the large-scale non-potential magnetic field in delta active regions. Due to the action of Coriolis force on the magnetic field and the differential rotation in the solar subatmosphere, the magnetic field in the solar atmosphere shows the dominant handedness with opposite signs in the northern and southern hemispheres. It is also found that this handedness is contributed by small-scale helical features in the active regions, in other words, the active regions are normally the mixtures of opposite

signs of helicity elements with a dominant sign, such as in active region NOAA 6618-6850-6891-6929. The imbalance of the current helicity in active regions was analyzed by Abramenko et al. (1996) and Bao & Zhang (1998), although α_{best} of linear force free field can also be used to fit the basic twist of magnetic field in active regions (Pevtsov et al. 1997).

It has been commonly known that, as the tilt angle of active regions follows the Hale-Nicholson law, the sign of writhe is positive (negative) in the northern (southern) hemisphere. We can find that the active regions discussed in this paper are consistent with the Hale-Nicholson law. As the analysis of active regions in this paper, the mean signs of the magnetic helicity are negative (left handedness) in active region NOAA 9026 and 5354-5395-5441-5470, but the mean tilt angles of large-scale magnetic field of active regions show the positive sign of magnetic writhe, due to the locations of these active regions at northern hemisphere.

We also can find that the mean sign of magnetic helicity is positive (right handedness) in active region NOAA 6818-6850-6891-6929, while the tilt angle of large-scale magnetic field of active region shows the negative sign of magnetic writhe due to the location of active region at southern hemisphere. For these delta active regions, the mean twist and writhe of magnetic field show opposite signs. It is opposite to the proposal showed by Linton et al. (1999) that the twist and writhe of kink magnetic ropes are with the same signs in delta active regions. This means that the analysis of large-scale helical property of delta active regions is complex and basically we can not use the kink model to analyze the properties for these delta active regions. The distribution and evolution of magnetic field in active region NOAA 9026, 6818-6850-6891-6929 and 5354-5395-5441-5470 show some evidence that some delta active regions topologically consist of more than one large-scale magnetic dipoles emerged from the subatmosphere. It is not suitable to simply use the correlation between the mean tilt angle and twist of magnetic dipoles (Tian et al. 2001) to examine the relationship between the twist and writhe of complex magnetic ropes formed from the subatmosphere, and also the disintegration of kink magnetic ropes of whole active regions.

In some cases, the local twist and tilt of magnetic field in delta active regions may play a key role. For example, the formation of mean tilt angle of active region 5354-5395-5441-5470 in 1989 March was a complex process as shown in Fig. 5, because the main part of magnetic field of positive polarity in the active region was the residue of the large-scale magnetic dipole in February, while the negative one became the enhanced network field near the active region. The deformed magnetic dipole occurred in the eastern side of the magnetic main pole of positive polarity and squeezed it in March in Fig. 5, which was only a part of active region in February. This part was important for a series of powerful flares occurred. As the local writhe and twist of magnetic ropes showing the same signs, their relationship probably can be described by the kink magnetic model, although there are still some questions on the relationship between the local kink and global non-kink magnetic ropes in active regions.

For summarizing the basic properties of some super delta active regions, the relationship between the twist and writhe of magnetic field is shown in Table 1. *Normal* in Table 1 means that the large-scale twist and writhe of magnetic field of active regions show opposite signs. The active region NOAA 6580-6619-6659 is included in Table 1, which was also a super delta active region in solar cycle 22 and presented similar properties. It will be analyzed in another paper.

Table 1 Relationship between the Large-scale Tilt Angle and Chirality of Magnetic Field

NOAA	Hemisphere	Tilt angle	Chirality (10^{-8} m^{-1})	Twist and writhe
9026	north	$20^\circ (14^\circ)$	$-2.8 \sim -3.8$	normal
5354-5395-5441-5470*	north	$11^\circ (22^\circ)$	$-1.6 \sim -4.2$	normal
6580-6619-6659	north	$68^\circ \sim 46^\circ (86^\circ \sim 50^\circ)$	$-3.3 \sim -4.5$	normal
6818-6850-6891-6929	south	$-18^\circ \sim -11^\circ (-20^\circ \sim -16^\circ)$	2.9	normal

* The value of α_{best} calculated from the vector magnetogram on 1989 April 11 is $-3.9 \times 10^{-11} \text{ m}^{-1}$.

4 THE FORMATION OF HELICAL MAGNETIC ROPES

The large-scale twisted magnetic ropes consist of small-scale flux tubes formed in the convection zone. The basic property of magnetic flux tubes in the active region was discussed by Parker (2001). The evidence of the local twist of magnetic field in active regions can be found in NOAA 6818-6850-6891-6929 inferred from the vector magnetograms in Fig. 3. The individual twisted sunspot magnetic fields contribute the large-scale magnetic helicity in the southern hemisphere.

The time scale on the emergence of magnetic field from the base of convection zone to the solar surface was analyzed by some authors (Dmitrieva et al. 2000). If one believes that the emerging time scale is in order of a month, the formation of a complex delta active region which normally has undergone several months in the solar surface is a complex process, i.e., the large delta magnetic configuration of active regions is contributed by an amount of magnetic flux bundles in the solar surface which formed at different times and the intervals of some magnetic bundles formed at solar surface are larger than the time scale of the emerging magnetic flux from the base of solar convection zone. It implies that the mean tilt angle and helicity of active regions in the solar surface are actually formed from contribution by flux tubes, which probably emerged from the subatmosphere separately.

5 THE GENERAL PROPERTIES OF DELTA MAGNETIC ROPES

In this section, we summarize the magnetic properties of delta active regions combining with some analyses on the vector magnetic field, current and magnetic helicity:

1) The delta active regions consist of the compact magnetic configuration of opposite polarity umbrae in the same penumbra (Zirin 1988). The highly sheared transverse magnetic field forms between the opposite polarities (Hagyard et al. 1984). The change of photospheric vector magnetic field during the powerful flares can be found in some delta active regions (Chen et al. 1989).

2) Except the twisted $\text{H}\alpha$ features normally accompany with non-potential magnetic field in the chromosphere in mature delta active regions (Zirin & Tanaka 1973), the helical soft X-ray configurations exist in the corona also. The developments of coronal helical configuration are delayed relative to that of the photospheric magnetic shear. This means that the magnetic non-potentiality transfers from the subatmosphere into the corona (Zhang 2001b).

3) There are several possibilities in the formation of delta magnetic configurations in active regions (Zirin 1988): (a) in the initial forming stage of a new delta dipole, the magnetic field shows the potential-like configuration (Zhang 1995a) and (b) the delta magnetic configuration

occurs in some developing stages of active regions due to the emergence of new magnetic flux of opposite polarities. There is probably no intrinsic difference in the formation or the behavior between δ spots and spots of normal magnetic configuration (Tang 1983).

4) It is found that the large-scale twisted magnetic field (current) in the solar atmosphere is formed from contribution by newly emerging magnetic flux (current) tubes. This means that the magnetic configuration of delta active regions probably does not twist significantly in the simple form as a whole in the subatmosphere before its emergence in the solar surface, because the delta magnetic configuration in the solar atmosphere has undergone a long term evolution sometimes.

5) The net flux imbalance probably is also a key factor on the delta sunspot regions (Zhang et al. 1994), while this imbalance probably relates to some developing stage of active regions only, as one excludes the vestige of a part of active regions.

6) The kink magnetic model can be used to analyze some compact delta-spot regions with the same mean signs between the twist and writhe magnetic field. However, we probably can not obtain a simple conclusion that the delta magnetic regions relate to the kink magnetic model generated in the subatmosphere,

6 RESULTS

After the analysis, we can summarize the main results in this paper in the following:

(1) By following the evolution of large-scale twisted pattern of the photospheric transverse magnetic field and the relationship with formation of delta magnetic configurations in solar active regions, we may find that the formation of some super delta active regions probably undergoes a relative long term evolution in the solar surface. The different magnetic ropes probably emerge at different developing stage of the delta active region. This means that the delta active regions probably are contributed by some magnetic ropes, which jam closely in the surface.

(2) In the initial stage of some delta regions, the magnetic field shows a dominant tendency of potential-like configuration in the solar atmosphere. The highly sheared transverse magnetic field forms near the magnetic neutral lines between the opposite polarities with the newly emerging magnetic flux in the delta active regions. It reflects the possibly forming process of delta active regions caused by the emergence of new magnetic ropes and the interaction of new ropes with existed ones.

(3) The total magnetic flux in delta active regions is probably imbalance. It relates to some evolving stage of active regions. The topological connectivity with surrounding of magnetic field can be diagnosed from the evolving process of field and also soft X-ray images of active regions. We probably can not analyze the basic twist and writhe of delta active region only by means of the vector magnetograms limited in local areas of strong field or on the especially evolving stage of active regions.

(4) Due to the complicity of formation of magnetic ropes from the subatmosphere, for analyzing the chirality of magnetic ropes, there are still some problems by simply using the kink model to present the basic properties of delta active regions.

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