Variations of Current Helicity in Active Region 10930 as Inferred from Hinode Spectropolarimeter Data and Cancellation Exponent

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Abstract. Current helicity derived from vector magnetograms possesses a well-pronounced scaling behavior, which can be studied by introducing a signed measure and calculating the power-law exponent (cancellation exponent). The time variations of this exponent seem to be related to flare activity of an active region. Here we focus on changes of current helicity in active region NOAA 10930 as derived from a set of Hinode spectropolarimeter data. Our findings are that the cancellation exponent first strongly increased on Dec 11 then rapidly decreased after a small sunspot-satellite developed. Afterward, the cancellation exponent began its gradual increase without significant new magnetic flux emergence. These two different modes of behavior may indicate different processes that ultimately led to an eruption: the first process is rapid injection of current helicity, while the second process is gradual redistribution of injected helicity over all spatial scales in the active region.

1. Introduction

The deviation of the solar magnetic field from a potential state is a measure of its free energy stored in a form of electric currents. Electric currents aligned with the magnetic field in the solar corona produce considerable azimuthal magnetic fields so that the resulting magnetic fields are strongly twisted. The current helicity of the magnetic field, defined as a product of the magnetic field and associated electric currents seems to be an important characteristic of an active region’s (AR) energy capability (Seehafer 1994). The sign of current helicity, averaged over an AR, indicates the sense of the predominant twist. Some general characteristics of current helicity (such as imbalance, hemispherical segregation, injection rate, etc.) have previously been studied (e.g., Pevtsov, Canfield, & Metcalf 1994; Abramenko, Wang, & Yurchishin 1996; Sokoloff et al., 2007; Magara & Tsuneta 2008; Régnier 2009; Su et al., 2009).

Current helicity distribution, derived from solar magnetograms measured in ARs, was shown to posses a well pronounced scaling behavior (Abramenko, Yurchishin, & Carbone 1998b). This study was based on the analysis of current helicity by means of a signed measure, a function that displays a linear range with a slope of $\kappa$, called cancellation exponent. Earlier reports seem to suggest that periods of enhanced flaring may be preceded by a noticeable decrease of this exponent (Abramenko, Yurchishin, & Carbone 1998a). Low spatial and temporal resolution of the data used precluded retracing detailed variations of $\kappa$ in every case. The spectro-polarimeter on board the
Hinode spacecraft (Tsuneta 2008) now provides data uniquely suitable for this purpose. Here we continue to study the time variations of the cancellation exponent and the helicity imbalance.

2. Data and Analysis

The Hinode/Solar Optical Telescope (SOT, Suematsu et al., 2008; Tsuneta et al., 2008) of a 50 cm aperture mirror is the largest optical solar telescope ever sent to space. Hinode Spectropolarimeter (SP, Ichimoto et al., 2008) obtains the full Stokes parameters using the Fe I 630 nm absorption line. During Dec 11-14, 2006 the SP instrument acquired 15 sets of data (fast mode, pixel size of 0.32 arcsec) for AR NOAA 10930. The data was later inverted with MELANIE code at National Astronomical Observatory of Japan.

This $\delta$-type sunspot group was rapidly developing with two opposite polarity sunspots enclosed by one penumbra and it was extensively studied (e.g., Abramenko et al., 2008; Magara & Tsuneta 2008; Magara 2009; Su et al. 2009 and references therein). Two X class flares in AR NOAA 10930 occurred Dec 13 and 14 2006 and were associated with a rapid emergence of a twisted sunspot of positive polarity located in close proximity to the main negative-polarity sunspot.

![Maps of current helicity for AR NOAA 10930 calculated for four different times. The white box indicates the area where the cancellation exponent was analyzed.](image)

Hinode/SP vector magnetic field measurements allowed us to derive a vertical component of the current helicity, $h_c = B_z \cdot (\nabla \times B)_z$, maps in the active region, which dis-
Variations of Current Helicity in AR 10930

313

3. Results and Conclusions

As it follows from Fig. 2 (left), the cancellation exponent strongly varied on Dec 11, when a small sunspot-satellite was rapidly developing. After the helicity injection peaked at 17:00UT (Magara & Tsuneta 2008), the cancellation exponent first rapidly decreased to its previous magnitude (Dec 12 06:00UT) and then began to slowly increase. We note that no significant magnetic flux was being injected at that time interval.

In general, an increase of the cancellation exponent indicates that the analyzed structure becomes either more fragmented (rapid fluctuation of sign) and/or the sign fluctuations become more powerful. The increase on Dec 11 was caused by injection of current helicity, while the gradual growth of the cancellation exponent after Dec 12 may indicate that the helicity injected at small scales (1”-6”) on Dec 11 was redistributed over variety of scales. This leads to a suggestion that magnetic complexity must propagate from the photosphere into the chromosphere and corona. This propagation can be evidenced in enhanced coronal intermittency (Abramenko et al., 2008) and enhanced non-thermal velocities (Harra et al., 2009).
In Fig. 2 (right) we plot sign-singularity measures at four time instances. Between 08:00UT and 17:00UT on Dec 11 a significant amount of current helicity was injected at scales of 1-6Mm (lightly shaded area). We speculate that as time progresses, the injected energy was redistributed over all scales (dark shade area), which resulted in a spectrum with longer linear range (boxes). Note that intermittency spectra derived from chromospheric and coronal data showed similar behavior (Abramenko et al., 2008). The diamond curve at 05:00UT shows a spectrum 1 day after the flare: although the spectrum is still steep, it runs well below the pre-flare spectra, which may indicate on a still complex, but exhausted magnetic structures.

In summary, we would like to stress that time variations of cancellation exponent support our earlier finding that magnetic energy is first injected in an AR from below the photosphere and then it propagates into the corona thus driving an AR to a highly critical state, when an eruption may occur due to any, even smallest disturbance.

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References

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