TWIST ESTIMATION OF THE ACTIVE REGION NOAA 11035

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Abstract. The active region (AR) 11035 was observed between 13 December and 22 December 2009, at the beginning of the solar cycle 24. This region developed more explosive events such as flares and coronal mass ejections (CMEs). The estimation of magnetic helicity is associated to the force-free field alpha parameter. We computed the alpha parameter in the active region zone using the MDI magnetograms and a 3D coronal magnetic field extrapolation.

Key words: solar physics, solar activity, active region, helicity.

1. INTRODUCTION

Solar flares and coronal mass ejections (CMEs) are manifestations of the magnetic energy release in the solar atmosphere. The magnetic energy is stored in the twisted magnetic field of the active regions. During the explosive events the magnetic energy is converted into thermal and kinetic energies, while the acceleration of energetic particles are due to the magnetic reconnections. The emergence of new magnetic flux tubes/ropes can lead to magnetic instabilities and interacting with the overlying fields result in the flares and associated eruptions. A CME is the result of the instability of the coronal field and its eruption carries away part of the magnetic helicity of its source magnetic field.

As Demoulin *et al.* (2002) showed, there are two principal mechanisms responsible for the magnetic helicity injection into the solar corona. The first one is the emergence of twisted magnetic flux tubes from the bottom of the convection zone, where dynamo action amplifies the fields. The second one is represented by the shearing large-scale photospheric motions, like the differential rotation, that lead to the twist of the field lines. These authors concluded that the shearing motions are not an efficient processes to inject magnetic helicity into the coronal field. The magnetic helicity quantifies how the magnetic field is twisted compared to its lowest energy state from the potential magnetic field state. van Driel-Gesztelyi, Dèmoulin, and Mandrini (2003) reviewed the observational signatures of the magnetic helicity.

In this paper we analyzed the evolution of the active region NOAA 11035, that developed more explosive events such as flares and CMEs. We investigate the

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Table 1

List of class C flares released by AR11035

Date	Begin	Max	End	Type
16 Dec	01:02	01:24	01:35	C5.3
16 Dec	12:36	13:02	13:20	C3.7
16 Dec	21:35	21:49	22:25	C1.4
18 Dec	18:48	18:55	18:58	C7.6
19 Dec	00:10	00:14	00:17	C2.9

helicity variations during this active region life in order to find an overall behaviour in relationship with the explosive events onset. Additionally we investigate the changes of the 3D coronal magnetic lines extrapolated from the photospheric magnetograms provided by MDI/SOHO. The measure of twist of the magnetic field lines is given by the force-free magnetic field parameter α, since the twist is given by $T = \frac{1}{4\pi}L$, where L is the field line length.

The current Solar Cycle 24 has been boring until the appearance of the active region NOAA 11035. The AR11035 was a fairly large group stretching across 11 degrees of solar longitude observed between 14 December and 22 December 2009. The sunspot 11035 grew rapidly and at its maximum of development became seven times wider than Earth. We payed a special attention to this active region since it gave the first C class flares of the present cycle.

2. OBSERVATIONAL DATA

We have examined the AR11035 in multi-wavelengths using space observations from SOHO (EIT and MDI) and Hinode (XRT), as well as ground based observations of H from BBSO (Big Bear Solar Observatory), for the period between 14 December and 22 December 2009.

AR11035 released 38 solar flares between 14 and 19 December, as listed by NOAA Data Center: 6 flares on 14 Dec., 3 flares on 15 Dec., 10 flares on 16 Dec., 3 flares on 17 Dec., 13 flares on 18 Dec. and 4 flares on 19 Dec. Among these, five flares were of class C. We summarize these one in table 1.

Figs.1 and 2 present the evolution of AR11035 in multi-wavelengths. The magnetogram observations of the AR11035 are displayed in Fig.1 and EIT/SOHO observations in the Fe 195 $\AA$ are displayed in Fig.2. A daily evolution of AR11035 in X-ray, registered by Hinode, is plotted in Fig.3, while Fig.4 catches the first C class flare of solar cycle 24.

The AR11035, that evolved from β magnetic class region to β/γ type (on 17 and 18 December 2009), were very productive in flares, 21 of them being of B class and 5 of C class. This high level of flare activity is due partially to the region

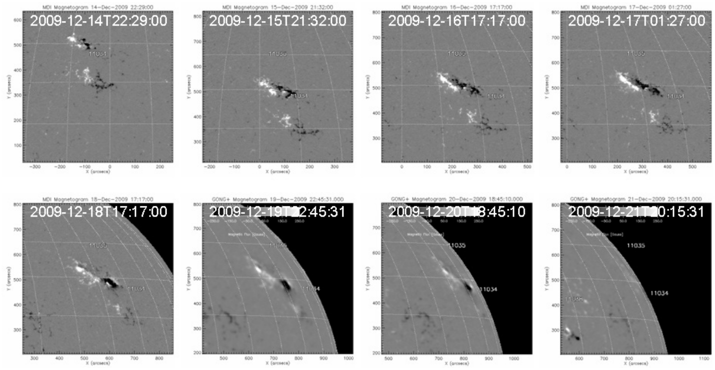

Fig. 1 – Evolution of AR11035 as seen on MDI/SOHO magnetograms.

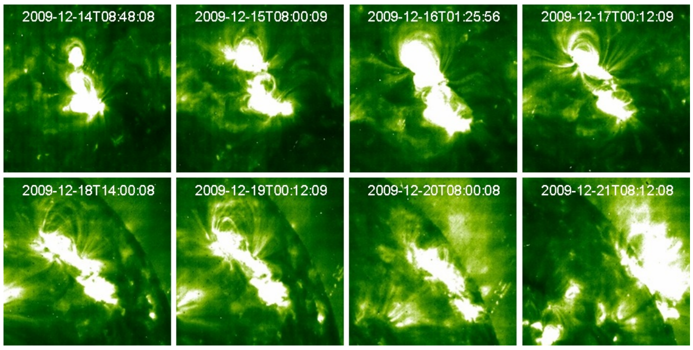

Fig. 2 – Evolution of AR11035 in EUV line 195 Å provided by SOHO/EIT instrument.

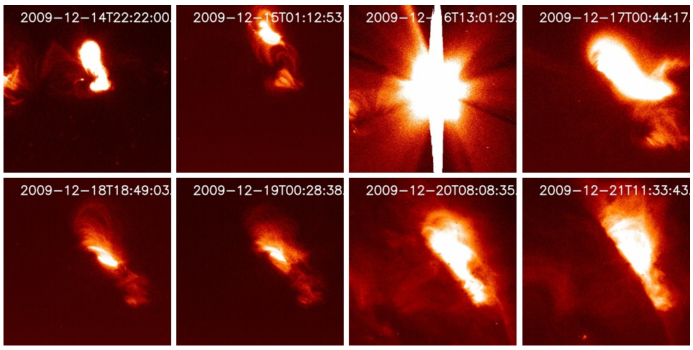

Fig. 3 – Evolution of AR11035 in X-ray provided by XRT/Hinode instrument.

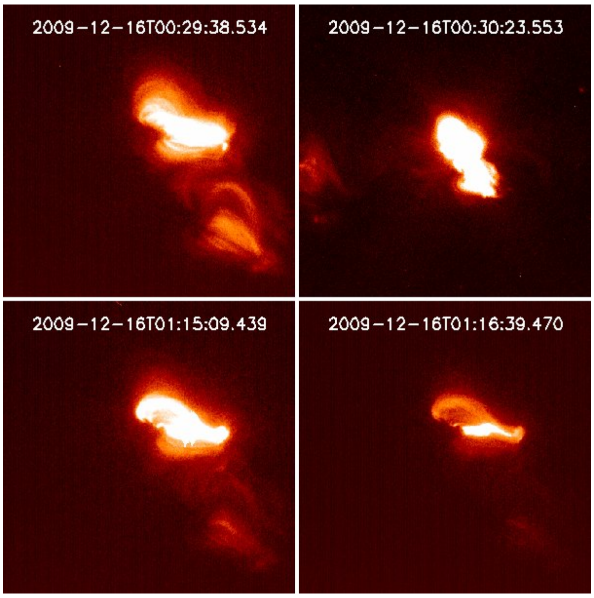

Fig. 4 – The XRT/Hinode images of C5.3 flare, first event of this class observed in solar cycle 24.

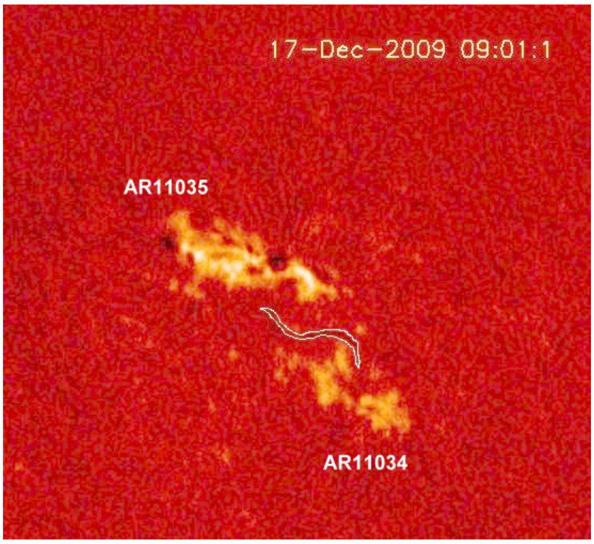

Fig. 5 – $H\alpha$ observations of AR11035 and AR11034 separated by a small filament, out lined here by its contour plot.

itself, but certainly it is due to the complex zone topological configuration. In the south neighborhood another active region was present even before the AR11035. It is AR11034 and both regions are separated by a small $H\alpha$ filament (Fig.5).

In spite of these important flares, no coronal mass ejection (CME) was registered in the known catalogues (CDAW, SEEDS, CACTUS). This fact could be explained by the relative simple magnetic topology of the region, may be due to the just beginning of the solar cycle when the magnetic field complex configurations had no still time to become mature.

3. CORONAL MAGNETIC FIELD EXTRAPOLATION

As a measure of torsion, we have computed the force-free field alpha parameter from the coronal magnetic field components, that ones extrapolated from the MDI magnetograms in the active regions zone.

$$\alpha = \frac{1}{Bz} \cdot \left(\frac{\partial By}{\partial x} - \frac{\partial Bx}{\partial y}\right) \tag{1}$$

An active region is an area on the Sun where the bipolar magnetic fields emerge through the photosphere into the chromosphere and corona. The magnetic field of an active region is modeled using the dipole configuration. The dipole model is mathematically simple and can be used to generate reasonable first-order approximations to the actual magnetic field. The 3D magnetic field lines are generated starting from on point on the surface and proceeding out from the surface. A dipole magnetic field are defined by

$$Bx = B_0 \cdot \frac{3xz}{r^5} \tag{2}$$

$$By = B_0 \cdot \frac{3yz}{r^5} \tag{3}$$

$$Bz = -B_0 \cdot \frac{(1 - 3 \cdot \frac{z^2}{r^2})}{r^3} \tag{4}$$

where $r = \sqrt{x^2 + y^2}$ and B_0 scales the strength of the magnetic field (Bx, By, Bz) in the Cartesian coordinates x, y, z.

We computed a non-linear force-free field coronal magnetic field in 3D, using an IDL code written by Lee *et al.* (2003). Each magnetic field line is generated from a set of initial established number of dipoles - we have considered ten dipoles. The x, y coordinates of the positive dipoles and the separately of the negative dipoles are found they are located where Bz reach a local extreme by Powells method.

4. DISCUSSIONS

Figs.6 display the variation of the computed α parameter at different moments of the day and different days. We have examined the peeks of these plots and related them with the moments of flare occurrences. Our conclusion was that the α parameter has positive variations when emergence of the magnetic field occurs in the respective region, and it has negative variations after the opening of the field lines at the explosive events occurrence. Unfortunately, the gaps in the MDI data made our work very difficult and our conclusions regarding the C flares unsure.

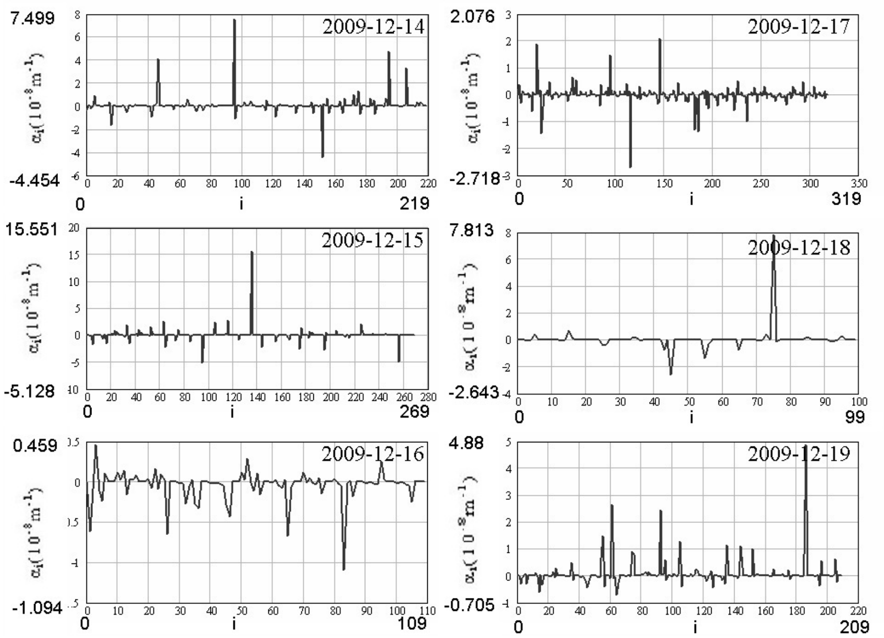

Fig. 6 – Results of alpha force-free field parameter computations for period between 14–19 December 2009.

But we have computed the force-free field parameter also for other flares occurred in AR11035. For instance, Fig.7 plots the α parameter at different moments of the flare registered on 17 December 2009: at the 15:01UT a B9.7 flare was registered in X-ray and at 15:12UT in $H\alpha$. The previous moment of the flare onset reveals a positive peak of the parameter variations. At the X-ray moment of the flare α we remark positive and negative peaks, while at the $H\alpha$ flare moment (onset and maximum phase) the force-free field parameter reaches a negative peak. Another aspect we remark on Fig.7 the α values at the X-ray moment (the second plot) ranges in the $[-200, 200]$ interval, while at the other moments it reaches local maxima of the order

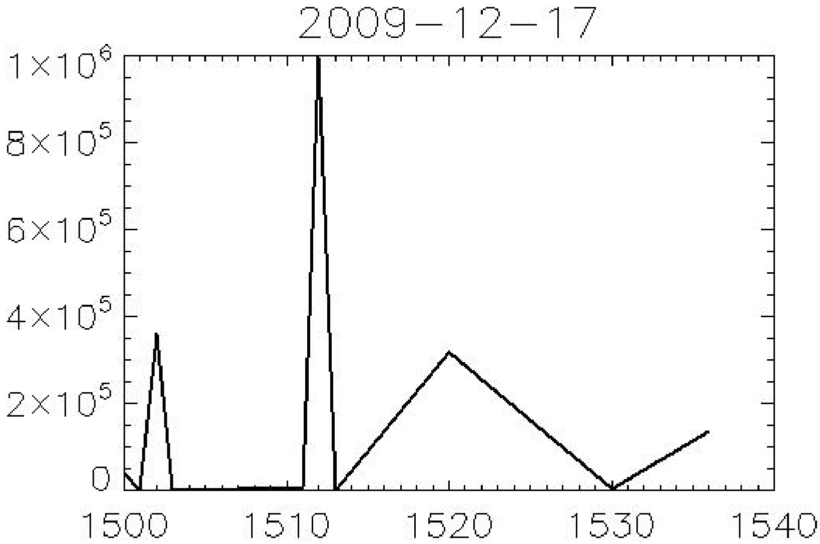

Fig. 7 – The force-free field parameter computations for the 9.7 flare registered on 17 December 2009.

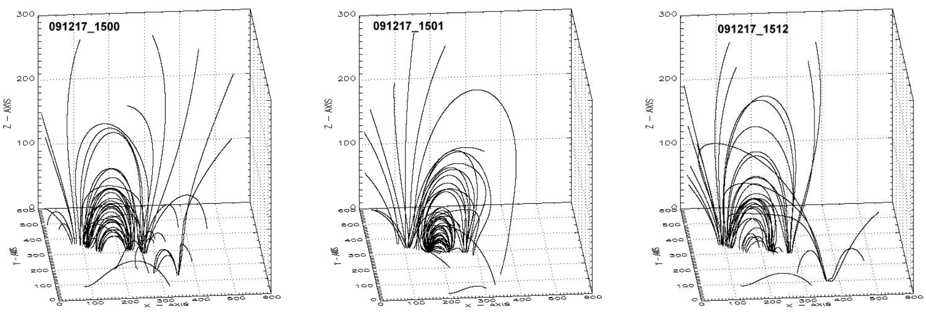

Fig. 8 – The 3D coronal magnetic filed lines extrapolation for the 9.7 flare registered on 17 December 2009 .

of 4000 or -6000 m^{-1}.

The 3D coronal magnetic field extrapolations, at the three same moments at which we have computed the α parameter, are displayed in Fig.8. We notice the opening of the magnetic field lines especially at the X-ray flare momentum, when α had the oscillations around zero value on all grid value (128 pixels of the AR11035 magnetogram).

The results of the force-free field parameter α computations for the AR11035 are similar to that obtained by Dumitrache, Dumitru, and Banciu (2012). The principal conclusion is that α parameter has positive peaks at magnetic flux emergence and negative peaks when the coronal magnetic field lines open and release the magnetic energy.

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