ANALYSIS OF TWO ACTIVE REGIONS BELONGING TO THE SOLAR CYCLE 24

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Abstract. The purpose of this work is to investigate two active regions: AR11073 and AR11076, observed between May 30th and June 7th, 2010, and between June 1st and June 7th, 2010, respectively. We also resume the evolution of these two regions appeared on the solar disk symmetrically with respect to the equator. Both active regions developed few flares. The force-free alpha parameter is considered to be a measure of the twist of the magnetic flux tube. We estimated the values of alpha at different moments of AR11073, the same as for AR11076, in order to investigate a possible symmetrical behavior of the magnetic flux tubes inside both active regions situated in different solar hemispheres. The computation of this parameter was performed using the coronal magnetic field components extrapolated from the MDI/SOHO magnetograms in the active region zones. Then, we took a look at the N-S asymmetry of the active regions registered from the beginning of the solar cycle No. 24 and until June 2010.

Key words: Sun: North-South asymmetry.

1. INTRODUCTION

Solar activity is defined by all phenomena that occur on the surface of and in the solar atmosphere (sunspots, flares, filaments, solar prominences). It is cyclical, with a mean period of about 11 years, called solar cycle and it is quantified by the (daily, monthly, yearly) relative sunspot number and other indices of active phenomena. A solar cycle never ends abruptly before it starts another, as there are periods in which two solar cycles coexist. The start of the next solar cycle manifests is marked by the rise of middle latitude active regions with a reversed magnetic configuration by comparison with the previous cycle sunspots. Statistically, the next cycle is considered to start when a minimum sunspot number is reached, i.e. at the crossing in time of the sunspot number curves of both cycles.

All theories of the periodicity of solar activity are based on substantially working hypotheses, as well as on a modern understanding of sunspots, such as that of G. E. Hale, in which magnetic fields and sunspots are linked. Hale suggested that the sunspot cycle period is of 22 years, covering two polar reversals of the solar magnetic dipole field.

H. W. Babcock (1961) proposed a theory to explain many of the observational features of the magnetic field and sunspot models observed on the Sun. His theory took into account Spörer's law, Maunder's "butterfly diagram", Hale's polarity law, the reversal of the general field of the Sun, the preponderance of preceding spots and configurations of magnetic regions.

The analysis of statistical terms of solar activity during one or more cycles denotes a series of problems related to the N-S asymmetry or to active longitudes. These aspects show the general, but also specific individual characteristics valid for any solar cycle.

The N-S distribution and asymmetries of several solar activity phenomena, such as the relative sunspot numbers, sunspot areas, filament activations, flares and coronal mass ejections (CME) have been investigated by various authors in the literature. We mention here the works of Waldmeier (1948), Waldmeier and Bachmann (1959), Bell and Glazar (1959), Bell (1962), Roy (1977), Verma (1987, 1992, 1993, 2000), Oliver and Ballester (1994), Ataç and Őzgűç (1996), Temmer at al (2001), Gao, Li and Zhong (2007). Bell (1962) found a long-term N-S asymmetry in the sunspot area data. Roy (1977) studied the N-S distribution for sunspots, flares and white light flares for a period of more than two solar cycles and found that the asymmetry in the Northern hemisphere increases with the importance of solar events. Swinson, Koyama and Saito (1986) investigated the relative sunspot numbers and sunspot areas and found a Northern hemisphere predominance of activity for the sunspot numbers between 1947 and 1984 (solar cycle 18-20).

Some authors demonstrated that not only the N-S asymmetry, but also the E-W asymmetry has a high statistical significance, as they are generally accepted and analyzed for miscellaneous solar cycles or periods of solar cycles. Although the solar activity appears symmetrical to the solar equator, some cycles are emphasized by more activity in one hemisphere.

But, are there perfectly symmetrical active regions of the solar equator? Our concern was to understand the behavior of two active regions positioned in different solar hemispheres that are geometrically symmetric relative to the solar equator. We investigated evolution of AR 11073 and AR 11076. If these regions were geometrically symmetric we were concerned to investigate the similarity of their flare activity and the helicity injection. We have estimated the force-free field parameter alpha, as a measure of the torsion of the magnetic flux tube inside both regions. We also extrapolated the 3D coronal magnetic field, using the photospheric magnetic field measured by MDI/SOHO instrument in the active region zones.

Finally, we made an overall estimation of the N-S asymmetry for the period between the beginning of the solar cycle 24 (2008 January 4th) and 2010 June 1st, when both regions were observed.

2. OBSERVATIONAL DATA AND POSITIONS OF AR11073 AND AR11076

The NOAA active regions AR11073 and AR11076 developed symmetrically on the solar disk with respect to the equator. AR11073 was visible in the northern hemisphere starting with 2010 May 30th, while AR 11076 appeared on 2010 June 1st in the southern hemisphere. On June 1st both active regions were almost at the central meridian passage, as displayed in Fig. 1.

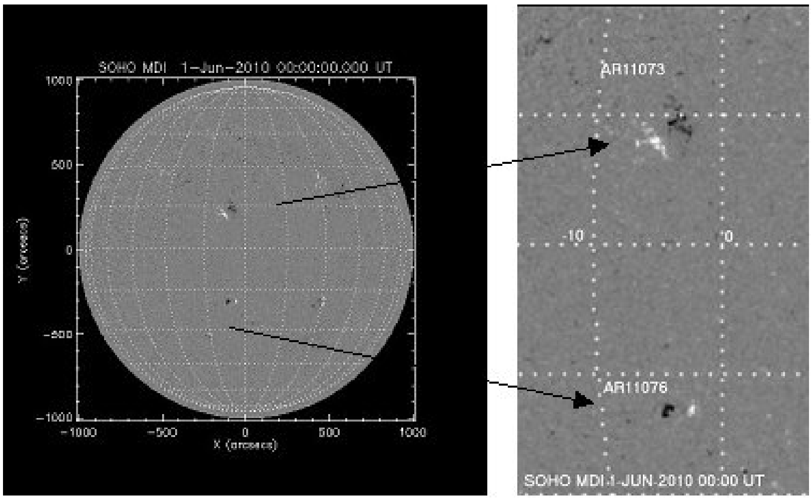

Fig. 1 – MDI/SOHO magnetogram registered at 20:48 UT on June 1, 2010. The AR 11073 and the AR 11076 are located in the northern and southern hemispheres, respectively.

Table 1

Positions of AR NOAA 11073 and AR NOAA 11076 between May 30 and June 7, 2010

Doy	Positions		Doy	Positions	
	AR11073	AR11076		AR11073	AR11076
30 May 2010	N13E21		4 June 2010	N19W44	S27W42
31 May 2010	N13E15		5 June 2010	N21W57	S19W63
1 June 2010	N12W05	S19W07	6 June 2010	N21W70	S19W75
2 June 2010	N12W18	S20W20	7 June 2010	N21W83	S19W88
3 June 2010	N12W31	S19W36			

We have gathered the positions of both active regions for the period between May 30th and June 7th 2010, as listed in Table 1.

Even if the active regions AR 11073 and AR 11076 rose on the solar disk symmetrically relative to the solar equator, from a geometrical point of view, by investigating their evolution we might say that their symmetry is only apparent.

Fig. 2 displays the evolutions of both active regions in Fe 195 Å wavelength (EIT/SOHO) during the period when they have been observed together on the solar disk, i.e. between May 31st and June 7th 2010.

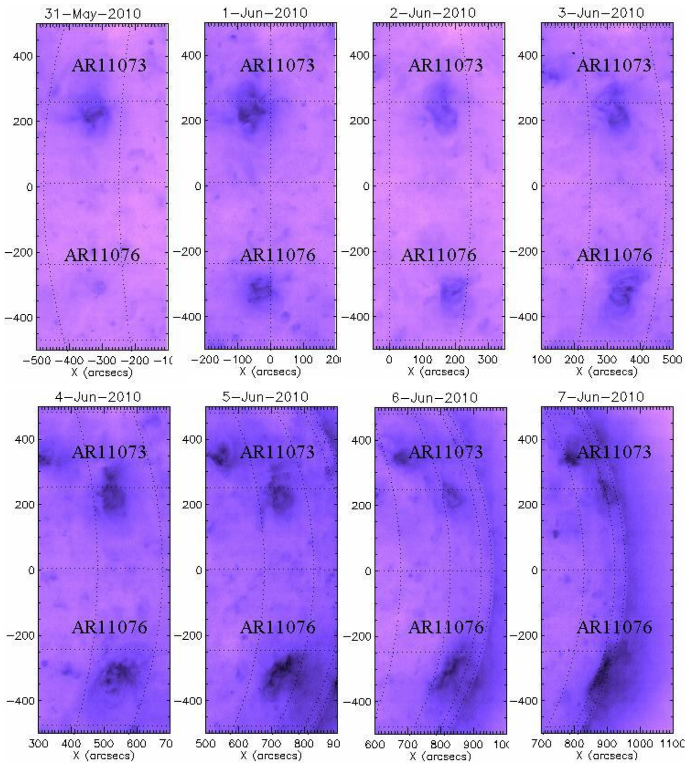

Fig. 2 – EIT images of AR 11073 (North) and AR 11076 (South) evolutions, for the period between May 31 and June 7, 2010.

Table 2

Flares occurred in AR 11076 for the period between May 30 and June 7, 2010

Date	Flares in AR11076			Position
	Begin	Max	End	
June 2	09:10	09:16	09:18	S20W15
	09:59	10:10	10:19	S19W15
	10:20	10:21	10:27	S20W16
	10:53	10:54	10:55	S20W16
June 3	01:58	01:58	02:01	S20W21

According to the international reports for solar activity (`http://www.solarmonitor.org`), we found that the active region from the Southern hemisphere is productive in solar flares, while the region from Northern hemisphere is more quiet. The flares released by AR11076 are listed in Table 2.

Comparing the activity of both regions we remark that AR 11076 has increased in area and sunspot numbers and have generated five flares, while AR 11073 displayed a very low activity with no flare occurred.

One supposes that flares can occur when magnetic helicity is injected from photosphere to increase the magnetic stress and produce the explosion in order that the structure gets a new equilibrium state. For instance, Park et al. (2008) found a helicity accumulation before flare events. Therefore we proceeded to the estimation of alpha parameter at different time moments during the evolution of AR11073 and AR11076, as a measure of twist of the magnetic field lines. We have computed the alpha parameter from the 3D coronal magnetic field extrapolation considering a dipole configuration. This extrapolation was performed using the longitudinal component of the magnetic field registered by MDI/SOHO at the photospheric level in the active regions zone.

The force-free field parameter is given by the formula:

$$\alpha = \frac{1}{B_z}\left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right). \tag{1}$$

The derived magnetic flux density components $\vec{B} = (B_x, B_y, B_z)$ are computed as a dipole:

$$B_x = B_0 \frac{3xz}{r^5}, \quad B_y = B_0 \frac{3yz}{r^5}, \quad B_z = -B_0 \frac{1 - \frac{3z^2}{r^2}}{r^3}, \tag{2}$$

where *x, y* and *z* are the Cartesian coordinates system, *r* is the magnitude of the position vector: $r = \sqrt{x^2 + y^2 + z^2}$, B_0 is the strength of the magnetic field. The dipole model is mathematically simple and can be used to generate reasonable first-order approximations to the actual magnetic field. The magnetic field lines are generated starting from one point on the surface and proceeding out of the surface. These computations were performed using an IDL code written by J. K. Lee (2002).

In this order we have used a set of fourteen MDI magnetograms at different moments during a day and for each day of observations. These time moments are approximately the same for every day and every active region studied.

Fig. 3 displays the results of the alpha force-free field parameter computations for both regions: AR11073 to the left and AR11076 to the right. We remark positive fluctuations of α at the beginning of a flare when magnetic flux emerges, especially on 2 and 3 June, for AR11076, and negative variations when the magnetic field lines open after the flare occurrences.

From the results we found that we cannot speak about a symmetric behavior of the magnetic flux tubes helicity for these two regions.

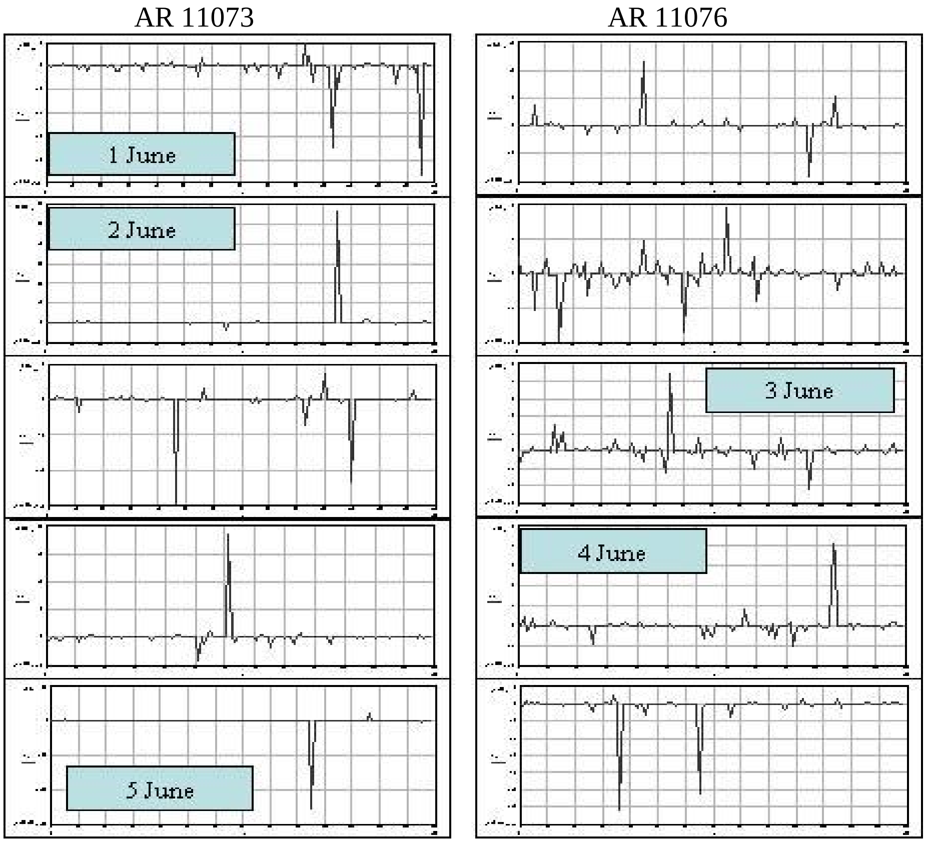

Fig. 3 – Plot of the force-free field parameter for AR 11073 (left) and AR 11076 (right) for the period between June 1 and June 5, 2010.

During these computations we have also obtained the 3D coronal magnetic field configurations at different moments of both active regions evolution and we have compared them with the coronal observations. Fig. 4 displays the 3D extrapolations of the coronal magnetic field lines from MDI magnetograms for both active regions, and for the most important moments as inferred from the alpha parameter computations displayed in Fig. 3. Each 3D plot has in the right parts the corresponding coronal images observed by AIA 131 (Atmospheric Imaging Assembly) instrument on board of SDO (Solar Dynamics Observatory). We notice a good agreement between the observations and our 3D extrapolations.

On 6th and 7th June, both active regions are still visible on the solar disk, but they are very close to the limb, and our algorithm cannot be applied.

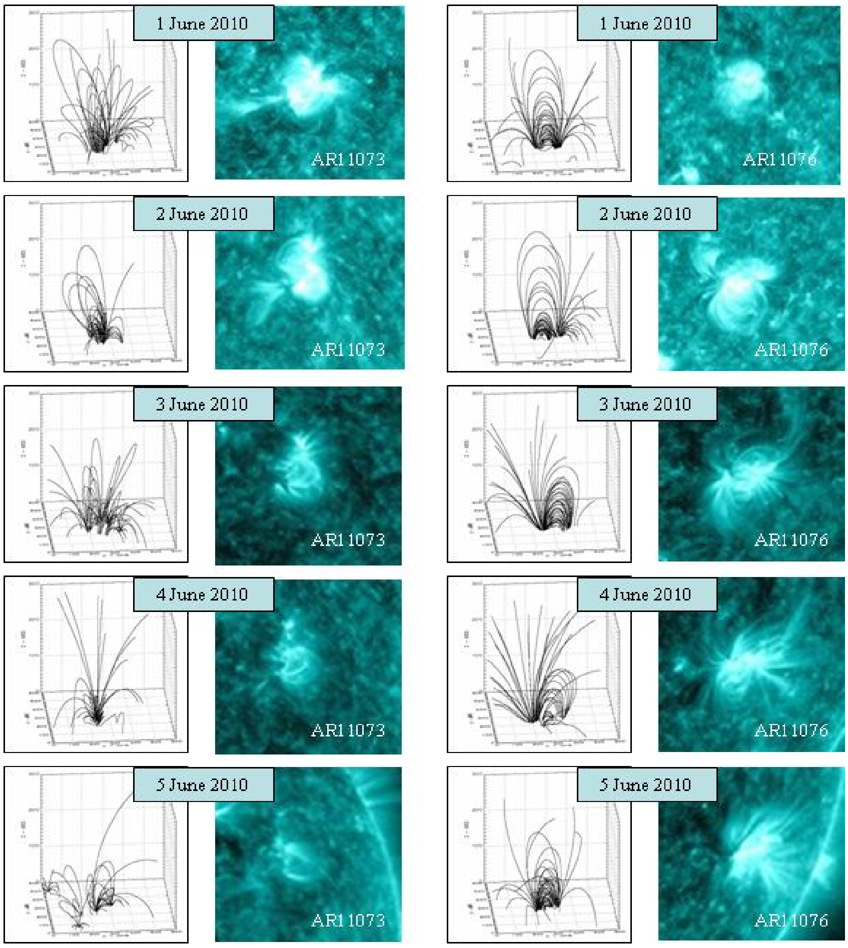

Fig. 4 – The 3D coronal magnetic field extrapolations compared to Fe 131 images registered by AIA/SDO (AR11073 left and AR11076 right).

3. ANALYSIS OF THE N-S ASYMMETRY

Although the Babcock model describes a solar cycle activity that develops symmetrically to the solar equator, actually all cycles are characterized by a predominance of one or another hemisphere activity. This asymmetry changes from a cycle to another and has a long-term variation that it is believed to be a secular one.

We have calculated the North-South distribution for the sunspot groups that have registered since the beginning of solar cycle 24 and until 2010 June 1st, when the AR11073 and AR11076 were observed together on the solar disk. In this order we have identified all sunspot groups of solar cycle 24 with their positions on the solar disk and computed the North-South (N-S) asymmetry A_{NS} index using the formula: $A_{NS} = \frac{N-S}{N+S}$. When $A_{NS} > 0$ the activity in the Northern hemisphere is predominant and when $A_{NS}<0$ the activity in the Southern hemisphere is predominant.

Calculating the index A_{NS} until the appearance of the two regions we previously studied we obtained $A_{NS} = 0.3333$ for the year 2008, $A_{NS} = 0.4166$ for 2009 and $A_{NS} = 0.1351$ for 2010. $A_{NS} = 0.2571$ for all three years period. These values indicate a predominant activity of the Northern hemisphere. Since the calculation is made on a short period of this solar cycle, it remains to be studied whether predictions that claimed the southern hemisphere predominance are confirmed.

We have plotted the butterfly diagram for the first three years of the cycle No. 24 in Fig. 5. As the graphic shows, the northern hemisphere is predominant in activity of active regions for this cycle beginning.

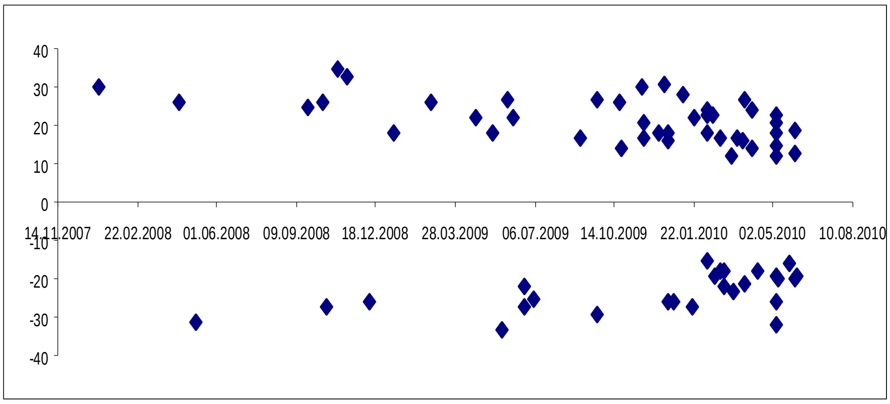

Fig. 5 – The latitudinal positions of active regions for period between 2008 and 2010: the northern sunspot groups are charted above *Ox* axis and the southern ones are charted under the *Ox* axis.

4. CONCLUSIONS

Although the active regions AR 11073 and AR 11076 appeared on the Sun at symmetric positions with respect to the solar equator, we have found that they developed a nonsymmetrical flare activity.

We have estimated the twist in the AR11073 and AR11076 by computing the force-free field parameter at different moments of the day, between 1st and 5th June 2010. The variations of this parameter displayed positive values when a magnetic flux emergence occurred in the respective regions, and negative values after the opening of the magnetic field lines at the explosive events occurrence.

We have analyzed the N-S distribution of the active regions for the beginning of the solar cycle No. 24. We have found that the activity of the northern hemisphere is predominant, although some predictions show that cycle 24 will have a more intense activity in the southern hemisphere. As our investigation covers only few years the study remains open.

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