Growth and decay of ARs: Sunspot areas with Fuzzy Sets + SDO

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Abstract

The emergence of the magnetic field through the photosphere has multiple manifestations and sunspots are the most prominent examples of this. One of the most relevant sunspot properties, to study both its structure and evolution, is the sunspot area: either total, umbra or penumbra area. Recently Schlichenmaier et al. (2010) studied the evolution of the AR NOAA 11024 concluding that, during the penumbra formation, the umbra area remains constant and that the increase of the total sunspot area is caused exclusively by the penumbra growth. In this paper the Schlichenmaier's conclusion is tested, investigating the evolution of the AR NOAA 11428 . Hundreds of HMI Intensitygram images are used, obtained by the Solar Dynamics Observatory, in order to describe the area evolution of the above ARs and estimate the increase and decrease rates for umbra and penumbra areas, separately. A simple magnetohydrodynamic model is then tentatively used in a first approximation to explain the observed decrease rates.

1. INTRODUCTION

The sunspots are one of the most recognized manifestations of interaction between the solar magnetic field and solar plasma. Among the important sunspot properties to study, are the structure and evolution of their area. Being able to separate sunspot substructures is a desirable outcome, since they evolve differently (cf. Fonte and Fernandes 2009 and references).

Previous works as Hathaway & Choudhary (2008) and Schlichenmaier et al. (2010) discuss this topic. In the second case the authors compute the area evolution of the active region (AR) NOAA 11024 and it is concluded that during the growth of the AR the umbral area remains constant.

2. DATA SERIES AND FUZZY AREA

In this study we use the images from Solar Dynamics Observatory (SDO) with 4096 x 4096 pixels and time steps of 10 to 20 minutes. The observed active region is NOAA 11428, with observations starting in 4 March 2012 and lasting for 11 March 2012.

To solve the difficulty to define the limit of the sunspot and in particular to define the limit between umbra and penumbra, we use fuzzy sets to compute the area of the sunspots. Figure 1 shows the intensity histogram obtained from a smoothed image, from which the membership functions to the fuzzy umbra and penumbra may be computed. The degrees of membership of each intensity value to the fuzzy umbra and penumbra are obtained using values U_1, U_2, P_1 and P_2, which delimit respectively the regions of uncertainty corresponding to the separation between the umbra, penumbra and photosphere (Fonte and Fernandes, 2009).

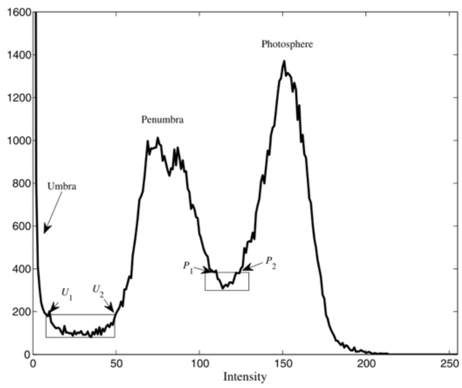

Figure 1. Example of the histogram obtained from one smoothed image. Values U_1 and U_2 represent the limits of the region of transition between the umbra and penumbra and values P_1 and P_2 the limits of the transition between the penumbra and the photosphere. Fonte and Fernandes (2009).

3. AREA CALCULATION AND SIMULATION

The obtained results for the area evolution, using the fuzzy theory, are shown in Figure 2, where the evolution of the minimum and maximum possible values for the area of the total sunspot (respectively the red and green lines), the umbra (respectively the dark blue and purple lines) and the penumbra (respectively the light blue and brown lines) are represented.

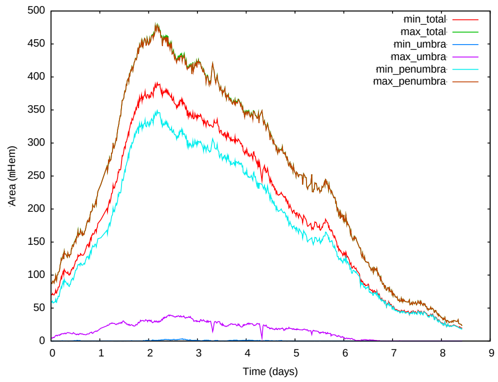

Figure. 2. Area evolution of the active region NOAA 11428.

Using the information from the evolution of the AR area, we compute the maximum sunspot area attained, the growth rate for the maximum umbra and the decay rate for the maximum area of total active region using a linear fit. The results are described in Table 1.

Table 1. Maximum area of AR and the results obtained for the growth and decay rates.

NOAA	Max area (μHem)	Umbra growth rate (μHem/day)	Total area decay rate (μHem/day)
11428	480	12	-85

4. NUMERICAL SIMULATION: DECAY PHASE

To try to understand better the processes involved in the decay phase of AR we test a simple MHD diffusion-advection numerical model in cylindrical coordinates. To simplify the process a circular sunspot is modeled and we assume that $\partial/\partial z = \partial/\partial\theta = 0$, and use a velocity field $u_r = u_0 r/r_0$, where r_0 is the initial radius of the sunspot. The systema of equations that have to be solved are represented in equations (1) and (2)

$$\frac{\partial B_z}{\partial t} = -u_r\frac{\partial B_z}{\partial r} + \eta\left(\frac{\partial^2 B_z}{\partial r^2} + \frac{1}{r}\frac{\partial B_z}{\partial r}\right) \quad (1)$$

$$\frac{\partial B_r}{\partial t} = B_r\frac{\partial u_r}{\partial r} - u_r\frac{\partial B_r}{\partial r} + \eta\left(\frac{\partial^2 B_r}{\partial r^2} + \frac{1}{r}\frac{\partial B_r}{\partial r} - \frac{B_r}{r^2}\right) \quad (2)$$

where η is the magnetic diffusivity and has the value of 0.2 Km^2s^{-1}.

The initial magnetic field is based in the observation of the AR NOAA 10933 structure (Borrero et al. 2011).

The results obtained using this simplified model and considering u_0 equal to -0.035 Km s^{-1} are represented in Table 2 and in Figure 3. The value for u_0 is adjusted in order to produce the best agreement between the observations and the simulation, for different initial radius tested.

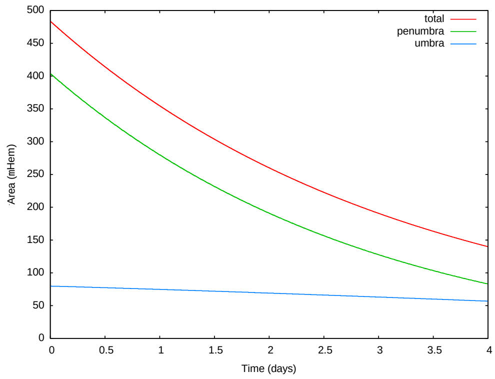

Figure 3. Example of the results obtained using the model.

Table 2. Results obtained using the model compared with the results obtained by fuzzy method using the observations.

NOAA	Simulated decay rate (μHem/day)	Observed decay rate (μHem/day)
11428	-61	-85

5. DISCUSSION AND CONCLUSIONS

Our results seem to be consistent with Schlichenmaier et al. (2010), though not conclusive yet. Although the umbra growth rate is much weaker than the penumbra's, there is some evolution that can be noticed. On the other hand the numerical model indicates that the decay rate of the AR NOAA 11428 could be explained by a global negative radial velocity field.

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