Sunspot characteristics of active regions NOAA 2268 and NOAA 2305

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Abstract. In this paper we present a study of two solar active regions NOAA 2268 and NOAA 2305 observed on January 28 and 29, and also on March 24 and 25 of 2015, respectively. Such active regions produced multiple solar flares including M-class flares as classified in the soft X-ray scale using GOES observation. We mainly use sunspot sketches obtained with a 15 cm diameter Takahashi telescope located at Universidad Nacional San Luis Gonzaga de Ica, Peru. The active regions were characterized on the basis of the sunspots number and the magnetic configuration. We also derived the physical speed of the spots under study, resulting 1.69 and 1.76 km s$^{-1}$ for the period of January and March, respectively. In addition, considering the calculated speeds we estimated the rotation period of the Sun for the dates mentioned above, which result in 28.9 days for January and 27.4 days for March. The present study is complemented with data taken by the Helioseismic and Magnetic Imager (HMI) instrument onboard the Solar Dynamics Observatory (SDO), which provides high resolution solar images in the continuum at 6173 Å as well as magnetograms.

1. Introduction

The Sun is made of plasma, in its core the energy is produced throughout the nuclear fusion building up helium nuclei from hydrogen nuclei by the mean of proton-proton chain reaction [1]. The energy produced in the core can take as long as approximately $10^7$ years of journey through the radiative and convective zones until arrive at the Sun’s surface known as the photosphere, where the plasma level is less dense than its interior [1]. Then the radiation passes through the chromosphere, transition region and the corona where the photons stop interacting with the outer atmosphere. This radiation is observed in almost the entire electromagnetic spectrum.

The Sun does not rotate as a rigid sphere, its equator rotates faster than their poles, this is called differential rotation, moreover, it is responsible of continuous twisting of the magnetic field lines. One of the most characteristic manifestations on the solar surface is the presence of sunspots. They are formed in perturbed areas known as active region (ARs), exhibit complex magnetic configuration and variable in time. A sunspot is composed of a dark central core named umbra and it is surrounded by filamentary radial structures called penumbra. The effective
temperature of the umbra is approximately 3700 K, ∼ 2100 K cooler than the photosphere [1]. The magnetic field of an umbra is around 2600–2900 Gauss [2], which is equivalent to 4000 times more intense than the value of the Earth’s magnetic field, while in the penumbra the magnetic field is in average about 1000 Gauss [1].

In 1844 Heinrich Schwabe noticed a regular variation in the sunspots number, approximately every 10 years. This finding was confirmed by Rudolf Wolf, who in 1849 conducted a more precise estimation and found a variation of 11 years [3]. Every 11 years the Sun moves through a period of fewer, smaller sunspots, prominences, and flares - called “solar minimum” and a period of more, large sunspots, prominences, and flares - called “solar maximum”. This activity of minimum and maximum is connected to a period of 22 years known as the Hale’s cycle. Wolf suggested that it would be more convenient to identify groups of sunspots rather than individual sunspots. Wolf defined the sunspots number as $R = k(10g + n)$, where $g$ is the number of sunspot groups on the solar disk, $n$ the total number of individual spots contained in a sunspot group, and $k$ the correction factor for the observer [3], being $k$ approximately 1.

In the vicinity of the ARs, solar flares may occur releasing large amounts of magnetic energy $10^{26} - 10^{32}$ erg in very short time interval (100–1000 s) [4]. The dissipation of the released magnetic energy leads to the acceleration of non-thermal particles as well as plasma heating in the chromosphere and the corona, resulting in a rapid brightening and simultaneous manifestation in almost the entire electromagnetic spectrum [5]. Solar flares are classified according to the soft X-ray flux variation recorded by the Geostationary Operational Environmental Satellites (GOES). The X-ray fluxes are measured in two bands 0.5–4.0 and 1.0–8.0 Å [6]. The excess of the flux is given in logarithmic scale, meaning levels A and B the lowest which represent mainly “quiet” Sun emissions, levels C, M, and X indicate increases of the flux due to solar activity and very intense events like solar flares. Solar flares can trigger coronal mass ejection (CME) in which large amounts of plasma is ejected into the interplanetary space. When CMEs are directed towards the Earth they are considered potentially geo-effective causing interplanetary shocks and geomagnetic storms, as well as secondary effects on the Earth.

2. Observations and Data

In this work we use mainly sunspot sketches obtained with a 15 cm refractor Takahashi EM-500 telescope, installed at the Facultad de Ciencias, Universidad Nacional San Luis Gonzaga de Ica. This telescope allow us to make observations of the solar photosphere. The data record is based on the projection method, which consists of projecting the solar disk image on a screen where a template of the solar disk of 15 cm diameter is placed, and on which we sketch and record the sunspots (Figure 1). This kind of data acquisition has been carried out regularly for several years and to date we have a large amount of sunspot records. In this paper we focus on the records taken on January 28 and 29 as well as on March 24 and 25 of 2015, respectively.
In order to compare our observations, we have used data from the Helioseismic and Magnetic Imager instrument on board the Solar Dynamics Observatory (SDO) satellite [7]. The HMI instrument provides high-resolution observations of the photosphere at wavelength 6173 Å, with a spatial resolution of 0.6" pixel$^{-1}$. It also provides magnetograms that were used to analyze the magnetic configuration of the ARs. In addition, we have taken extreme-ultraviolet (EUV) data at 211 and 193 Å from the Atmospheric Imaging Assembly (AIA) on board the SDO, which allowed us to follow the morphological evolution of the solar flares associated with the ARs under study.

To verify the intensity and number of flares produced by the ARs of our interest, we used GOES satellite data which provides soft X-rays information from the Sun. In our study we use data in the channels 0.5 - 4.0 Å (3.0 - 25 keV) and 1.0 - 8.0 Å (1.5 - 1.0 keV). In panels (a) of Figures 2 and 3 we present soft X-ray emissions for the period of January 23 to 30 and March 23 to 31 of 2015, respectively. In January emission enhancement were observed in soft X-ray due to several M-class flares that took place between January 28 to 30. In contrast during March the Sun was less active exhibiting mainly C-class flares and only one M-class on March 25. In panels (b) of Figures 2 and 3 we also show EUV band images of the flares during their maximum phase. The EUV images show emissions of the hot corona at temperature of about 2 MK.
Figure 2. Upper left panel: GOES X-ray emission at 0.5-4.0 and 1.0-8.0 Å, corresponding to January 23-30 of 2015. In the bottom panel it is also shown an enlarged view of the emission for January 29. It can be see an increase of the solar activity during the last days of this month. Right panels: extreme-ultraviolet image at 193 Å showing the active region NOAA-2268 during the M-class flare occurred on January 29 of 2015 at 11:39:00 UT.

Figure 3. Same as in Figure 2 but for the period of March 23-31, 2015. During this period the solar activity shows low or moderate levels. Right panels: extreme-ultraviolet image showing the active region NOAA-2305 at 211 Å during the M-class flare occurred on March 25 of 2015 at 04:51:01 UT.
In table 1 we summarize the characteristics of the studied ARs. We present the locations in heliographic coordinates, the sunspots number, the magnetic classification, and the number of flares, respectively. Details of the analyzed sunspots are given in the next section.

| Date       | Time (UT) | Lat. CMD | NOAA | CIASEST | Zurich Class | Magnetic Class | Flares class |
|------------|-----------|----------|------|---------|--------------|---------------|--------------|
| 28/01/2015 | 15:41:00  | S10W05   | 29   | 13      | E            | BG            | 3 1          |
| 29/01/2015 | 14:30:00  | S10W20   | 35   | 23      | F            | BG            | 2 1          |
| 24/03/2015 | 15:44:00  | S08E31   | 15   | 20      | E            | BGD           | 2 -          |
| 25/03/2015 | 15:39:00  | S08E19   | 26   | 26      | E            | BGD           | 1 -          |

3. Analysis and Results
In this section we present the results of our analysis, considering sunspot sketch data obtained with a refractor telescope. The morphology of the sketched sunspots are used to classify them following the Zurich catalog, as well as to determine the magnetic configuration. We also compare the sunspot records with observations by the HMI instrument aboard the SDO satellite. On the other hand, some physical parameters derived from the sketched data are also presented, such as the physical speed of sunspots and the rotation period of the Sun.

3.1. Sunspots characteristics and magnetic configuration
We characterize briefly our sunspot sketches obtained with the projection method, and compare with the observational report provided by the Space Weather Prediction Center (SWPC) of the NOAA. We determine the Wolf’s number considering the sunspots number in our observation. According to the Zurich catalog, the sunspots can be classified as E and F because they are bipolar sunspots surrounded by several penumbrae. In relation to the magnetic configuration, the sunspots are classified as beta-delta (BD) during the period of January, whereas beta-delta-gamma (BDG) for the period of March. The BG configuration is characterized by the mixture of polarities in a dominantly bipolar distribution, while in case of BDG the configuration of the sunspots exhibit two cores sharing a common penumbra. This latter known as delta spots are more prolific to trigger solar flares [6][8].

In left panels of Figure (4) we present our sunspot sketches on January 29 and March 25, 2015, respectively. For comparison it is also shown observations of the photosphere at 6173 Å (middle panels) and their corresponding magnetograms (right panels) taken by the HMI instrument. From the figure we see that our sunspot sketches obtained with the projection method are in good agreement in terms of morphology and sunspots number, with those observed in HMI images. It is also noted that the magnetograms for the dates mentioned above exhibit a complex magnetic configuration, particularly on January 29, where the positive polarity (white region) is surrounded by the negative polarity (black region). Indeed, because the complexity and the existence of delta sunspots in the studied ARs, several solar flares have occurred (see Table 1).

5 National Oceanic and Atmospheric Administration
6 Centro de Investigación de la Actividad Solar y sus Efectos sobre la Tierra
7 Central Meridian Distance
8 Beta-Gamma
9 Beta-Gamma-Delta
Figure 4. Left panels: sunspot records obtained with the projection method on January 29 and March 25, 2015. Middle and right panels: images observed in the continuum (photosphere, 6173 Å) by HMI onboard the SDO satellite and their corresponding magnetograms (positive polarity: white color; negative polarity: black color).

3.2. Physical speed of the sunspots

Taking into account the sunspot sketches obtained on January 28 and 29, 2015 at $t_1=14:30$ and at $t_2=15:41$ UT, respectively, we proceed to calculate the physical speed $v$ considering the following relation of proportionality as in [9],

$$\frac{d_{cl}}{D} = \frac{m_{cl}}{m_{de}}$$

(1)

Here $D$ denotes the “real” diameter or the angular size of the Sun, being equal to two times the solar radius ($2R_s$), where $R_s \approx 974.3$ arc-seconds ($6.82 \times 10^5$ km) as estimated from the ephemerides provided by the Solarsoft\(^{10}\). On the other hand, $d_{cl}$ is the “real” diameter of the latitude in which the sunspots would be located. Similarly, $m_{de}$ and $md_{cl}$ represent the “apparent” diameter or solar equator and the “apparent” latitude in which the sunspot is observed, both variables estimated from our records resulting in 15.0 and 14.9 cm, respectively.

So, equation (1) is reduced to $d_{cl} = 0.99D$; taking for $D = 1.36 \times 10^6$ km we obtain the value of $d_{cl} = 1.35 \times 10^5$ km.

In Figure (5) a schematic picture of the sunspot trajectory is shown, in which the sunspots depicted by the dark structures on the disk travel a distance $d$ from day-1 to day-2. This represents the “real” distance traveled by the sunspots from January 28 to 29. We measure $d$ by using the following relation

$$\frac{d}{d_{cl}} = \frac{md}{md_{cl}}$$

(2)

where $md$ is the apparent distance traveled by the sunspot in our sketch, being equal to 1.7 cm. Having calculated $d_{cl}$ previously, we get $d = 1.54 \times 10^5$ km. Next, the physical speed is derived as follows

\(^{10}\)The Solarsoft system is a set of integrated software libraries, data bases, and utilities which provide data analysis environment for solar physics
\[ v = \frac{d}{\Delta t} \]  

In our analysis, \( \Delta t = 24 \text{ hours} + (t_2 - t_1) \) is the time spent by the sunspot for traveling from the initial position at \( t_1 \) to the final position arriving at \( t_2 \), that is, \( \Delta t = 90660 \text{ seconds} \). Therefore the physical speed \( v \) is \( 1.69 \text{ km s}^{-1} \).

![Figure 5](image)

**Figure 5.** Schematic picture of the procedure we used for the calculation of sunspot physical speeds and rotation period of the Sun. Panel (a) shows the position of the sunspot at time \( t_1 \), panel (b) shows the position of the same sunspot at time \( t_2 \), in panel (c) we show a combined image showing the sunspot displacement \( d \) from \( t_1 \) to \( t_2 \).

### 3.3. Rotation period of the Sun

The rotation period was calculated tracing the sunspot trajectory. Following a standard procedure we estimate (i) the distance \( c \) traveled by the sunspot during a solar rotation that in analogy it would describe a circumference, (ii) such a distance could be calculated using the circumference of the circle \( c = 2\pi r_s \), here \( r_s \) is the radius of the circumference where the sunspot is located. In our case the previous equation reduces to \( c = \pi dcl \), since \( dcl \) represents the diameter of the latitude where the sunspot is located at, then we obtain \( c = 4.24 \times 10^6 \text{ km} \). Therefore, the rotation period is

\[ T = \frac{c}{v} = \frac{4.24 \times 10^6 \text{ km}}{1.69 \text{ km s}^{-1}} = 2.50 \times 10^6 \text{ seconds} = 28.9 \text{ days} \]  

(4)

Similar analysis has been done for the sunspot records taken on Mach 24 and 25, considering the following parameters: \( \Delta t = 86100 \text{ seconds} \), \( m_d = 1.7 \text{ cm} \), \( m_dcl = 14.9 \text{ cm} \) and \( R_s \approx 962.91 \text{ arc-seconds} \) \((6.74 \times 10^5 \text{ km})\). Using equation (3) we obtained the physical speed \( v=1.76 \text{ km s}^{-1} \). Regarding the rotation period, we got \( T = 27.4 \text{ days} \).

### 4. Summary and Conclusions

We studied the ARs NOAA 2268 and NOAA 2305 during the periods January 28 to 29, and March 24 to 25 of 2015, respectively. From the GOES soft X-ray observations we identified several solar flares associated with the studied ARs, including M and C-class flares. In the magnetograms we confirmed the complex magnetic configuration of the ARs, in consequence the number of observed flares for the studied period.
By using our sunspot records obtained with the projection method, we derived the physical speed of the sunspots. From these results we also estimated the rotation period of the Sun. Our results are quite similar with the standard values. On the other hand, the morphological characteristics we found in our sunspot observations are very close to that observed in the HMI continuum images. Finally, despite the projection method to record sunspots is not considered a sophisticated technique nowadays, still it can be used to calculated basic physical parameters of the Sun such as we have presented in this work.

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6. Reference lists
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