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# An Analysis Study of Sunspot Numbers and Solar Radio Flux (10.7 cm) for the Raising Phase of the Solar Cycle 25

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**Abstract:**

The present study used the solar radio flux (F10.7 cm) and the sunspot number (SSN) created throughout five years, beginning in December 2019 and ending in December 2023, for the solar cycle 25. The number of sunspots and the solar radio flux were measured monthly using data from the WDC-SILSO, Royal Observatory of Belgium, Brussels. A five-year link between the two variables was constructed, marking the start of the solar cycle 25 (2019 to 2023) years. Understanding their relationship and the degree to which they impact solar activity, which affects terrestrial and space technology, is also important. For sunspots, the highest value reached (127.6) in 2023, while the lowest value (1.8) was attained in 2019. With time, the value increased like the number of spots, rising and falling until it achieved its maximum value over the course of the five years (159.1 radio flux number) in 2023. Both serve as markers for rising and falling solar activity levels. Through statistical analysis and graphs for each of them that depict the pattern of solar activity for that time period, this study demonstrated the strong, persistent association between the number of sunspots and solar radio flux. Additionally, helpfully, the rising phases of the solar cycles 24 and 25 were compared over the same period, including the first five years. This forecasts what the 25th cycle's supplemental chart will look like for the next five years.

***Keywords:*** Solar cycles, sunspots, solar radio flux (F 10.7 cm), solar activity.

# دراسة تحليلية لعدد البقع الشمسية والتدفق الراديوي الشمسي (10سم) للطور الصاعد من الدورة الشمسية 25

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**الخلاصة**

في هذه الدراسة تم إجراء دراسة احصائية لعدد البقع الشمسية التي تكونت خلال خمس سنوات وكذلك التدفق الراديوي الشمسي (عند الطول الموجي 10.7سم) ابتداء من شهرايلول 2019 حتى شهرايلول 2023 للدورة الشمسية 25 حيث تم أخذ بيانات شهرية لعدد البقع الشمسية والتدفق الراديوي الشمسي من ( المرصد الملكي لبلجيكا، بروكسل) وتم رسم العلاقة بينهما لمدة خمس سنوات، والذي يمثل بداية الدورة الشمسية 25 لسنوات من (2019 إلى 2023). وكذلك معرفة العلاقة بينهما ومدى تأثيرهما على النشاط الشمسي والذي بدوره يمتد تأثيره إلى التكنولوجيا الأرضية والفضائية، حيث أعلى قيمة تم الوصول لها (127.6) في 2023 وأدنى قيمة (1.8) في 2019 للبقع الشمسية. بينما التدفق الراديوي الشمسي كانت قيمته ترتفع وتخفض

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بتناوب مع استمرار بزيادة مثل عدد البقع مع مرور الوقت حتى وصلت الى اعلى قيمة له خلال الخمس سنوات (159.1عدد التدفق الراديوي) في سنة 2023 . وكلاهما يمثل مؤشر الزيادة والنقصان في النشاط الشمسي. بينت هذه الدراسة العلاقة الجيدة المتوافقة بين عدد البقع الشمسية والتدفق الراديوي الشمسي من خلال الدراسة الاحصائية والرسوم البيانية لكل منهما اللذان يمثلان اسلوب النشاط الشمسي لتلك الفترة وتم ايضا مقارنة الطور الصاعد لدورة الشمسية 24 مع الطور الصاعد لدورة الشمسية25 لنفس الفترة ايضا لخمس السنوات الاولى ومما يساعد ايضا على التنبؤ بما سوف يكون اليه الشكل البياني التكميلي لدورة 25 لسنوات الخمس المقبلة.

## 1. Introduction:

For thousands of years, the Sun has been a model star and a significant subject of scientific and cultural inquiry. It is a study topic because of its closeness to the Earth and significance for the origin of heat and light in the planet's atmosphere. Its significant influence on the Earth and its strata has led to extensive research. The Sun is divided into two primary regions: the inner region, which is typically where a number of significant interactions take place. Energy is produced when nuclear fusion takes place. Radiation is released from the exterior area as it attempts to disperse this energy. Gamma and X-rays make up the majority of this radiation, and energy also disperses through the movement of heat [1,2]. In one study, four alternative methods—Linear Regression (LR), Random Forest (RF), Radial Basis Function (RBF), and Support Vector Machine (SVM)—were used to predict the maximum capacity of the solar cycle. The SILSO global data center, the Royal Observatory in Belgium, provided the monthly sunspot data used in this study, which covered the cycles from 10 to 24 from 1856 to June 2018. All of the earlier studies predicted that the peak of the solar cycle 25 would fall between 2023 and 2024, where Cycle 25 was predicted to be either less than or similar to cycle 24 by the majority of earlier research employing the aforementioned methodologies [3-5]. While records of observations in China date back to 2000 years, the study of sunspots started at the beginning of the seventeenth century. They were closely monitored, and the long-term behavior of sunspots was elucidated by examining how their features evolved over time on various time scales, including days, months, and years, with respect to energy intensity, field intensity, area, and so forth [6]. The solar cycle is the change in solar activity over time. It begins weak, then rises little by little until it reaches its peak, then decreases again. The reason for the small number of sunspots at the beginning of the cycle is that the Sun’s magnetic field is weak, and this weakness in the field hinders the appearance of sunspots, but with the passage of time or over time [7]

In the realm of morphological image processing, methods were employed to detect the outer limits of sunspots by changing the upper hat. This permits discoveries to be made in a single step by eliminating any profile to darken the edges. Additionally, Watson and associates employed a technique in 2009, using a distinct shade, after developing the code for these areas to separate them. There were various studies to predict solar cycles, such as a comprehensive review of methods in Petrovay 2020, while Jiang et al. 2023 presented a comparison between the several previous solar cycle 25 templates and prediction models for solar activity for sunspot numbers and magnetic flux [8-10].

This investigation will reveal that the Sun's magnetic field becomes stronger, leading to a rise in the number of sunspots. We have attempted to study solar activity for the first five years of the solar cycle 25, from the number of sunspots and solar radio flux, because it is increasingly important to consider the nature of the solar activity and its fluctuation in the recent period owing to its relationship to the Earth. In addition, an analysis of its activity and statistics based on the number of sunspots (SSN) from 2019 to 2023.

## 2. Theoretical part

### 2.1 Solar activity:

Variations in radiation and features, as well as other effects on the solar structure, result from solar activity. This is becoming more important because it affects many other areas [8]. Sunspots, solar flares, solar winds, coronal mass ejections, energetic particles, and solar flux 10.7 cm are all examples of solar activity [1], which encompasses any natural occurrence on or inside the Sun. Solar emissions vary in frequency and strength due to the fact that they often contain large quantities of energy and mass, which change as the Sun goes through its phases of a cycle [11]. The sunspots that have been researched here are solar activities that are typically visible above the Sun's atmosphere. Sunspots are seen as an indication of solar activity, with a cyclical rise and fall that lasts around 11 years [12].

### 2.2 Solar cycle:

The number of sunspots visible on the surface of the Sun systematically increases and decreases, reaching a maximum every 11 years; this process is called the solar cycle [1]. The Sun's radiation levels and other visible features, such as sunspots and flares, undergo periodic changes as a result of solar activity. The average duration of the solar cycle is around 11 years, with a range of 9–13 years. The sunspot cycle is formed by the magnetic field, according to the magnetohydrodynamic (MHD) theory, which includes more complex interactions between plasma flows and magnetic fields in the solar convection zone (SCZ) [13, 14]. Figure 1 shows that solar activity cycles vary according to changes in the secular time scale that occurred during big minimums (e.g., Vecchio et al. 2019), such as the Maunder minimum from 1645 to 1715 (Hathaway 2015) and the Grand Maxima periods from Usoskin et al. (2007).

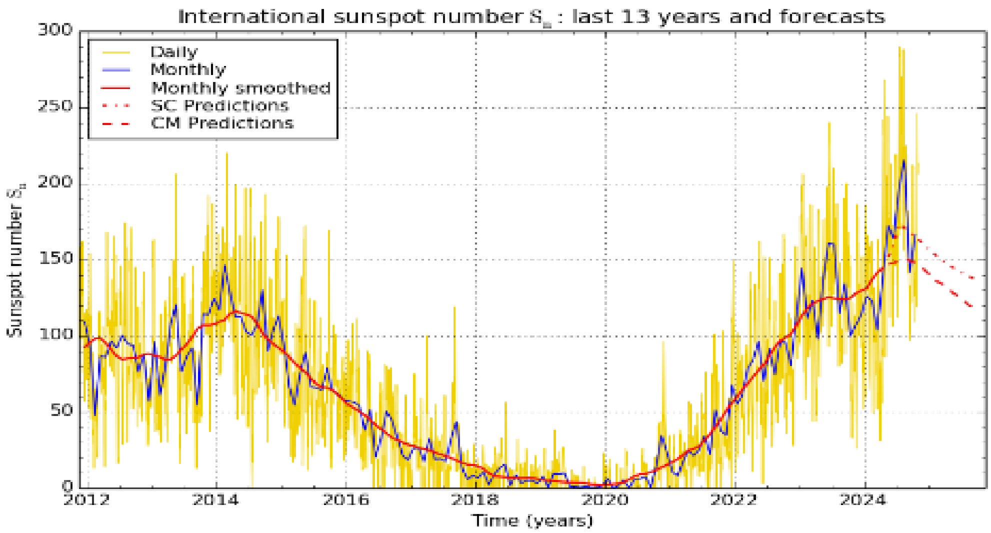


**Figure 1:** The relationship between the sunspot number and times for the solar cycle 24 and the rising phase of the solar cycle 25 [15].

### 2.3 The Butterfly Diagram:

One such illustration is the butterfly diagram, which shows the sunspot clusters in relation to their locations throughout time and solar latitude. Figure 2 shows solar activity in the Northern and Southern Hemispheres, depicted as butterfly wings made of the Sun's rays. Over the course of a butterfly's life cycle, its wing span varies unless there is a very strong solar cycle, these cycles will not overlap for more than a year or two at the most [16].

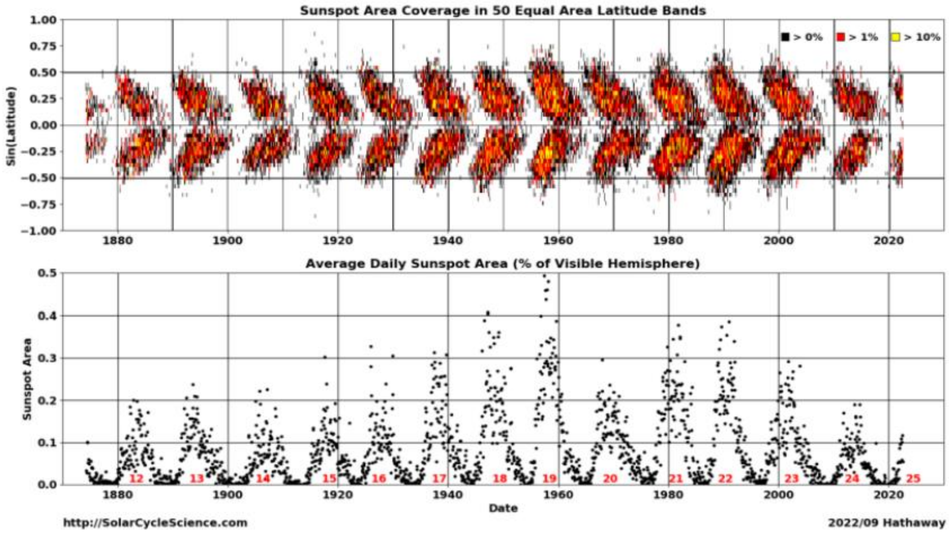


**Figure 2:** A diagram showing the solar cycles over several years that create a butterfly outline [16].

## 2.4 Sunspot :

Darker and cooler areas called sunspots emerge in the photosphere of the sun and are thought to be active areas. Couples, not individuals, are the most common sightings. The photosphere can become a breeding ground for sunspots, which are surface spots on the Sun. Extremely low surface temperatures are characterized as regions with strong magnetic fields that prevent heat from escaping, hence the local temperature is lower than the ambient air. The size of each sunspot increases and decreases in a regular pattern of eleven years. The solar cycle describes this phenomenon [1]. The presence of magnetic field lines within sunspots, which start at the photosphere's core and progress into the solar corona, indicates that these spots are magnetic structures. A black core defines each sunspot. There are often two parts to sunspots: Umbra and Penumbra instead of the shadow, which is dark and contains the core, and the penumbra, which is less dark and shaped like a halo. These sunspots can be distinguished from the typically tiny holes by the presence of a semi-shadow region [17]. On average, there is a 1500-degree temperature differential between these locations and the surrounding regions due to the effect of magnetic fields, which act to retain some of the convective energy [10, 17]. Due to their vast size distribution and the fact that their diameters can occasionally reach $6x10^4$ km or even greater, most sunspots that are visible to the human eye appear to be multiple smaller spots rather than a single larger one [4]. Two sunspots, one facing north magnetically and the other south magnetically, will start to form, and they can be connected to lines in the magnetic field [1]. For over 400 years, researchers have had access to data sets and historical usage of the sunspot number (SN), an indication of solar activity. Midway through the nineteenth century, Rudolf Wolf came up with an equation to determine the most probable number of sunspot clusters. The legendary Wolff technique [16] describes this approach.

$$SN = k\,(10\,g + s) \qquad \text{.........(1)}$$

The variable k represents the scaling factor. As a result, SN = 11 is the result of counting a single sunspot group as one spot on the Sun (s = 1).

### 2.5 Smoothed Sunspot Number(SSN):

Every day, using the Wolff equation, scientists determine the sunspot number, which serves as a worldwide measure of solar activity that allows us to track the progression of the solar cycle [11]. The number of sunspots changes substantially depending on its source, and that it is computed monthly, annually, or for a particular year has been observed [18].

### 2.6 Solar radio flux (F 10.7 cm):

The Sun's continuous output of radio waves with a frequency of 10.7 cm, or 2800 MHz, is called a solar radio flux (unit. 1sfu = $10^{-22}$ W·m$^{-2}$·Hz$^{-1}$) This flow has been continuously measured by the Canadian Solar Energy Monitoring Program every day since 1946. Using solar energy values, one may determine the energy obtained [18]. In addition to solar magnetic activity and UV radiation emissions, extreme ultraviolet (EUV) light can be used to measure a solar eclipse [11]. Major space weather events can affect power and electricity networks, worldwide communications, and transportation, including solar flares, coronal mass eruptions, and magnetic storms, all of which are studied by huge satellites over the eleven-year solar cycle [9]. Many areas rely on accurate forecasts, but those involving weather and the environment are particularly dependent on accurate forecasts that boost efficiency in terms of dependability and safety [18]. The darker portion of a sunspot is known as the shadow, while the lighter portion is known as the semi-shadow. The density of sunspots is crucial to comprehending atmospheric physics, and it is essential to know how these two areas vary from one another. A big shadow of intensity typically has two, three, or even more points, and it seems like this intensity is quite variable and complex [13,19]. As mentioned in the eighth point, space weather storms—also known as geomagnetic storms—cause substantial material and financial damage to satellites, power distribution, and aviation, among other societal events. Statistical estimations are utilized to determine the likelihood of catastrophic space storms happening, which helps in avoiding or reducing the impact of space weather [20]. Sunspot counts on the solar disk were not observed to change quasi-periodically during the many solar cycles until 175 years ago [21].

## 3. Results and Discussions

In this research, the data values for the monthly smoothed sunspot numbers and the solar radio flux (10.7 cm) were taken from the monthly data (definitive and provisional) monthly mean sunspot numbers from WDC-SILSO, Royal Observatory of Belgium, Brussels (sidc.oma.be/silso/home) [22]. For just the first five years, it marks the beginning of the solar cycle 25, which began in December 2019 and continues until the completion of the 11-year solar cycle. A representation of the sunspots for cycle 25 from the end of the year 2019 in the eleventh month is considered the end of cycle 24 and the beginning of cycle 25, and this changing behavior is clear in table (1).

**Table 1:** Shows the number of sunspots (SNN) generated in the year 2019, which represents the end of the solar cycle 24, and part of it contains the beginning of the solar cycle 25

| Months | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sun Spots No. (SNN 2019)** | 5.4 | 5 | 4.5 | 4.3 | 3.9 | 3.7 | 3.5 | 3.4 | 3.1 | 2.6 | 2 | 1.8 |

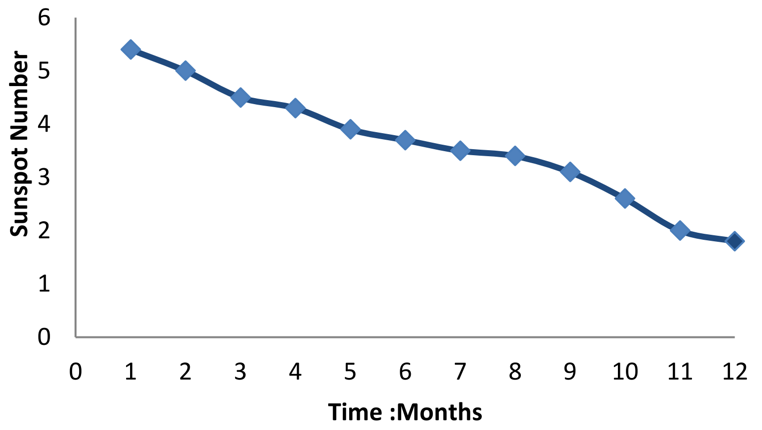


**Figure 3:** The number of sunspots in 2019, which marks the end of the solar cycle 24 and the beginning of the solar cycle 25

This research presents a study of solar activity, which is attributed to the recent rise in solar activity, which is sunspots, a statistical study for the first five years from 2019 to 2023 of the solar cycle 25. A statistical study of the number of sunspots formed during this cycle, where the second table contains the number of sunspots for the first five years of cycle 25, which were taken monthly for each year. We notice that the number of these sunspots increases continuously during each month of the year until it reaches its highest value and then begins to decrease after that since cycle 25 is still at its beginning. That is, the first five years only, we will only notice the increase, noting that the highest value is according to studies, unless it is communicated because it is likely that it will be in the year 2024.

**Table 2:** The number of sunspots (SNN) generated in the first years from 2020 to 2023 of the solar cycle 25.

| Months | Sunspot Number (SSN) | | | |
|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2023 |
| Jan | 2.2 | 17.2 | 60.1 | 113.3 |
| Feb | 2.7 | 19.0 | 64.7 | 117.8 |
| Mar | 3.0 | 21.7 | 68.7 | 121.0 |
| Apr | 3.6 | 24.8 | 73.0 | 122.7 |
| May | 5.6 | 25.8 | 77.4 | 123.9 |
| Jun | 7.9 | 27.6 | 81.1 | 125.6 |
| Jul | 9.0 | 31.4 | 86.7 | 125.5 |
| Aug | 9.5 | 35.4 | 92.6 | 125.4 |
| Sep | 10.5 | 40.2 | 96.5 | 126.1 |
| Oct | 11.9 | 45.2 | 99.0 | 127.2 |
| Nov | 13.6 | 50.8 | 101.2 | 127.6 |
| Dec | 15.3 | 55.9 | 106.7 | 125.2 |

In the second table, we notice that the beginning of cycle 25 was in the last month of the year 2019, that is, in December, and it contained the lowest value of sunspots for their first appearance. The value was 1.8, and it was the gateway to cycle 25 which usually appeared small in size and was often in the form of pairs. However, they appeared they were alone, and sunspots were abundant in the central regions of the Sun, where they were close to the equator, and they continued their movement across the solar disk from east to west, as they followed the movement of the Sun's rotation. Since the Sun's magnetic field was weak at the beginning of the solar cycle, we saw a small number of sunspots at the beginning of the cycle. Sunspots took about two weeks to move from the eastern end to the western end on the surface of the Sun, and when sunspots were formed, the life cycle took periods that extended from days to weeks and may also extend to months. We notice that the number increased continuously from 1.8 in December 2019 to 125.2 in December 2023. Note that the number of sunspots for the last months of the year 2023, taken from the aforementioned location, are still expected values and are not final.

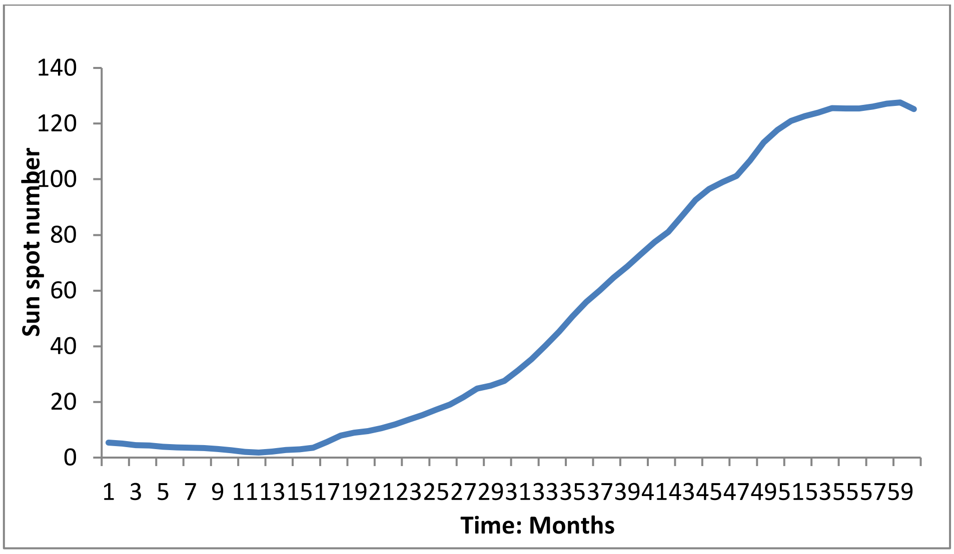


**Figure 4:** The increasing number of sunspots (SSN) during the first five years of the Solar Cycle 25

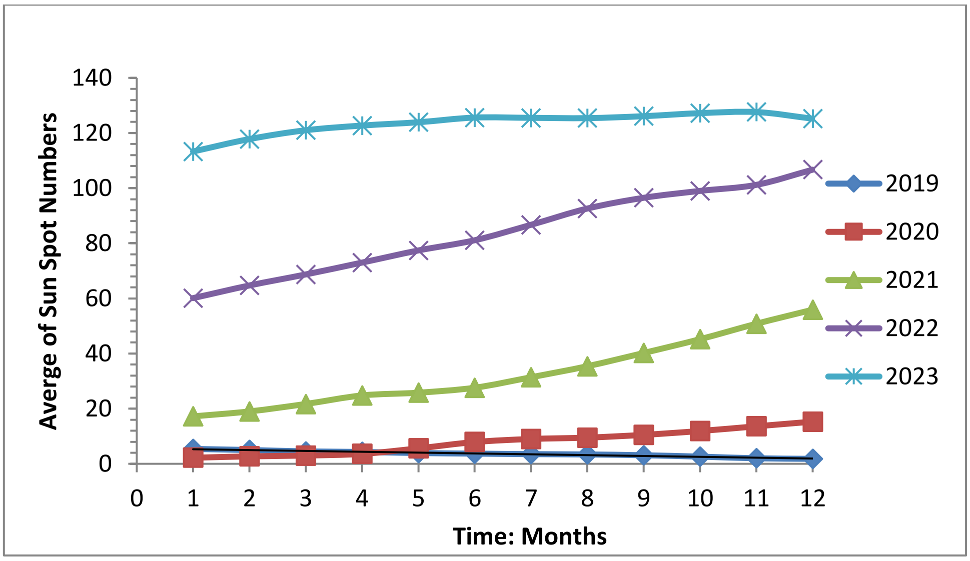


**Figure 5:** The average number of sunspots for the years (2019-2020-2021-2022-2023).

Figure 5 represents the variation of the rate of increasing sunspots for each of the years (2019-2020-2021-2022-2023) and compares them with each other, as it shows how every year in which cycle 25 advances. The rate of sunspots increases for each month of the year, and this increase continues with the increase in solar activity represented by an increase in the number of spots which is due to the increase in the activity of the Sun, and over time they become more numerous and larger in size and continue clearly and can be seen as dark spots whose location changes over time and also continues to change in polarity. We also notice in the figure that only in 2019 the average number of sunspots is in a different direction for the rest of the four years, because it combines the end of solar cycle 24 and the beginning of solar cycle 25.

In Table 3, we see the solar radio flux, which is also apparent and an indicator of solar activity, as it contains the final for the 24th cycle and the beginning of its value for the 25th cycle, represented in the month of December, and this is what we will notice in its graph.

**Table 3:** Solar radio flux (F 10.7 cm), of solar activity, as it contains the final values for the 24th cycle and the beginning of its value for the 25th cycle,

| Months | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Solar radio flux sfu ( 2019) | 70 | 69.8 | 69.7 | 69.6 | 69.6 | 69.7 | 69.7 | 69.8 | 69.7 | 69.5 | 69.3 | 69.3 |

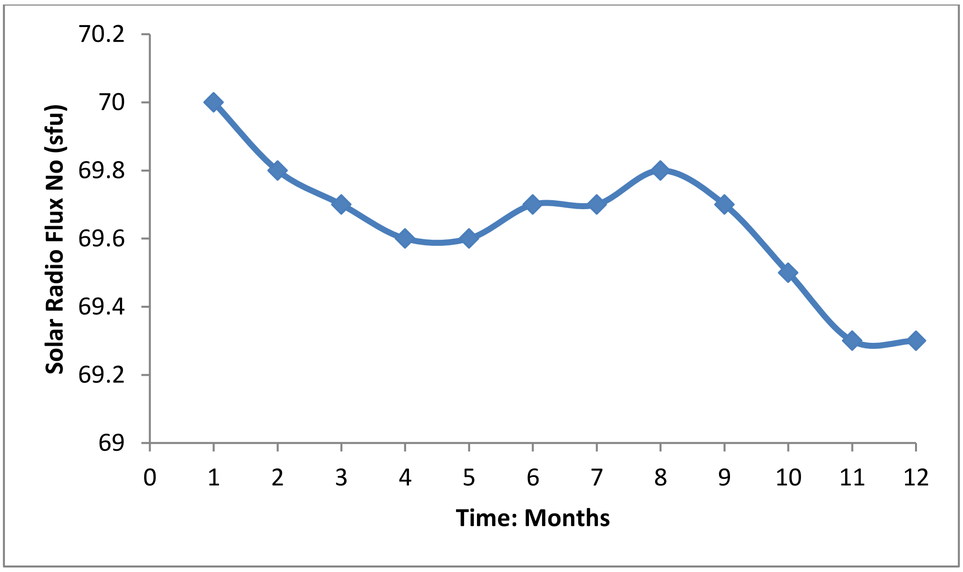


**Figure 6:** The radio flux (F 10.7 cm) in the year 2019 for the final values of cycle 24 and the beginning values of cycle 25

In order to study the solar cycle 25, we can see that the solar radio flux started to increase in 2020 and kept going up. Certain values would go up, while others would go down. The data for the solar radio flux in Table 4 came from (radio flux of 10.7 cm were taken from the monthly data (definitive and provisional) monthly mean sunspot numbers from WDC-SILSO, Royal Observatory of Belgium, Brussels (sidc.oma.be/silso/home)). [22] Since radio waves are always there, even when sunspots aren't visible, they're a good fit for measuring solar activity.

**Table 4:** Solar radio flux, of solar activity in the first years of the beginning of its value for the 25th cycle,

| Months | Solar Radio Flux (sfu ) | | | |
|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2023 |
| Jan | 69.5 | 17.2 | 104.7 | 148.6 |
| Feb | 69.8 | 19 | 108.4 | 152.3 |
| Mar | 70.1 | 21.7 | 112.1 | 154.7 |
| Apr | 70.5 | 24.8 | 115.9 | 156 |
| May | 71.6 | 25.8 | 119.2 | 157.6 |
| Jun | 73 | 27.6 | 122.4 | 159.1 |
| Jul | 73.8 | 31.4 | 127.3 | 157.8 |
| Aug | 74.1 | 35.4 | 133 | 155 |
| Sep | 74.5 | 40.2 | 137.4 | 152.9 |
| Oct | 75 | 45.2 | 139.8 | 151.6 |
| Nov | 75.5 | 50.8 | 141.4 | 149.9 |
| Dec | 76.2 | 55.9 | 144.3 | 147.1 |

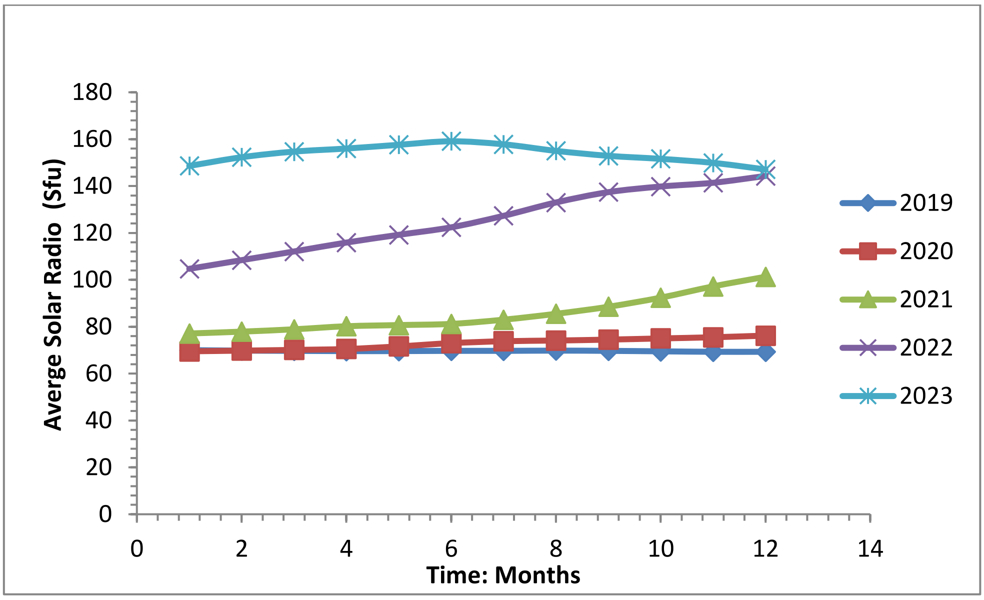


**Figure 7:** The average solar radio flux (F 10.7 cm) for each year, starting from the year 2019 until 2023

Figures 7 shows the solar radio flux (F 10.7 cm) for each year, starting from the year 2019 until 2023, so that we can see the extent of the compatibility of the radio flux for each of its months of the year and the extent of the compatibility between years of the flux with the continuity of its value with the continuous increase represented by the increase in solar activity.

**Table 5:** Shows the relationship between the average sunspot number and the average solar radio flux during the solar cycle 25 from the year 2019 until 2023**.**

| Years | Total solar radio flux(sfu) | Total sunspot number |
|---|---|---|
| **2019** | 69.64167 | 3.6 |
| **2020** | 72.8 | 7.9 |
| **2021** | 85.325 | 32.91567 |
| **2022** | 125.4917 | 83.975 |
| **2023** | 153.55 | 123.4417 |

Figure 8 shows the rate of sunspots continues to increase with the rate of solar radio flux (F 10.7 cm)for each of the five years from 2019 to 2023, as the values have converged significantly to each other, and we notice that they are in one position in the year 2023.

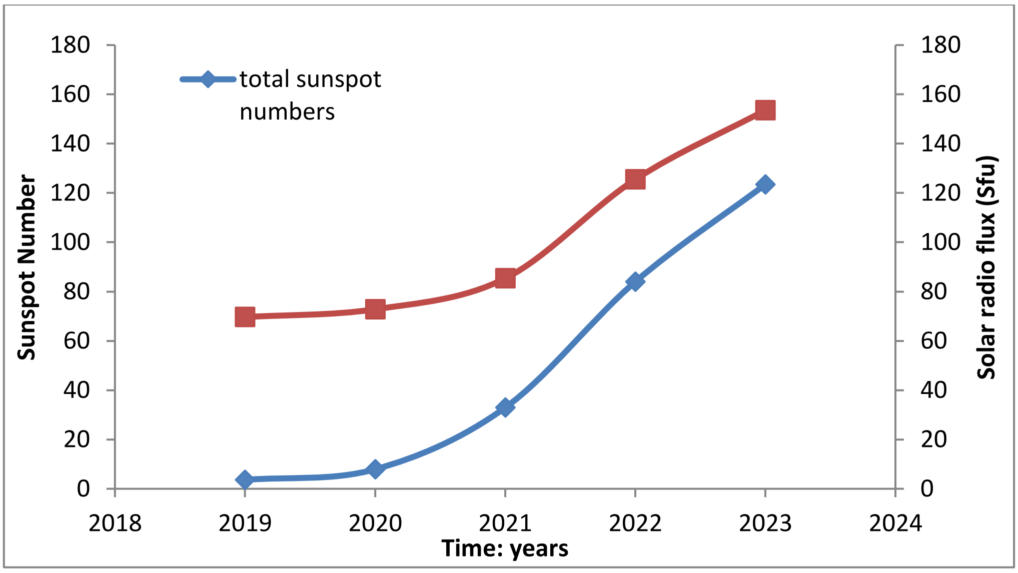


**Figure 8:** The total sunspot number (SSN) with the average of solar radio flux (F 10.7 cm) during the solar cycle 25

The fourth-order polynomial fittings were performed and functions are given in Figure 9 ( a and b), the highest values for the five years of solar cycle 24 were compared with the five years of solar cycle 25 with regard to the number of observed sunspots. We notice from the figure that the first peak in cycle 24 was between 80 and 100, while the greatest peak was compared to 140. As for the highest values for cycle 25, the peak was close to 140, while the greatest peak was close to 160.

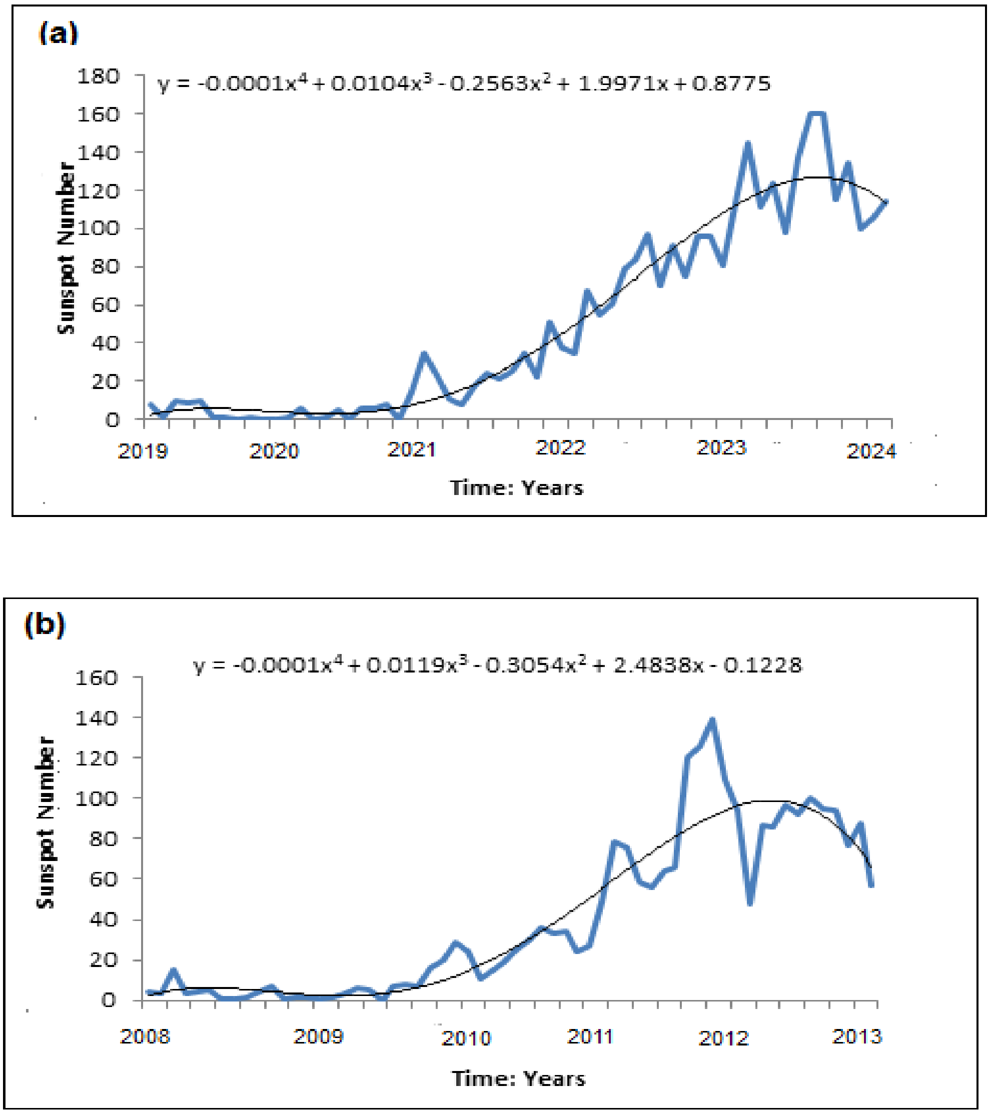


**Figure 9:** Observed monthly sunspot numbers for five years to (a) the Solar cycle 25 and (b) the Solar cycle 24

**Conclusion:**

1- The number of sunspots has been steadily declining this year. Solar cycle 24 has come to a close, the magnetic field has reversed direction, and a new cycle, solar cycle 25, will begin in December, according to this evidence.

2- Beginning of solar cycle 25, sunspots start to be few in number because solar activity is low and the magnetic field strength is low, which is indicated by a shift in polarity. Then, they keep going up every month, and after five years, the number of spaces is comparable to growth, with each passing year adding more and more.

3- Researching the correlation between sunspot numbers and solar radio flux (F 10.7 cm) yielded the following statistical conclusion: solar radio flux (F 10.7 cm) values increased in direct proportion to sunspot numbers.

4- Solar cycle 24 and solar cycle 25 were only compared for the first five years of the present cycle. We can see that cycle 24 was weaker than cycle 25 by comparing their upper and lower numbers; as a result, we can expect to see a stronger solar cycle than the one before it.

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