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Chromosphere Activity Relation with Solar Dynamo Magnetic Activity Cycle

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Abstract. In this article, we analyzed the abnormal thickness of the chromosphere above the coronal holes (CH) at the poles of the Sun for 13 years (2010-2022), on the 15th of every month, by using AIA/SDO telescope data. We used the light emitted from helium-2 (He II) at a wavelength of 304 Å at about 50,000 K to investigate the solar holes in its north and south poles. This light is emitted from the chromosphere and the transition region. According to the values of the graphs obtained by the MATLAB program and the comparison between solar cycles during the 2010-2022 years, it was seen that the Full width of the intensity curves at half maximum (FWHM) in the poles, and as a result the magnetic activity of the sun and especially the activity of coronal cavities as the main source of the solar dipole magnetic field before cycle 25 is significantly greater than this thickness before cycle 24. According to the relationship between the number of sunspots and the solar activity in the coronal holes at the solar poles with a time delay of 2 to 5 years, we expect the maximum increasing in the number of sunspots around the year 2025. As a result,in terms of the number of sunspots, the height of the solar cycle 25 is probably higher than the cycle 24, which was a low sunspot number cycle. We also concluded that the thickness of the chromosphere has an inverse relationship with solar dynamo magnetic activity cycle.

Keywords: Solar cycle 24 and 25, Coronal Activities, Sunspots, Chromosphere Thickness

1 Introduction

The Sun's magnetic field, what we call the interplanetary magnetic field, is carried throughout the solar system by the solar wind, and its properties are constantly changing in both strength and direction. A magnetic field is a term that describes regions of space that are altered by moving electric charges. Magnetic fields arise from circulating electric currents produced by the rotation of the object [22]. The planetary and solar magnetic fields are thought to arise in the same fluid, (internal conduction) ionized gas in the Sun. This makes two points:

1) The ionized gas rotates around the sun and is stirred by the convection process, and as a result, the energy resulting from these processes is converted into a magnetic field.

2) When the electrically conductive gas moves in the sun, the electric currents and the magnetic field must move with this gas. Thus, the gas is like a hook, a rope pulling

the magnetic field around the Sun as it moves around the Sun. In fact, the ionized gas not only creates the magnetic field, but also pulls it toward itself during differential rotation pulls.

The sun's chromosphere consists of structures called spicules [5,6,7,8]. Spicules are plasma explosions that occur approximately every 5 minutes [8,9], and the material inside them moves upward at a speed of about 80 km s^{-1}. Spicules can be seen even in quiet sun. Jets play a powerful role in the mass balance of the solar corona [18]. The brightness of small jets varies with temperature and altitude, and spectroscopic studies provide valuable information about them through changes in the profile of spectral lines [11,15,16]. The Doppler shift in these lines determines the speed in the line of sight and its changes with time and height from the surface of the sun [19,20,21,22]. By shifting the spectral lines, it is possible to measure the non-thermal rotational speeds, which leads to indirect observations of torsional Alfven waves [9,10,11,12,13,14]. These waves can heat the corona by erupting hot plasma and transferring energy in the form of hydrodynamic magneto waves [17]. The lifetime of these jets depends on the inclination of the magnetic field in the photosphere and lower chromosphere [7]. The tilting of the field reduces the acoustic cut-off frequency and allows the photospheric wave spectrum with a dominant five-minute period of P-mode [15,21].

The width and position of the tachocline region plays an important role in stellar dynamical models in creating a solar dynamo or generator by twisting the weak toroid field to create a stronger toroidal field. The differential rotation within the tachocline region creates a quadruple toroid field. At this stage of the dynamo rotation, the buoyant up welling in the convection zone causes the appearance of a toroid magnetic field through the photosphere and causes the formation of sunspot pairs [1]. The coronal cavity is a region on the Sun where the Sun's magnetic field lines extend far into space. This causes a hole in the corona, the outermost layer of the Sun. These holes appear dark in X-ray and UV images of the Sun and are temporary regions of relatively cool, low-density plasma in the Sun's corona (upper atmosphere). So coronal holes are not literally holes in the sun, but they look like this during extreme ultraviolet wavelengths. These holes are constantly changing shape because the corona is not uniform and is affected by the magnetic field. The magnetic field lines in coronal holes do not curl downwards and do not return to the Sun. These lines are called "open field lines" [25]. At the peak of the sunspot cycle, when the Sun's magnetic field is very active and disturbed, coronal holes can appear almost anywhere on the Sun. At solar minimum, when there are fewer sunspots and the magnetic field is more stable, coronal holes are usually more common and appear near the sun's north and south poles. More stable coronal holes can sometimes last for several solar cycles (27 cycles) fasting to continue. The study of coronal holes is important for understanding the space environment around the Earth through which our technology and astronauts travel. These holes were first seen by the Skylab X-ray telescope in Earth orbit [17].

2 research method

Thousands of spectral lines have been observed and cataloged in the solar spectrum. Hydrogen is the most abundant element, followed by helium [26]. In our comprehensive research, the images were obtained from 2010 to 2022, for 13 years, on the 15th day of every month, from 13:30 for three minutes, 15 consecutive data from the area above the coronal holes in the north pole of the Sun, from the release of 304 Å due to the Helium 2 resonance line formed at about 50,000 K, taken by the EE telescope (Solar Atmospheric Imaging Collection)(approx. 2340 data). The cadence between frames is 12 seconds (five images every

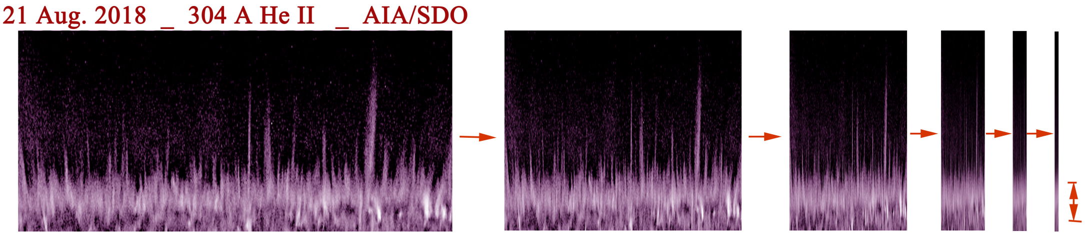

Figure 1: From left to right, the method used to measure the thickness of the "abnormal solar polar region" on 21 August 2018 from the emission of 304 Å due to the helium resonance line 2- formed at about 50,000 K for ten minutes, by summing and averaging images (areas outside the coronal hole areas, with high quality.)

Table 1: Chromosphere width at half maximum height in pixels (0.6 arcsec per pixel) from 2010 to 2022

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1		11	17	15	18	11	30	35	18	40	31	33	18
2		42	18	13	13	35	40	18	0	38	18	33	33
3		9	15	29	35	12	35	0	28	29	42	13	20
4		9	9	20	15	15	0	15	15	20	20	22	15
5	0	7	20	11	20	27	24	15	15	18	20	20	18
6	0	10	18	30	20	22	33	11	9	0	11	9	
7	11	20	14	24	29	15	28	8	0	0	13	11	
8	24	7	20	18	53	18	15	0	18	13	18	13	
9	15	15	13	18	30	18	15	22	25	18	22	20	
10	22	30	22	11	31	31	14	15	17	18	18	22	
11	15	8	27	22	15	18	20	21	29	23	31	18	
12	31	7	40	13	15	18	13	31	42	31	33	15	

minute), in FITS protocol. After obtaining and summing the images on the disk, we flattened them using MATLAB software, then we compressed the areas above the coronal holes in the South and North Poles regions to the extent of one column (see Figure 1). The graphs related to these data were plotted (15 data on the 15th day of every month)and measured the width at half the height of the maximum exactly at the first maximum. We recorded them as the width of the chromosphere at this point of the poles of the Sun (see Figures 2 and 3). This thickness actually shows the width of the area above the coronal cavity where the magnetic field lines and as a result plasma and coronal mass escape into the space, and by measuring and studying it, we can find out the extent of the sun's magnetic activity in that area.

3 Data analysis

Selected figures show the sub-width of the chromosphere at half height at the north pole of the Sun in the 15th months of different years (see Figure 5). In these graphs, the unit of the horizontal axis is the pixel, and the unit of the vertical axis is the light intensity. Each pixel is 0.6 arc seconds, and each arc second is 730 km. With these calculations, easily and with high accuracy, the thickness of the chromosphere in the areas above the coronal holes can be

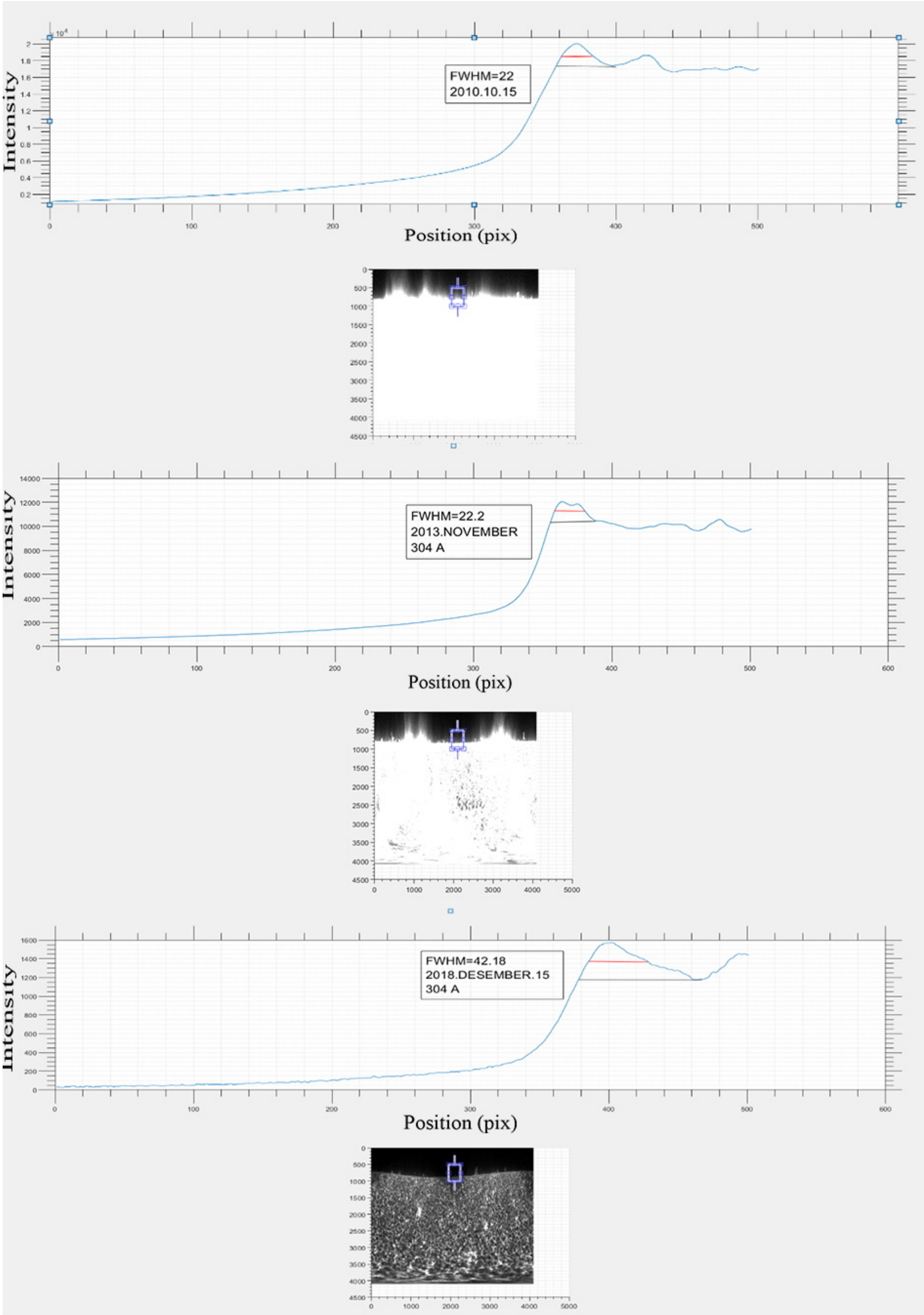

Figure 2: The width of the chromosphere at half the maximum height above the coronal hole of the north pole of the Sun, in pixels (0.6 arcsec per pixel) in 2010, 2014 and 2018 of cycle 24.

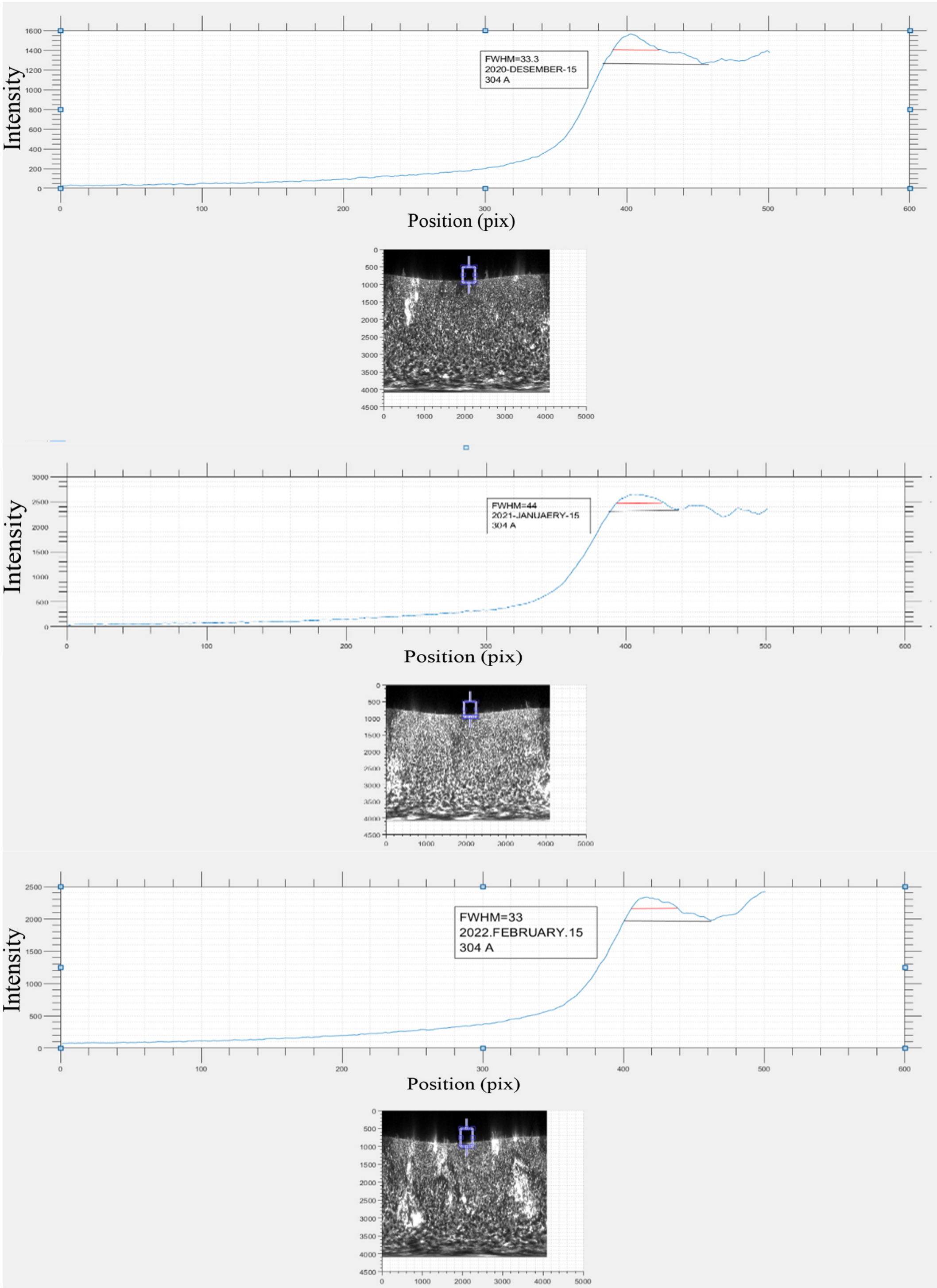

Figure 3: The width of the chromosphere at half the maximum height above the coronal cavity of the North Pole of the Sun, in pixels (0.6 arcsec per pixel)in the beginning years of cycle 25 from top to bottom, 15 December 2020, 15 January 2021, and 15 February 2022 respectively.

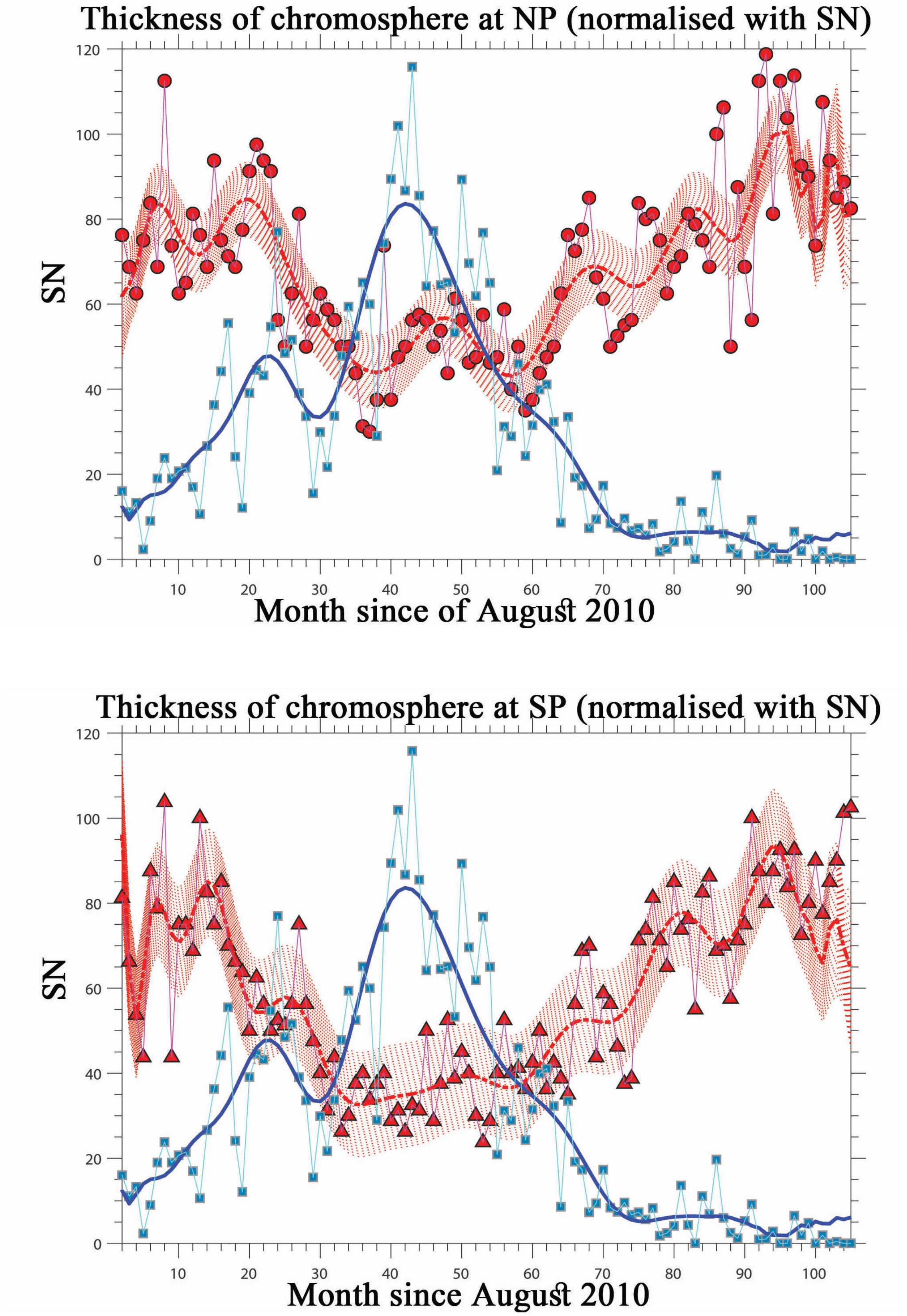

Figure 4: comparing the graph of the number of sunspots with the graph of the thickness of the chromosphere in the north pole (top) and the south pole of the sun (bottom) and observing the relationship between them (blue curve: number of spots, red curve: thickness of the chromosphere).

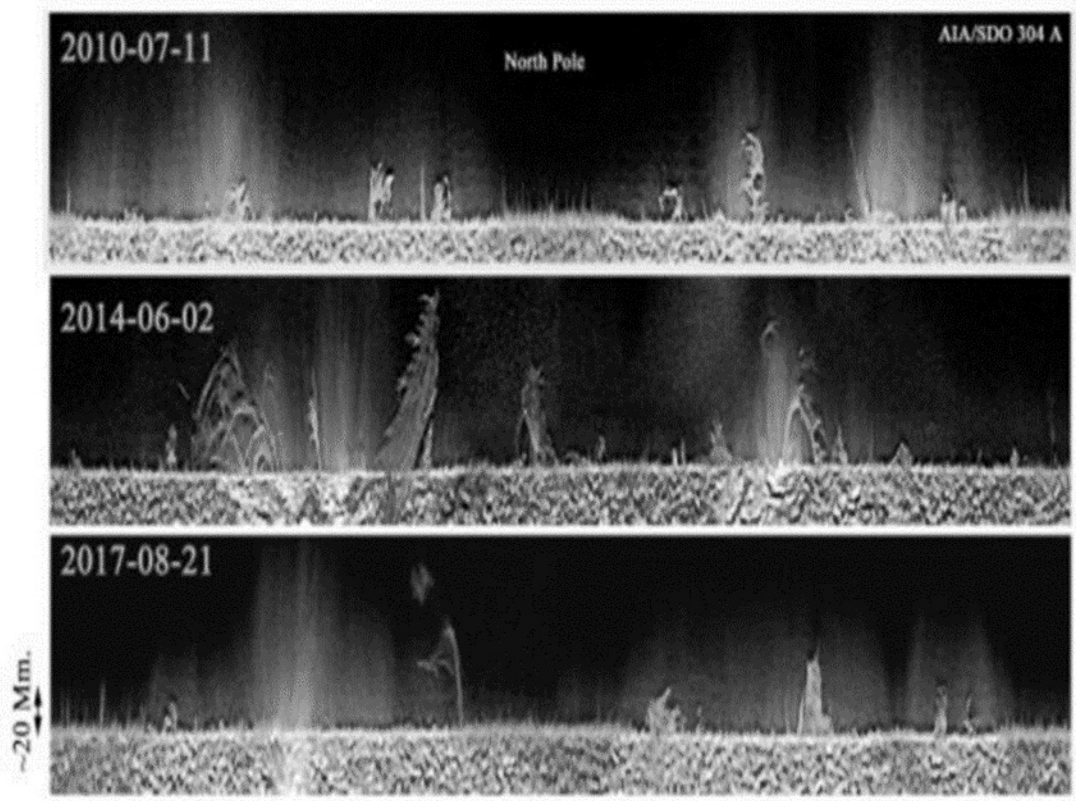

Figure 5: Comparison of the solar disk in the minimum early, peak and minimum of the end of the 24 solar cycle (in the minimum years we see an increase and in the solar maximum we see a decrease in the thickness of the chromosphere at the poles).

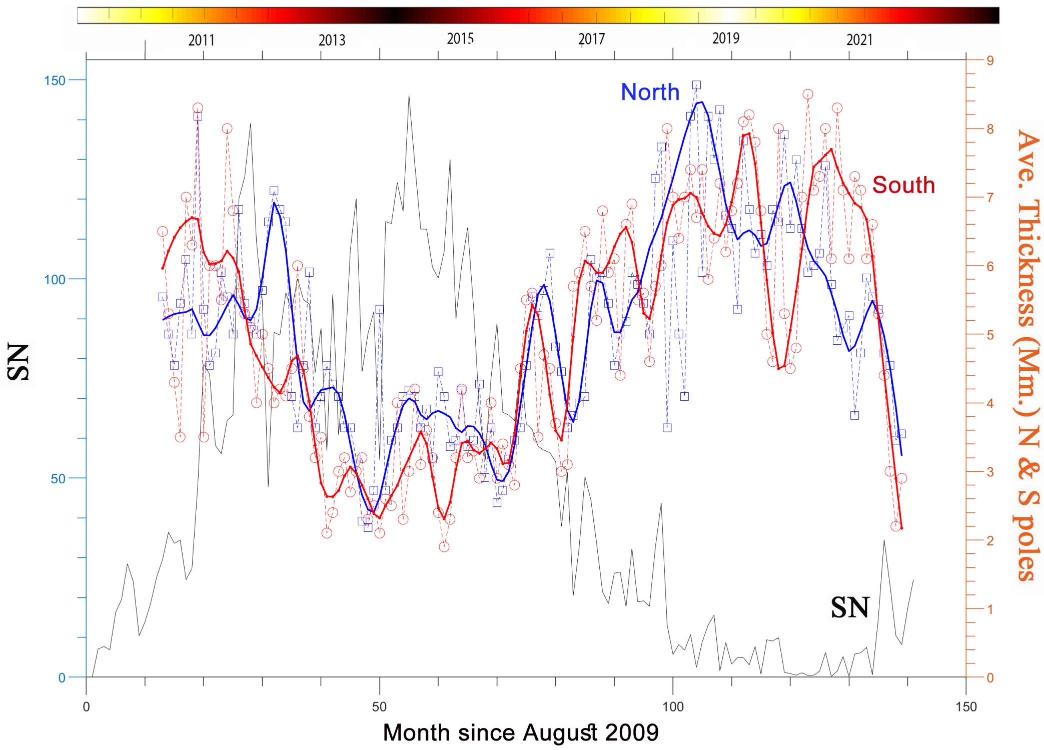

Figure 6: The number of polar events observed during the period before cycle 25 is double compared to the period of years before cycle 24.

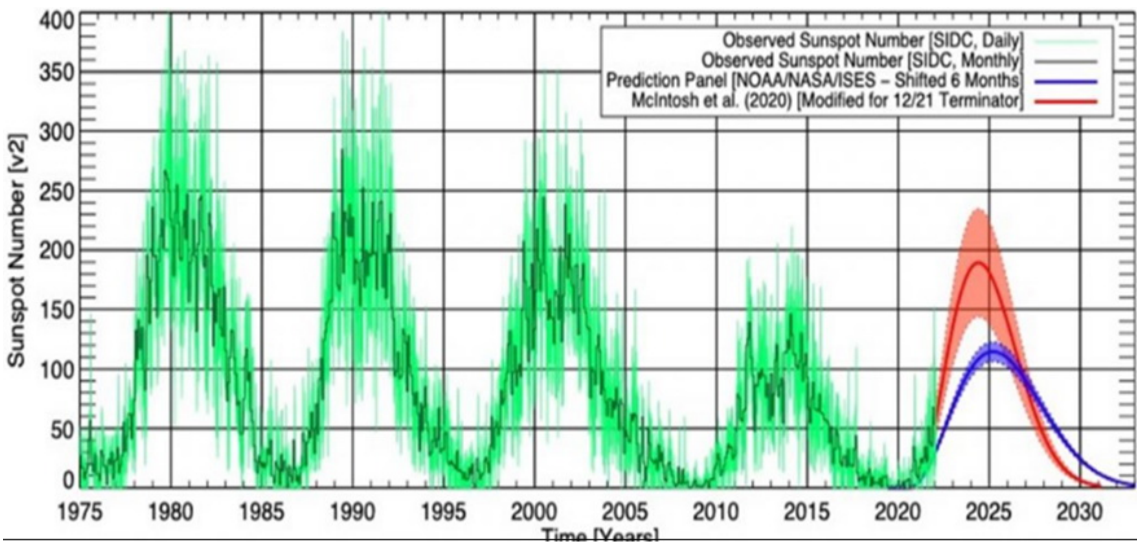

Figure 7: This figure shows the initial predicted number of sunspots, shown as the blue line. The green lines show the observed sunspots that tend towards the red line [27], solar cycle 25

calculated in Km. The table 1 shows the width of the chromosphere at half maximum height in the north polar regions of the Sun, above the coronal holes for 13 consecutive years.

In this research, after repeating these steps for the south pole of the sun and obtaining the thickness of the polar regions, including the so-called abnormal thickness of the margin above the coronal cavities, we compared this thickness with the sunspot number (SSN) and concluded that the thickness of the chromosphere increases in minimum sunspots number, and vice versa, increases in solar maximum sunspot number. Of course, there are exceptions in the activity of these areas, but the basis of our results were the general diagrams, and comparison with the sunspot numbers. Figures 4 and 6 show the graph of the thickness of the chromosphere in the north pole (top) and the south pole of the sun (bottom) and observing the relationship between them (blue curve: number of spots, red curve: thickness of the chromosphere)

Also, according to Figure 2, we concluded that the abnormal thickness of the chromosphere in the beginning years of cycle 24 (2010) is more than the peak years of this cycle (2014), and the remarkable conclusion was that, in the end years of this cycle, the thickness of the chromosphere increased significantly compared to the beginning years of the cycle. This issue was confirmed in the flat images that we obtained from the Sun's disk by telescope data during the solar cycle 24 with helping MATLAB program, and we observed with a high percentage that in the solar minimum years (2017 and 2010). In this cycle, we saw an increase in the width of the sun. In the peak years of the cycle (2014), we had a decrease in the width of the chromosphere in the polar regions. With considering clearly in 2017, the height of the spicules or the increase in the thickness of the chromosphere increased significantly as a result of the magnetic field in the polar regions. Also, according to Figure 3, in the beginning years of cycle 25, we observed a significant increase in the thickness of the chromosphere.

On the other hand, according to the values of the obtained graphs and the comparison between solar cycles during the cycle, it was seen that in general, the thickness of the chromosphere width at half the maximum height before cycle 25 (2018-2020) is significantly more, comparing this thickness before the cycle 24 (2009-2011). This means that the magnetic activity of the sun and especially the activity of the coronal holes as the main source of the bipolar magnetic field of the sun before cycle 25 is significantly higher than the years before starting cycle 24 [4].

During the solar maximum, when the number of sunspots reaches a maximum, coronal holes in the poles extend to low latitudes and decrease in the polar regions and increase in the equatorial regions. In fact, these mono-polar and low-density regions, which appear dark, exist both at the sun's poles and at the equator. But during the solar maximum, the area of the polar coronal holes decreases, while the area of the equatorial (non-polar) coronal holes increases. What happens is that the open-polarity magnetic field weakens, decreases, becomes zero, and then reappears with the opposite polarity [28].

4 Conclusion and discussion

In order to statistically investigate the relationship between coronal holes and sunspots during the solar cycle, we must know that there is a close relationship between the evolution of the polar coronal holes area and the wolf sunspot number, with a time delay of about half of the solar cycle. We also know that solar activity through the sunspot number modulates the geomagnetism, producing CMEs, flares, and associated disturbances.Occurrence of the maximum coronal mass ejection rate and the number of sunspots are almost two years apart.Two to five-year delay in the CME rate becomes apparent only when the sunspot number index is taken into account. Therefore, after significant increasing in the magnetic activity at the poles before cycle 25, as well as after its onset in 2021, compared to the years before the start of the cycle, we observed 24. In the next 2 to 5 years, around 2025, we expect an increase in the number of spots [3].

Therefore, according to our findings and measurements of the activity level of the polar regions and considering the relationship between the number of spots and the activity in the coronal cavities, the height of cycle 25 in terms of the number of spots is probably higher than cycle 24, which was a low altitude cycle. Figure 7 shows the initial predicted number of sunspots, shown as the blue line. The green lines show the observed sunspots that tend towards the red line in solar cycle 25 [27]. As the graphs presented, sunspots rapidly increase from 2019 to 2022. We hypothesize that solar cycle 25 is a relatively high altitude cycle. Because big cycles usually start early [24]. Solar cycle 24 had an average length of about 11 years and was the fourth least intense since regular records began with solar cycle 1 in 1755. This cycle was the weakest cycle in the last 100 years. The progression of solar cycle 24 was unusual. The sun's northern hemisphere led the sunspot cycle, peaking more than two years before the southern sunspot peak. This caused the solar maximum to have fewer sunspots than when the two hemispheres are in phase [24]. Normally, at any time, one hemisphere may dominate the other. But the northern and southern hemispheres are never more than ten months apart. They do not go out of phase [24]. As solar cycle 25 speeds up, stronger solar storms are more likely to erupt, increasing the potential for potential disruptions to satellites, radio communications, and power systems. This is a very real threat. More than 35,000 objects orbit our planet in the ionosphere-thermosphere, including the International Space Station, weather and communications satellites, and other assets of various countries, and more are launched each year. When the ionosphere-thermosphere system is affected by solar and geomagnetic activity, these assets are adversely affected, and it is necessary to overcome these problems according to the results of research in this field and to consider the necessary measures to pave the way for space and outer space research.

References

[1] Andreeva, O., Abramenko, V., & Malashchuk, V. 2022, Open Astronomy, 31, 22.

[2] Hathaway, D. H. 2015, The Solar Cycle.

[3] Koutchmy, B., Filippov, E., Tavabi, J-C., Nons, O. 2021, Proceedings of the Annual meeting of the French Society of A&AS, 238.

[4] Charbonneau, P. 2010, Living Reviews in Solar Physics, 7, 1.

[5] Tavabi, E., Koutchmy, S., & Ajabshirizadeh, A. 2011, New Astronomy, 16, 296.

[6] Tavabi, E., Koutchmy, S., & Ajabshirizadeh, A. 2019, Advances in Space Research, 47.

[7] Tavabi, E. 2012, J. Modern Physics, 3, 1786.

[8] Tavabi, E., Koutchmy, S., & Ajabshirizadeh, A. 2013, Solar Phys., 283, 187.

[9] Tavabi, E. 2014, Astrophys. Space Sci. 352, 43T.

[10] Tavabi, E., Koutchmy, S. 2014, Ap&SS, 352, 7.

[11] Tavabi, E. 2014, Ap&SS, 350, 489.

[12] Tavabi, E., Koutchmy, S., & Golub, L. 2015, SoPh., 290.

[13] Tavabi, E., Ajabshirizadeh, A., Ahangarzadeh Maralani, A. R., & Zeighami, S. 2015, J. A&A, 36, 307.

[14] Tavabi, E., Koutchmy, S., Ajabshirizadeh, A., Ahangarzadeh Maralani, A. R., & Zeighami, S. 2015. A&A, 573, 7.

[15] Tavabi, E., & Koutchmy, S. 2019, ApJ., 883, 41T.

[16] Tavabi, E., Zeighami, S., & Heydari, M. 2022, Sol. Phys., 297, 1.

[17] Vaiana, G. S. 1976, Mathematical and Physical Sciences, 281, 365.

[18] Zeighami, S., Ahangarzadeh Maralani, A. R., Tavabi, E., & Ajabshirizadeh, A. 2016, Sol. Phys., 291, 847858

[19] Zeighami, S., Tavabi, E., & Amirkhanlou, E. 2020, JApA., 41, 18Z.

[20] Zeighami, S., & Tavabi, E. 2021, J. the Earth and Space Physics.

[21] Zeighami, S., & Tavabi, E. 2021, IJAA.

[22] Zeighami, S., Tavabi, E., & Ajabshirizadeh, A. 2022, J. the Earth and Space Physics.

[23] https://sdo.gsfc.nasa.gov/data/dashboard/?d=0193;0171;HMIBC.

[24] http://earthsci.org/space/space/sun/sun.html.

[25] https://space weather live.com.

[26] https://lifeng.lamost.org/courses/astrotoday/CHAISSON.

[27] https://blogs.nasa.gov/solarcycle25.

[28] http://www.astronomyknowhow.com/sun.htm.

[29] http://solarcyclescience.com/AR_Database/daily_area.txt.