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SOLAR ACTIVITY CYCLE 25: THE FIRST THREE YEARS

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Abstract. We analyze features of current solar activity cycle 25 for the first three years of its development (2020–2022). Compared to cycle 24, the current cycle is shown to exceed the previous one in the number of sunspot groups (1.5 times), the number of flares (1.8 times), and the total flare index (1.5 times). We have found that distributions of sunspot groups during cycles 24 and 25 differ in maximum area. Solar cycle 25, unlike cycle 24, exhibits the most significant increase in the number of sunspot groups with areas up to 30 pmh and in the interval from 570 to 1000 pmh. In contrast to cycle 24, the degree of north-south asymmetry in cycle 25 is significantly reduced. This allows us to predict an increased height of cycle 25, as compared to cycle 24 (by 20–50 %), in accordance with the Gnevyshev—Ol rule, as well as the possible unimodal nature of the cycle.

Keywords: solar activity cycle, sunspots, solar flares, north-south asymmetry.

INTRODUCTION

In heliophysics, the dynamics of 11-year solar activity cycles (Schwabe—Wolf cycles) is commonly described using a smoothed representation of the cycle by Formula (1) [Obridko, 2008],

$$W_i = \left(\sum_{i-6}^{i+5} W_i + \sum_{i-5}^{i+6} W_i \right) \Bigg/ 24, \qquad (1)$$

where W_i *is* the monthly average Wolf number for the *i*th month. As inferred from the Worldwide Network's data on the level of solar activity (SILSO data/image, Royal Observatory of Belgium, Brussels), the W_i values smoothed by (1) reveal a minimum between 2019 and 2020, which, according to the common method, allows us to assume that solar cycle 25 began in January 2020. Thus, cycle 24 lasted exactly for 11 years (from January 2009 to December 2019).

The work is concerned with the initial phase of cycle 25 from January 2020 to December 2022, and performs a comparative analysis of similar phases of the two consecutive cycles — 24 and 25.

1. SUNSPOTS AT A MINIMUM OF SOLAR CYCLES 24/25

According to NOAA data, the first sunspot group No. 12620 of cycle 25 appeared long before the minimum of cycle 24 — in December 2016, but it was a single phenomenon. The systematic appearance of sunspot groups in cycle 25 was preceded by the appearance of the so-called ephemeral active regions (ARs) (without sunspots) from 2017 onwards [Golovko, 2020]. In fact, the first sunspots of cycle 25 appeared during the deep minimum of cycle 24 in July 2019 (2219 Carrington rotation (CR)). The newly appeared AR was assigned number 12744, following the NOAA nomenclature. This sunspot group emerged at a latitude of 27° S; the location of magnetic polarities and the latitude suggested that the group belonged to the new cycle. Ephemeral ARs also appeared earlier in the new cycle, but there were no sunspots in plages of such regions.

At the same time, a sunspot group of the old cycle was observed during the same CR (No. 12745, 2° N). Similar low-latitude ARs emerged during the following four rotations (sunspot groups 12746–12749). During this period, there were no ARs of the new cycle on the Sun. During CR 2223 (beginning of November 2019), the second sunspot group of the new cycle was detected — No. 12750 (southern hemisphere, 28° S), after which approximately one sunspot group of the new cycle began to appear during each solar rotation. During CR 2225 (January 2020, the formal solar minimum), there were already three sunspot groups of the new cycle, including the first N-hemisphere ARs Nos. 12754 and 12756 at 24° N and 22° N respectively.

Termination of cycle 24 lasted until July 2020. In January, sunspot group 12757 was detected; in April, 12760; and the old cycle's last AR 12766 was observed in July 2020 during CR 2232.

2. DEVELOPMENT OF CYCLE 25 IN THE ASCENDING PHASE

Further, only the new cycle developed, and in each rotation the number of ARs gradually increased (Figure 1). From 2218 to 2265 CRs (June 2019 – December 2022), 426 sunspot groups of cycle 25 and 11 sunspot groups of cycle 24 were registered. Groups of the two cycles were simultaneously observed during the

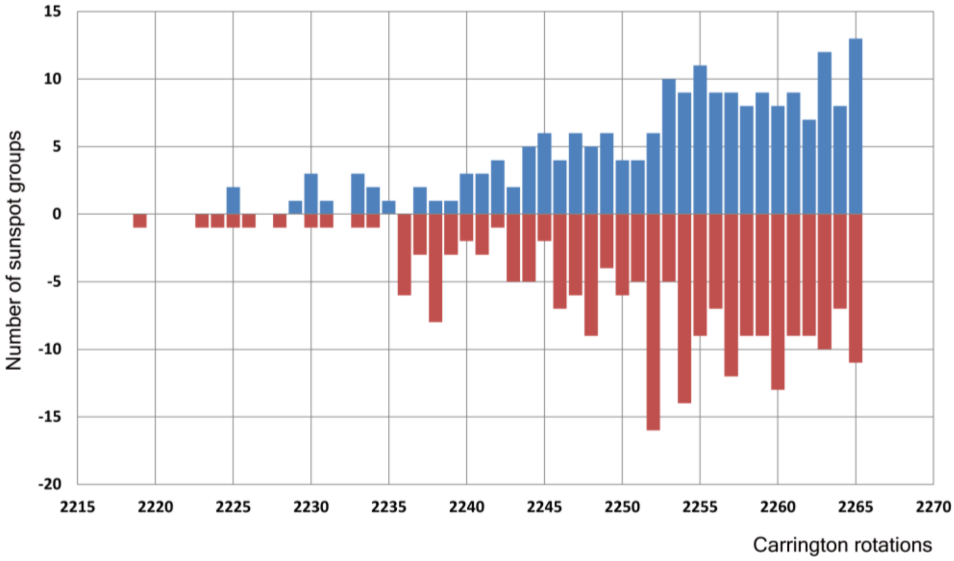

Figure 1. Growth rate of the number of sunspot groups *N* during the ascending phase of cycle 25 from CR 2215. The cycle minimum, according to Formula (1), corresponds to CR 2225. N-hemisphere sunspot groups (blue); S-hemisphere sunspot groups (red) (negative values are given for clarity)

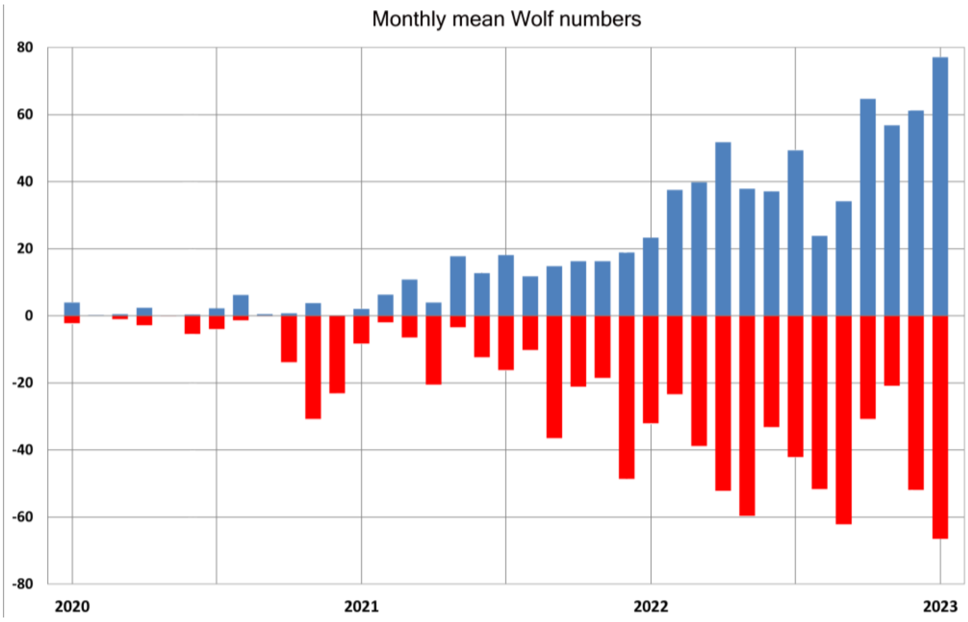

Figure 2. Monthly average Wolf numbers *W* in cycle 25 for hemispheres. The first month along the X-axis is January 2020, the last month is January 2023.

the year — from July 2019 to July 2020. Among groups of the new cycle, 224 ARs have been detected in the southern hemisphere; and 202 ARs, in the northern hemisphere.

Figure 2 illustrates the development of the cycle — monthly average Wolf numbers *W* separately for the N (blue) and S (red) hemispheres.

To estimate the degree of north-south asymmetry for each solar rotation from 2215 to 2265, we have calculated the asymmetry coefficient *A*

$$A=(N_n-N_s)/(N_n+N_s), \quad (2)$$

where N_n, N_s are the numbers of sunspot groups in the N and S hemispheres in a given solar rotation. The dynamic pattern of *A* during this period is shown in Figure 3. The S hemisphere is seen to be initially more active ($A=-1$ suggests that during this solar rotation sunspot groups were only in the S hemisphere, whereas there were no sunspot groups in the N hemisphere). This was followed by a period when sunspot groups appeared mainly in the N hemisphere. Approximately in the middle of the period under study, sunspot groups developed in both hemispheres, and the degree of asymmetry of the hemispheres began to gradually decrease. Zero values of *A* at this phase indicate the same number of sunspot groups in this rotation in both hemispheres. During 2022 (the third year of the cycle, the last 12 points in the chart), solar activity developed almost symmetrically relative to the equator.

Figure 4 illustrates the distribution of maximum values of the area of sunspot groups. Sunspot groups in cycle 25

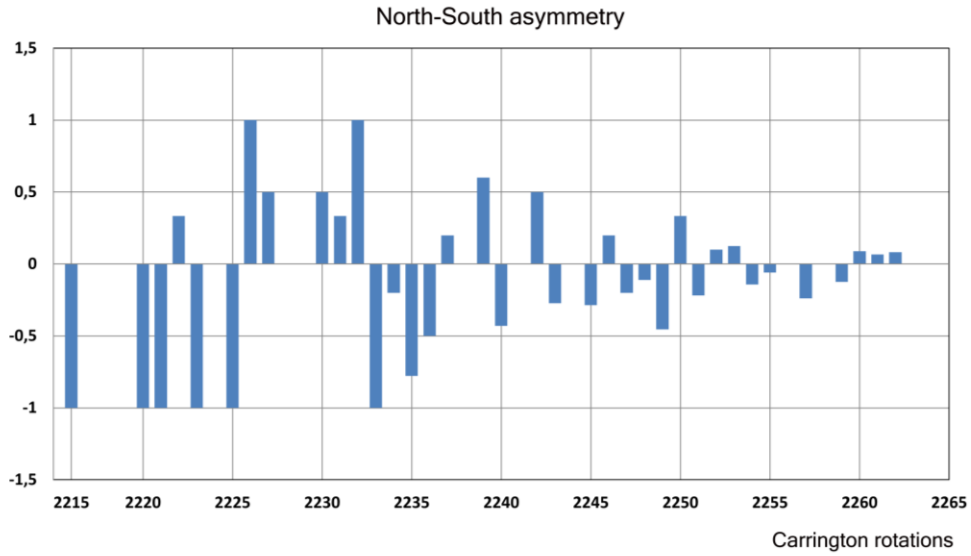

Figure 3. Change in the north-south asymmetry parameter *A* for a number of sunspot groups during solar rotations 2215–2265

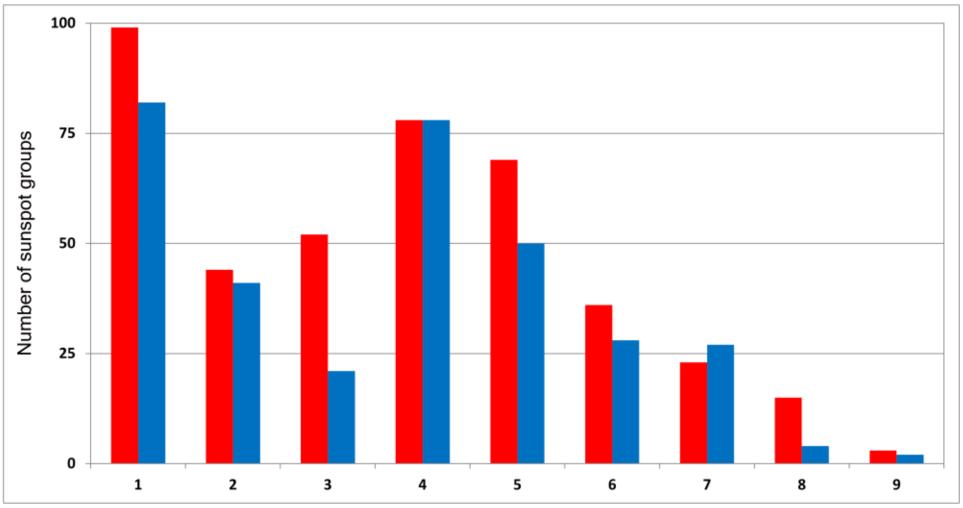

Figure 4. Area distribution of sunspot groups in cycle 25 (red bars) and in cycle 24 (blue bars) during the first three years of the cycles. Explanations are given in the text

(red), sunspot groups in cycle 24 (for comparison) (blue) for the same period during the first 42 rotations (36 months) from rotation 2225 corresponding to the minimum (beginning) of the cycle.

Intervals of maximum area values are given in a logarithmic scale. Interval 1 represents the area of sunspot groups within 10 pmh; interval 2,10–20 pmh; interval 3, 20–30 pmh; interval 4, 30–100 pmh; interval 5, 100–180 pmh; interval 6, 180–300 pmh; interval 7, 300–570 pmh; interval 8, 570–1000 pmh; interval 9, over 1000 pmh.

A similar bimodal pattern is clearly seen in the distribution of sunspot group areas for the first three years of cycles 24 and 25. There are also some differences. In cycle 24, 333 sunspot groups were observed for the first 42 rotations from the beginning of the cycle (426 groups in cycle 25, which is almost a quarter more). In cycle 25, significantly larger number of small sunspot groups have been recorded (with an area to 10 pmh; the first column of the histogram in Figure 4). Large groups also appeared in both cycles (AR 12786 with an area of 1000 pmh; AR 13014 with 1100 pmh; AR 13153 with 1080 pmh in cycle 25). In cycle 24 during the first three years, there were also large-scale sunspot groups — Nos. 11302 (1070 pmh) and 11339 (1540 pmh), but there have been significantly more large-scale sunspot groups of the eighth area range (from 570 to 1000 pmh) in cycle 25 — 15 against 4. Referring to Figure 4, in almost all ranges maximum AR areas in cycle 25 exceed those observed in cycle 24.

Figure 5 shows variations in monthly average *W* from January 2008 (cycle 24, black line) and from January 2019 (cycle 25, red line).

The rate of increase in activity during the ascending phase of the cycle is seen to be similar for the two cycles, but cycle 25 surpasses cycle 24 in most intervals we compare. An intense burst of activity in the 45–47th months of cycle 24 is matched by a similar burst in the 48th–51st months of cycle 25.

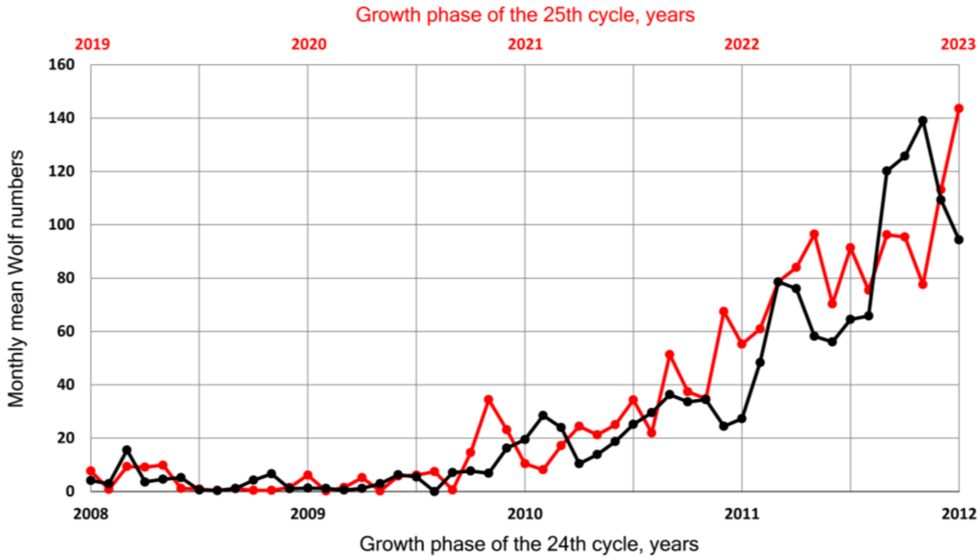

Figure 5. Monthly average W during the ascending phase of cycles 24 (black curve) and 25 (red curve). Along the X-axis are the months T from January 2008 for cycle 24 and from January 2019 for cycle 25 (superimposed). The last point of the plot corresponds to January 2012 (cycle 24) and January 2023 (cycle 25)

Parameters of flare sunspot groups in cycles 25 and 24 in the first three years

Cycle	Number of sunspot groups including flare groups	Number of flares in the N/S hemispheres (unidentified)	Number of flares including M- and X-class ones	Flare index of M and X classes	Total flare index
25	426 (228)	1244/1194 (396)	2834 (224)	61.86	134.05
24	329 (157)	818/480 (234)	1532 (140)	51.21	88.81

3. FLARES DURING THE ASCENDING PHASE OF CYCLE 25

The so-called flare index is traditionally used to estimate the energy of solar flares. As is known (see, e.g., [Ishkov, 2010]), since 1976 the soft X-ray flux from a flare in the range 0.1–0.8 nm (12.5 eV – 1 keV) according to GOES data has been taken as the index. Classes have been introduced which evaluate ranges of maximum X-ray intensity in accordance of the following rules:

- $(1\div9)10\text{-}6$ W/m^2 (Class C);
- $(1\div9)10^{-5}$ W/m^2 (Class M);
- $(1\div n)10^{-4}$W/m^2 (Class X),

where n is limited by sensor capabilities. On the basis of this nomenclature, the following conventional notations were introduced for X-ray flares: small — flares of class C and below; medium – flares of classes M1–M4.9 (10^{-5}–$4.9\cdot10^{-5}$W/m^2); large/strong — flares stronger than M5 ($5\cdot10^{-5}$W/m^2). "The X-ray class of a flare is M6.6" means that the radiation from the flare during its maximum was $6.6\cdot10^{-5}$W/m^{2}and it is considered strong.

Solar flare activity in current cycle 25 (further, we analyze only X-ray flares from class C and ignore lower-energy events) after a long pause began on May 29, 2020 in AR behind the E-limb: during the day, M1.1, C9.3, and C1.0 X-ray flares were observed, whereas there were no sunspots on the disk. Since then, flares did not appear for another two months and began to occur on August 08, 2020.

Let us examine the statistics of solar flare activity in cycle 25 for the first three years of its development (2020–2022). Data on flare activity during the first 36 months of cycle 25 and (for comparison) cycle 24 is presented in Table.

There were flares in at least 228 of 426 (54 %) sunspot groups observed on the solar disk during the first 36 months of cycle 25.

A total of 2834 X-ray flares (including unidentified ones) occurred from January 01, 2020 to December 31, 2022, including 2610 C-class X-ray flares, 215 M- and 9 X-class flares. During this period, X-class flares gave a total flare index of 11.8; M-class flares, 50.06. The integral flare index, in view of numerous C-class flares, was 134.05.

We can state that according to all the tabulated parameters during the cycles' phases we compare, cycle 25 is higher than the previous one. The percentage of flare-active sunspot groups is also slightly higher in cycle 25: 54 % versus 48 %. The amount of energy released by the flares during the first three years is 1.5 times larger in cycle 25.

The degree of north-south asymmetry in cycle 25 is significantly lower: the flare index was distributed almost evenly between the hemispheres: 61.2 in the N hemisphere; 58.5 in the S hemisphere; 14.4 for unidentified flares. The corresponding values in cycle 24 looked different: 24.3 in the N hemisphere; 59.1 in the S hemisphere; 5.6 for unidentified flares.

4. DISCUSSION AND RESULTS

We present data on solar activity (sunspot groups and flares) for the first three years of cycle 25.

Pishkalo [2008] reviews the predictions of the development of solar cycles 24 and 25, which have been made by different authors using various approaches and models. Spread of the estimates turned out to be very wide. More recent predictions of the development of cycle 25 are reviewed in the monograph [Obridko, Nagovitsyn, 2017].

In many works concerned with forecasting the parameters of cycle 25, it has been suggested that the cycle will be low — approximately as high (or even lower) as cycle 24 [Miletsky, Ivanov, 2006], low or moderate [Obridko, Shelting, 2009; Ishkov, 2017; Obridko, Nagovitsyn, 2017]. A number of features of cycle 24 have been interpreted by some researchers as evidence for the beginning of the era of low cycles. Predictions suggesting a global decrease in the level of solar activity, such as the Dalton minimum or even the Maunder minimum, have been debated a lot. Olemskoy and Kitchatinov [2013] examining global minima have pointed out that an increased level of north-south asymmetry of solar activity may reflect changes in the dynamo mode and may indicate a decrease in the level of solar activity. Notice that the strongest asymmetry was observed in low bimodal cycle 24, which featured two time-separated maxima: in 2012 due to a burst of activity in the N hemisphere, and an unexpected higher maximum in 2014 due to a burst of activity in the S hemisphere.

Note that during the first three years of cycle 25 the degree of north-south asymmetry appeared to be much lower than in the previous cycles: for example, in 2022, sunspot activity developed almost synchronously in both hemispheres. At the same time, the overall level of sunspot and flare activity turned out to be higher than in the previous cycle. This is quite consistent with the Gnevyshev—Ol rule, according to which odd cycles are higher than even ones. The only known violation of the rule is cycles 22–23. The general evolution of current cycle 25 suggests that it will surpass cycle 24 in a number of parameters.

Current SILSO forecasts [https://www.sidc.be/silso/forecasts] for many months during the ascending phase of cycle 25 predicted the expected maximum of the current cycle for July 2025, assuming its height to be approximately equal to the maximum of cycle 24. Nevertheless, comparing the prediction curve and the real Wolf number values already in 2021–2022 has shown that the cycle exceeds the predicted parameters and increases faster than the prediction curve.

Ishkov in a number of his works (e.g., [Ishkov, 2020]) indicates that from cycle 24 solar activity has entered an era of low solar activity when cycles of low and medium amplitude can form, but there are no high cycles. In this regard, cycle 25 will probably belong to the category of moderate cycles and will exceed the height of cycle 24 in accordance with the Gnevyshev—Ol rule. We believe that the behavior of the current parameters of cycle 25 argues for the validity of such a prediction.

Note an important feature of a number of previous cycles: bimodality, or double-peak pattern. In particular, it was observed in cycles 22–24, and this feature was most pronounced in cycle 24 (Figure 6 borrowed from [https://www.sidc.be/silso/monthlyhemisphericplot].

An important parameter for predicting features of cycle 25 is therefore information about the degree of north-south asymmetry. The degree of asymmetry, including the north-south asynchrony, — an increase in the time interval between maxima in different hemispheres (first in N, then in S) — increased from cycle 22 to cycle 24 (see Figure 6). The question was whether this trend would continue to develop in cycle 25.

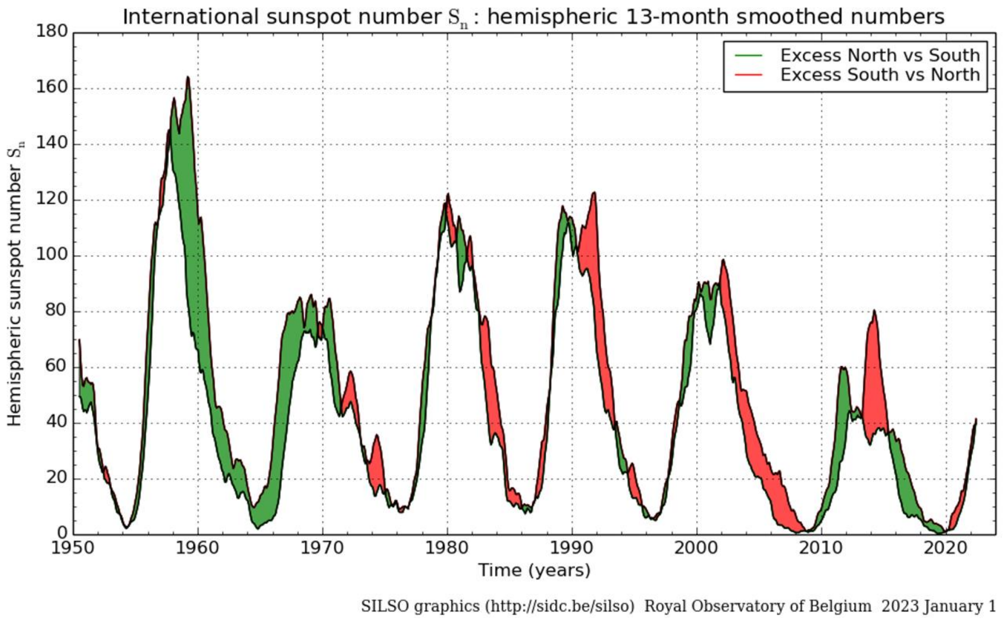

Figure 6. Variations in monthly average Wolf numbers smoothed over 13 points in the previous six cycles. Green color indicates predominance of sunspot groups in the northern hemisphere; red, in the southern hemisphere. The plot was taken from [https://www.sidc.be/silso/monthlyhemisphericplot]

The first three years of the current cycle have shown that the trend is broken: the north-south asymmetry has significantly decreased, which is manifested both in the parameters of sunspot formation and in flare activity indices. As of the beginning of 2023, both the sunspot formation and the flare activity behave quasi-symmetrically relative to the solar equator; variations in the asymmetry coefficient *A* are small, its modulus is close to zero. This allows us to cautiously predict that this trend will continue, adhering to the principle "tomorrow is like yesterday and today". In this case, we can expect the development of cycle 25 as single-peak or with a relatively flat plateau during the maximum phase. Such a development should lead to an overall increased level of activity at solar maximum (compared to the bimodal variant, when two maxima associated with different hemispheres are separated in time), and hence to the height of the cycle being by 15–25 % higher than that of cycle 24.

Summing up, let us point out the main features of the development of cycle 25 we have identified in this study.

1. For the same period of time (36 months from the beginning of the cycle), 1.5 times more sunspot groups appeared in cycle 25 than in cycle 24. There were also individual (few) sunspot groups of a large area (1000 pmh).

2. The percentage of flare-active sunspot groups over the given period is 54 % (48 % in cycle 24). During solar cycle 25, 2834 flares of all classes have been observed, which is 1.8 times higher than in cycle 24 (1532) for a similar period. Moreover, according to the results of the first two years of the cycle, this difference is even more significant — 2.8 times (!). The total flare index for three years in cycle 25 reached the value of 134.05, which is 1.5 times higher than the corresponding value for cycle 24 (88.81). In cycle 25, 9 X-class flares have been observed (in cycle 24, there were 8 similar flares during this phase), but there have been 1.6 times more M-class flares in the current cycle than in cycle 24 — 215 versus 132.

3. Percentage of M and X flares of the total number of flare events in cycle 24 was 9.1 % (11.5 % during the first two years), whereas in cycle 25 it is 7.9 % (a total of 5.7 % during the first two years). The differences are likely to be due to the relative increase in the number of small-scale sunspot groups during cycle 25, which can usually generate only weak flares, as compared to cycle 24 (see Figure 3).

4. The north-south asymmetry of the location of sunspots in cycle 25 decreases as the ascending phase of the cycle develops. In this phase, it is still, however, difficult to judge on this parameter for the cycle as a whole. By the beginning of 2023, there is no data that could indicate a future bimodal pattern of the cycle, associated with strong north-south asymmetry, similar to that in cycle 24 [Isaeva et al., 2020].

5. According to the current SWPC NOAA forecast [https://www.swpc.noaa.gov/products/solar-cycle-progression], as of March 10, 2023, it is expected that at maximum of the cycle the smoothed monthly Wolf number will be as large as 115.3 (in cycle 24, it was 116). Nonetheless, in terms of the dynamics of sunspot activity, cycle 25 can be noticeably higher than cycle 24. We think that in these units it can reach 140–150. The Gnevyshev—Ol rule [Vitinsky et al., 1986] will be valid in this case.

Cycle 25 has already exhibited a much larger number of sunspot groups, both the smallest and the largest. Similar changes also occur in the distribution of flares: there is an increase in the number of both the weakest and strongest events. It seems likely that Ishkov's prediction according to which cycle 25 will belong to the category of moderate cycles is confirmed.

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