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Polar regions activity and the prediction of the height of solar cycle 25

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ABSTRACT

The forthcoming solar cycle (SC) 25 was believed to be rather low when the sunspot number (SN) is used as a measure of the activity level. The most popular prediction was made by the NOAA/NASA Solar Cycle 25 Prediction Panel in 2019, including works based on dynamo-type models. However, we discovered that the height of SC25 could be high, using different observations for measurements of the level of the polar-region activity above the limb at high latitudes several years before the start of SC25 and also after its beginning in 2020. The polar-region activity, which we consider, seems to be related to the polar coronal-hole (CH) activity, and it was significantly higher before SC25 than before SC24. It is also possibly reflected in the so-called chromospheric prolateness observed at solar minimum. Accordingly, we suggest that SC25 could indeed be significantly higher than SC24, which was a very low SN cycle.

Key words: solar cycle, cycle 25, polar regions activity, polar faculae, X-ray bright points, macro-spicules, polar mini ejections, chromospheric prolateness

1 Introduction

The solar activity, reflected by the sunspot number (SN), modulates geomagnetism, producing coronal mass ejections (CMEs), solar flares, solar energetic particles (SEPs), and associated disturbances. The prediction of the height of the forthcoming SC 25 expressed by the SN has been the subject of many studies since 2019 (Nandy, 2021). These studies are mainly based on statistical, mathematical, and/or heuristic methods, taking parameters from the analysis of past cycles. They led to the prediction of the SC 25 height similar to the low height of preceding SC 24, sometimes significantly lower, indeed. Some predictions used solar activity parameters justified by the solid belief that the solar activity is fully governed by a dynamo mechanism occurring inside the Sun (see, e.g., Kitiashvili, 2020 and her reproduced from NASA graphics of SC 23 to 25 in Fig. 1). This conclusion led to the prediction published in the more theoretical paper of Kitiashvili (2021) presenting numerical dynamo-model simulations, which made an accurate description of past and current global dynamics. The model uses recent advances incorporating the Parker-Kleeorin-Ruzmaikin dynamo model. The popular dynamo model is the Babcock-Leighton (B-L) model describing the transformation of a general poloidal field of the rotating Sun into a toroidal field through the differential rotation visualized near the surface. It rather well reproduces the behavior of sunspots of different sign for each hemisphere during a SC. The regeneration of the new poloidal field (after 11 years) is another aspect of the model that is left not well understood despite many attempts to guess what is going on in polar regions during the cycle. The reversal of the dominant polarities in polar regions has been observed to occur during the years of SN maximum since 1970. However, several puzzling features like M-regions, active longitudes, the occurrence of long-living big single sunspots, the cyclonic and widely distorted behavior of extended interacting active regions, the occurrence of coronal holes (CHs) not predictable with the Babcock-Leighton dynamo model, the polar regions cycles and/or field-reversals, and finally the large dispersion of heights of SN cycles are however the subject of hot debates. More important for practical obvious reasons is the prediction of the solar cycles in advance (Nandy, 2021). Without going too far into the details of the supposed relationships of the polar-region activity cycle and the SN cycle (Tlatov and Tlatova, 2020), let us point out that the possible relationship concerns the high-latitude polar activity, definitely above the latitude of 70°. At lower latitudes where the polar crown filaments are still observed, it seems well established that the migration of residual sunspot-region magnetic fields are indeed observed.

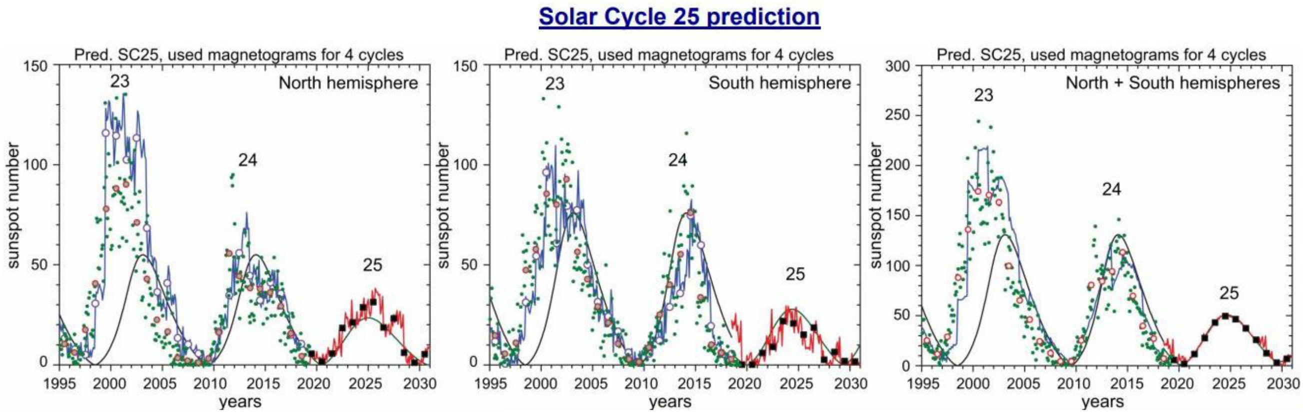

Fig. 1. Past recent SC of SN and extrapolated SC25 based on solar dynamo model by I. Kitiashvili, from a NASA document; see also Kitiashvili (2020).

2 The polar regions activity during SCs

It has been suggested (following the Ohl's law) that the polar-region activity, associated with the recurrent geo-activity, in the years around the solar minimum of SCs is rather correlated with the height of SCs+1 (e.g., Tlatov, 2009). Accordingly, the height of the following SC could be predicted based on these data. Additionally, there is now a growing consensus on the key role of polar magnetic fields as seeds for the next SCs (Makarov et al ., 1987). Finally, there is a suggestion that the chromospheric shell, observed in cool spectral lines, changes its height or thickness in polar regions during the SC (see Filippov et al. (2007)), making the chromosphere to be oblate at SN minimum and prolate during the years of SN maximum, reflecting the influence of a global magnetic field during the SC.

2.1 Polar facula, CH, and polar magnetic-field variations

We first looked at the polar-region activity on the disk using proxies like the density and brightness of polar faculae (small-scale white-light (W-L) brightenings of several hours duration). Their apparent intensities, or better their radiative fluxes, and their number were visually evaluated from W-L full disk filtergrams taken by the Heliospheric and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO) after compensating the center–limb variations. This was done during the years of SN minimum of SC23 and SC24. Some research was also carried out using similar filtergrams taken by the Michelson Doppler Imager (MDI) onboard the Solar and Heliospheric Observatory (SOHO) in the years of SC22. Unfortunately, we discovered that the analysis could be biased by the variable during the years and decades quality of filtergrams mainly due to the slightly changing quality of the focusing near the limbs and finally by the absence of good data at the beginning of SC24. We can just qualitatively report the evaluation of the apparent number of polar faculae that shows a definitely lower number before SC24 and seemingly more contrasted fluxes with a larger number before and also during the first years of SC25. This is especially apparent in the polar coronal holes (not seen in continuum intensities) when the solar B-angle is favorable (roughly in March-April for the S-pole and September-October for the N-pole).

Since we believe that the polar-facula activity reflects the behavior of the polar-region magnetic field through the so-called reconnection phenomena, it is interesting to compare this behavior using the unique measurements of net (mean) polar large-scale magnetic fields done at the Stanford WSO for several SCs (see Fig. 2 and http://wso.stanford.edu/#MeanField). Nothing really significant seems to emerge from the recorded behavior of the strength of the mean fields but a general decreasing tendency along the cycles since 1975 when such measurements were started. It could be necessary to examine the synoptic maps in details to go further. The impression is that during the last SC these measurements could possibly suffer from an instrumental drift producing a weaker calibrated signal and it would be important to have another series from another observatory to check the conclusions. Note that it is rather "misliding" to have to consider data with different spatial resolution because the bright features correspond to polar faculae that presumably have both polarities mixed but unbalanced. The averaging procedure is then puzzling, using an arithmetic summing or the so-called unsigned average flux density that depends on the pixel size and conversely, using the algebric summing giving a lower value. The value of the average polar-cap magnetic field was found to reach an amplitude well above the value measured at the Stanford WSO (Svalgaard et al., 1978) after making corrections for the projection effect. Finally, as shown in an analysis where Mount Wilson data are compared to Kitt Peak data of better spatial resolution (Murray, 1987), averaging over a large aperture will presumably reduce the measured flux of a mixed polarity field relative to that measured in a small aperture.

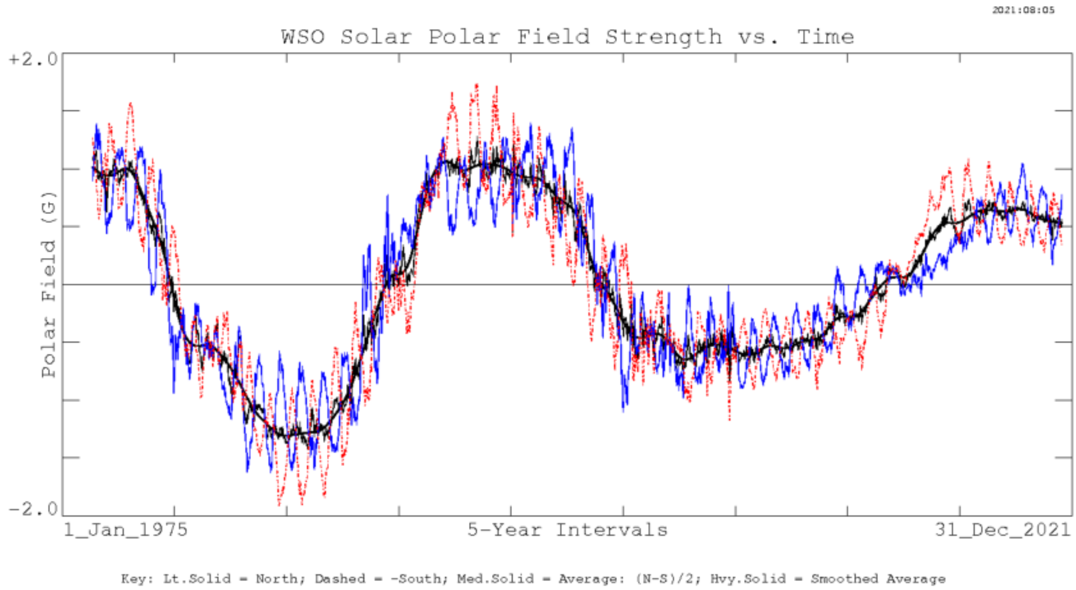

Fig. 2. Strength of the net mean polar magnetic fields measured during the last SCs from the Stanford mapping of large scale magnetic field fluxes. Note the yearly periodicity due to the influence of the B-angle variations for each hemisphere.

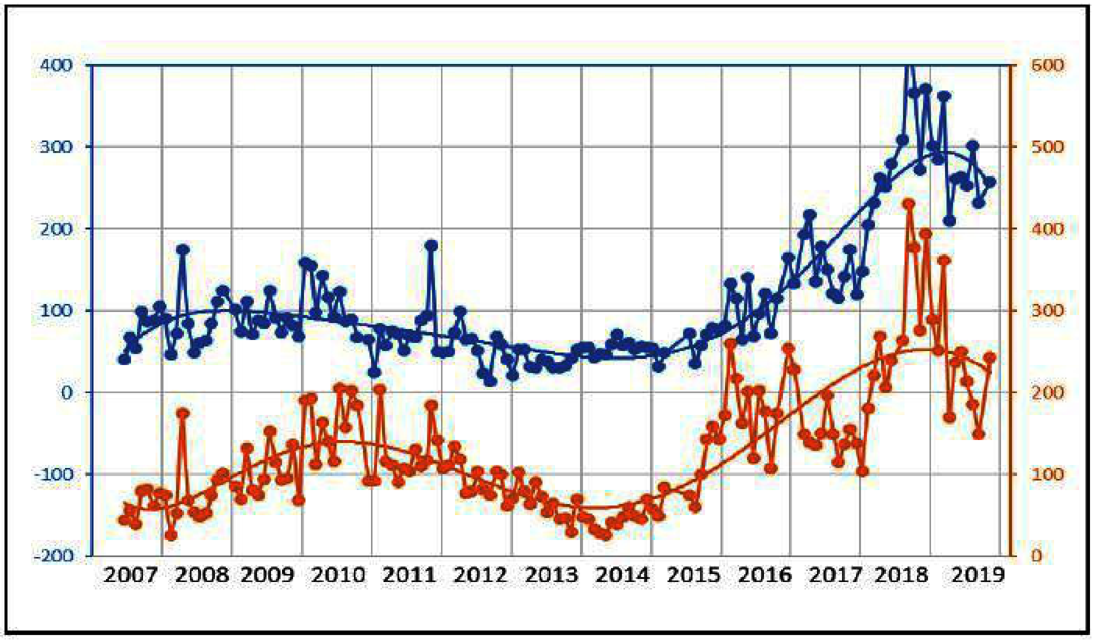

Fig. 3. Pic du Midi Observations of ejections in H_α during the last SC24 shown in blue for the N-pole (amplitudes given by the scale at left) and in brown for the S-pole (the scale at right). Values in ordinate are the monthly numbers.

2.2 H_α ejection activity recorded at the Pic du Midi Observatory during SC24

Let us now consider the polar-cap activity as measured above the limb. During the last SC24, the Pic du Midi Observatory coronagraph working with an H_α filter was used all along the years to observe the "cool" corona with a good resolution permitting as well to measure the number of small ejection events above the occulted by the coronagraph limb inside the spicular fringe of typically 7″ to 10″ thickness. These events are usually called ejections or spikes, or macro-spicules (see Noëns and Wurmser (2000) for a description of the method used and for more detailed results). In Fig. 3 we show the most significant results reported for each solar hemisphere.

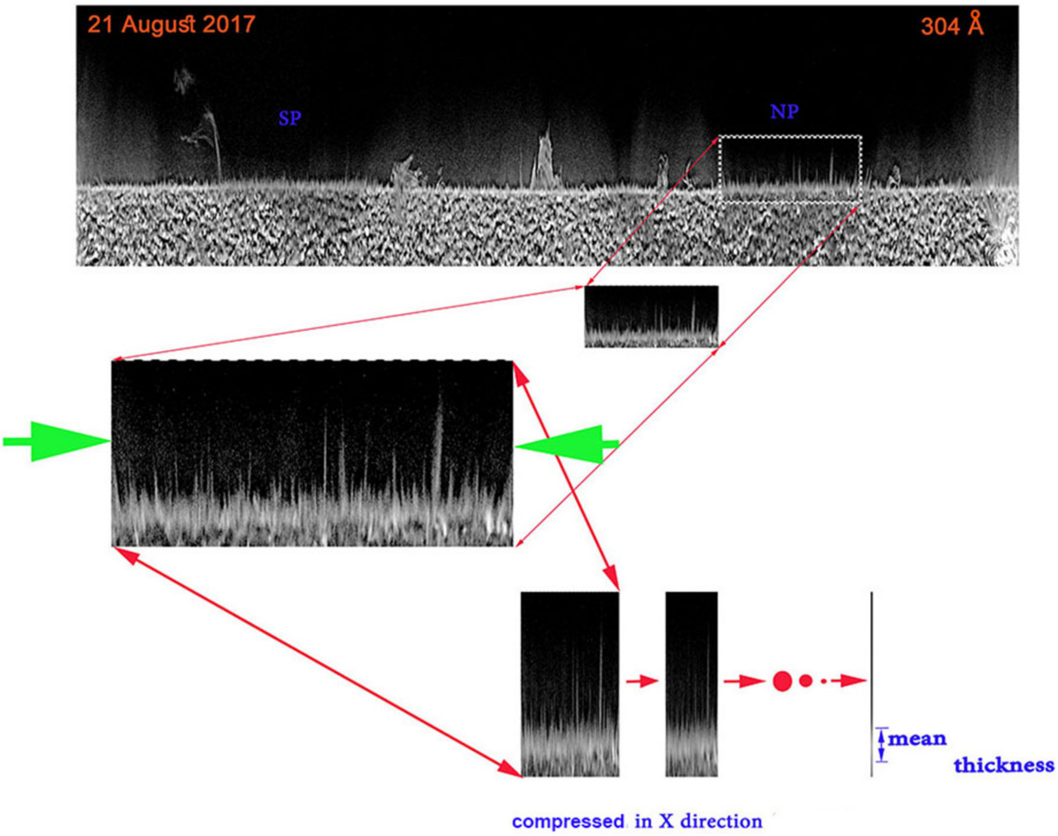

Fig. 4. Partial frame reconstructed image of a typical polar region to demonstrate the method used for measuring the "abnormal" thickness of the 304 Å emissions (due to the HeII resonance line formed around 50 000 K) in this polar region visualized in polar coordinates after averaging (by summing) the 304 Å AIA images of SDO for 10 min. Such extensions were measured during more than one solar cycle in both the South and North polar regions.

There is a definite change in the number of polar events observed in the years before SC24 and SC25. The average number of events observed in the period 2018–2020 (years before SC25) is typically by a factor of 2 greater than the average numbers of events observed in the period 2009–2011 (years before SC24). Note that the team at the Pic du Midi Observatory checked their results several times for any instrumental bias they could have, without finding a reasonable explanation. The effect looks to be of the solar origin.

2.3 Polar regions HeII 304 Å activity from AIA of SDO mission images

Extensions above the limb in polar regions were additionally studied. They are believed to be due to the events of ejections in nearly radial directions in the temperature transition region. They were called macro-spicules in the time of the SkyLab observations made in CIV line emissions, in contrast to spicules seen lower everywhere around the disk at lower temperatures, including regions outside the coronal hole regions. High-quality filtergrams taken by the Atmospheric Imaging Assembly (AIA) onboard the SDO in the HeII resonance line 304 Å are now available, and they were used after summing original frames for 10 min in order to improve the signal/noise ratio. We also worked in polar coordinates in order to measure more easily and more precisely the effective thickness (FWHM) of the polar regions in 304 Å emissions, including the so-called "abnormal" thickness of the fringe above CHs (see Fig. 4 for an illustration of the different steps used to deduce these FWHM).

In Fig. 5 we show the results of measuring the FWHM of the 304 Å shell for the last SC24. Unfortunately, we could not look at the data starting right after minimum of the sunspot activity, in 2009, just because the SDO mission started to provide data just 1 year later. Again in both hemispheres we recorded a seemingly more important activity reflected by the FWHM thickness of the 304 Å shell before SC25 compared to the level recorded before SC24.

3 Conclusion

We looked at the activity of polar regions using several proxies: i/ density of polar faculae from visually evaluated HMI of SDO mission W-L filtergrams and the Stanford WSO large-scale magnetograms evaluating polar regions magnetic net fluxes (using these on-disk observations, there is no definite evidence of SC25 to be significantly different from being of low amplitude, which has been predicted by the NASA Solar Cycle 25 Prediction Panel); ii/ numbers of cool ejection events from a 15-year survey of the Pic du Midi CLIMSO H_α observations (Noëns and Wurmser, 2000); iii/ averaged

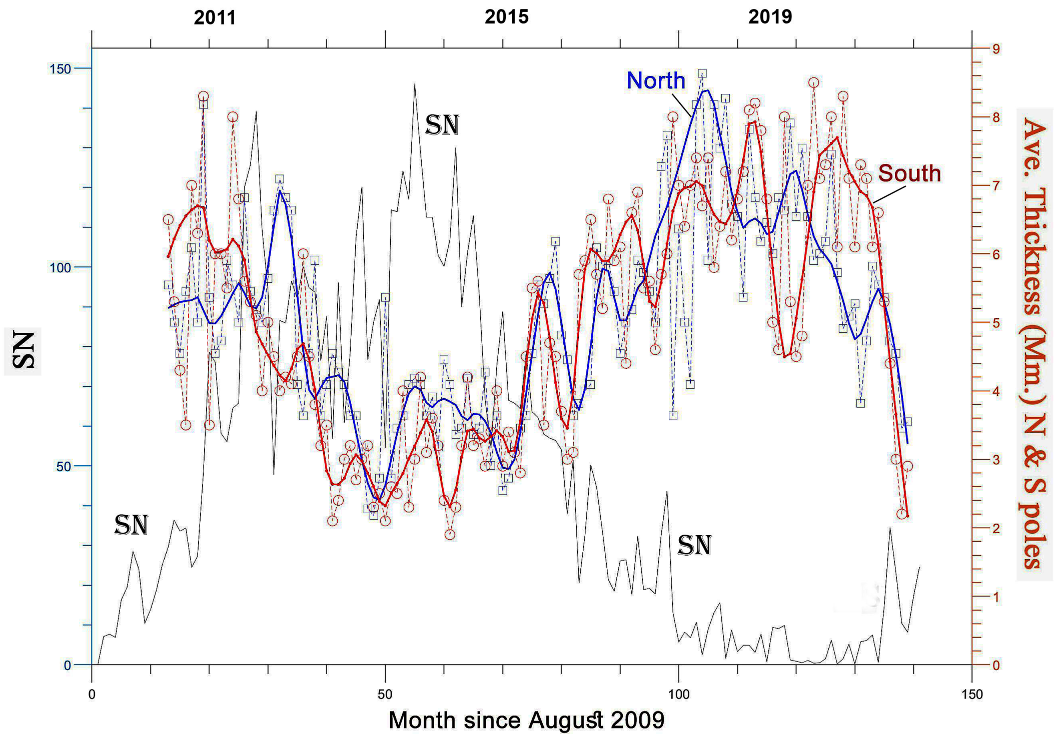

Fig. 5. Polar activity variations evaluated in the HeII 304 Å emissions above the limb in summed images similar to image of Fig. 4, using the measurement of the "thickness" (FWHM) of the shell in radial directions. The sunspot number variations are shown starting in August 2009, at time of sunspot minimum (full black line) but, unfortunately, no data available at that time from the SDO mission that started in August 2010, one year later.

extensions of the 304 Å shell in polar regions related to the polar CH macro-spicule activity with unfortunately a small missing part at the very begining of SC24 (see Fig. 5).

Time variations of these two off-disk parameters qualitatively point to the possibility that SC25 could reach higher levels, of the order of 2 times the height of SC24, in contrast with the moderate height predicted by the SC25 Prediction Panel of NASA and NOAA (Chair: Doug Biesacker). The reason of this discrepancy is not clear, although we note that indeed only off-disk observations instead of the classical on-disk observations look convincing. We better wait the occurrence of the (double) maximum of SC25 in 2025–2026 to go further with the interpretation. Another interesting parameter seemingly related to this topic is the definite observation of the chromospheric prolateness (ovalisation) in the years of the minimum of 2018–2020 that was discovered in the years 1998–2000 (before SC 23) (Koutchmy et al., 1999) and that was not well measured in 2010–2011 (before SC24). In rather "cool" spectral lines like H_α or the H and K lines of CaII, the smoothed upper edge of the solar chromosphere is prolate in the North-South direction at the epoch of minimum solar activity (Filippov and Koutchmy, 2000), and we again noticed the effect in 2020–2021 full disk images of the Pic du Midi CLIMSO H_α observations. In case the SC25 will really be higher than predicted in 2019 (see, e.g., Fig. 1), we plan to come back to the topic of the chromospheric prolateness near the time of SN minima, using a more statistically significant analysis.

References

Filippov B., Koutchmy S., 2000. Solar Phys., vol. 196, no. 2, pp. 311–320.

Filippov B., Koutchmy S., Vilinga J., 2007. Astron. Astrophys., vol. 464, no. 3, pp. 1119–1125.

Kitiashvili I.N., 2020. In Kosovichev A.G., Strassmeier K., and Jardine M. (Eds), Solar and Stellar Magnetic Fields: Origins and Manifestations, Proceedings IAU Symposium, vol. 354, pp. 147–156.

Kitiashvili I.N., 2021. Mon. Not. Roy. Astron. Soc., vol. 505, iss. 4, pp. 6085–6102.

Koutchmy S., di Folco E., Auchere Fr., et al., 1999. In Vial J.-C. and Kaldeich-Schü B. (Eds), 8th SOHO Workshop: Plasma Dynamics and Diagnostics in the Solar Transition Region and Corona, ESA Special Publication, vol. 446, p. 385.

Makarov V.I., Leroy J.L., Noëns J.C., 1987. Sov. Astron., vol. 31, p. 560.

Murray N., 1992. Solar Phys., vol. 38, pp. 419–422.

Nandy D., 2021. Solar Phys., vol. 296, no. 3, eid. 54.

Noëns J.-C., Wurmser O., 2000. Astrophys. Space Sci., vol. 273, pp. 17–23.

Svalgaard L., Duvall T.L., Scherrer P.H., 1978. Solar Phys., vol. 58, pp. 225–239.

Tlatov A.G. 2009. Solar Phys., vol. 260, pp. 465–477.

Tlatov A.G. and Tlatova K.A., 2020. Geomagnetism and Aeronomy, vol. 60, no. 7, pp. 825–830.