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On the quality of sunspot images from observations at the STT-2 of CrAO

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ABSTRACT

We perform a statistical analysis of the quality of sunspot images on a five-point scale obtained during the maxima of cycles 20–25 from April to September 1969–2023. In total, 747 observation days were analyzed taking into account scheduled maintenance works associated with aluminizing the telescope mirrors. The image quality assessments by different observers are shown to be in good agreement. For images assessed by more than three points (275 observation days), it was obtained evidence in favor of a deterioration in the quality of images since 1979. We give reasons for the necessity of conducting timely repair and maintenance works at the solar tower telescope STT-2 of CrAO.

Key words: Sun, observations, magnetic fields, image quality

1 Introduction

Sunspots are closely related to solar activity, which determines space weather and significantly impacts Earth's technosphere and biosphere. It is thus not surprising that measurements of the magnetic fields of sunspots on the solar surface have gained considerable attention since the first spectral visual measurements by Hale in 1908 at the Mount Wilson Observatory. In 1942, regular spectral photographic measurements of the maximum magnetic fields of sunspots and pores began at the Potsdam Observatory (the archive of the Crimean Astrophysical Observatory (CrAO) contains data for 1958, 1964, and 1965–1967). Although the accuracy of sunspot magnetic field measurements with a complete splitting of Zeeman components within a line can reach ±50 G (Severny, Stepanov, 1956), a comparison of the same sunspots observed at Mount Wilson and Potsdam revealed significant random and systematic errors. The maximum strength values determined at these observatories could differ by more than a factor of three (Severny, Stepanov, 1956).

For the director of the Simeiz Observatory, Academician G.A. Shain, these discrepancies in measurements were one of the compelling reasons in favor of constructing a new observatory in Crimea that would meet all necessary requirements. The unstable atmospheric conditions on the southern coast, caused by the proximity of mountains and the sea, led to a significant deterioration in the quality of images during photometric and spectral observations of astrophysical objects.

In 1943–1944, during the Great Patriotic War, the Simeiz Observatory was robbed and destroyed. The history of the Simeiz Observatory ended both physically and legally. This period is described in detail in the memoirs of Dobronravin (1998). It became necessary to build an independent Crimean astrophysical observatory.

In 1944, several expeditions were organized to select a site for the new observatory in Crimea that could meet all necessary requirements. For this purpose, atmospheric dust levels were measured, as well as the jitter of the solar disk edge by using a special scale placed into the eyepiece. The extent and brightness of the circumsolar aureole were assessed using a photoelectric photometer designed by Academician Fesenkov. Not only air humidity measured with a psychrometer but also the wind speed determined using an anemometer or visually through the Beaufort scale were considered. The pattern and the quantitative assessment of cloud cover and precipitation were also taken into account. The difference in the results of measurements obtained by different observers using the same instrument was explored, as well as the possibility of sudden temperature fluctuations (Gaze, 1948).

Observations conducted by A.B. Severny and O.A. Melnikov near the Mangush settlement (Partizanovka), now known as Prokhladnoye of the Bakhchisarai district, provided evidence on the superior quality of daytime images compared to other locations in Crimea, including Simeiz. This was primarily indicated by measurements of the jitter of the solar disk edge using a refractor with an eyepiece, as well as by fine details on the solar disk (spots, faculae, flocculi, and granulation) visible on the screen.

On June 30, 1945, the Council of People's Commissars of the USSR and the Academy of Sciences of the USSR decided to establish CrAO, obliging the Council of People's Commissars of the Crimean ASSR to establish a protective zone with a radius of 3 km to preserve good astronomical conditions. Large-scale construction was prohibited within this zone, and any other construction required approval from the Presidium of the USSR Academy of Sciences. Half a century later, on October 2, 1997, owing to the dissolution of the USSR, the Supreme Council of the Autonomous Republic of Crimea adopted a similar decision, prohibiting new construction in this zone without the approval from the interdepartmental commission of the Council of Ministers of the Autonomous Republic of Crimea.

Despite the measures taken to preserve the astroclimate and the importance of continuous monitoring of solar image quality, no research on this issue has been conducted since 1944. This work aims to analyze the dynamics of the quality of sunspot images over the past 50 years based on a unified technique using data from the STT-1 and STT-2 telescopes of CrAO.

2 Technique and processing of observations of the maximum magnetic field strengths in sunspots

The solar tower telescope STT-2 was constructed in the early 1970s based on the mechanical elements of the STT-1 (Severny, 1955), which was under reconstruction at that time. New sitall optics was manufactured for it at the workshops of CrAO. The telescope was designed for spectral and monochromatic observations of the Sun.

The primary mirror of the STT-2, with a diameter of 450 mm and a focal length of 12 m, along with the Cassegrain system, allows for solar images up to 300 mm in size to be taken at the spectrograph slit. The spectrograph is equipped with two gratings and cameras, which enables the recording of spectra with different dispersions. Currently, the telescope is used not only for daily measurements of the maximum magnetic field strengths in sunspots but also for obtaining solar images in the HeI 1083 nm line.

A method for measuring the maximum magnetic field strengths in sunspots was described in detail in the monograph of Stepanyan (1992). Regular measurements are conducted visually at the STT-2 using the absorption line of FeI λ 6302.5 Å in the fourth order of the spectrum with a dispersion of ≈ 0.36 Å/mm. The line is a simple Zeeman triplet with significant magnetic splitting (Landé factor $g = 2.5$).

A polarizing attachment consisting of a polaroid mosaic and a $\lambda/4$ plate is placed in front of the spectrograph slit. The angle between the axes of the polaroid mosaic and the $\lambda/4$ plate must be 45°, so the entire attachment should be rotated to balance brightness in strips of different polarization. A plane-parallel plate (line shifter) is installed in the cassette part of the spectrograph at the focal plane of the camera mirror, which allows one to determine its rotation angle. The magnetic field magnitude is measured by aligning the σ_l- and σ_r-components located in adjacent strips by rotating the line shifter.

To convert magnitudes of the rotation angles of the line shifter into magnetic field strengths, the line shifter is calibrated. The polarity of the magnetic field is determined by the appearance of the right or the left σ-component in the reference (or identical) strip of the polaroid mosaic.

The quality of sunspot images depends on the jitter of the solar disk edge, contrast, and blurring, which significantly affects the accuracy of the observed magnetic field values. The quality is assessed using a five-point scale (see Table 1).

Table 1. Criteria for assessing the quality of images from the STT-2 using a five-point scale.

Assessment	Image quality
1	Very poor (penumbra is not visible)
2	Poor (penumbra is visible, but penumbra structure is not visible)
3	Fair (penumbra structure is visible, but granulation is not visible)
4	Good (granulation is above visibility threshold)
5	Excellent (granulation is visible, and the solar limb is stable)

3 Results of statistical analysis

For the analysis, we used archival observation data on the maximum magnetic field strengths in sunspots obtained with the STT-2 between 1979 and 2023, as well as data obtained with the STT-1 in 1969 using the same technique and the same spectral line (Stepanyan, 1992). The quality assessments of images taken from April to September during the maxima of cycles 20–25 were considered. This is explained by the most favorable conditions for solar observations and the authors' attempt to maximally increase the sample of homogeneous data. In Table 2, the first column indicates the year of observations; the second column, the total number of observation days per season N_s; and the third column, the number of observation days $N_{j>3}$ with the image quality assessment $j > 3$.

Table 2. Number of observation days during the maxima of solar cycles 20–25.

Year	Total number of days per season N_s	Number of days with $N_{j>3}$
1969	121	39
1979	117	66
1989	130	62
2001	124	48
2011	144	28
2023	111	32

Out of the 747 observation days analyzed, 275 with $j > 3$ were selected. To obtain a normalized indicator of image quality per season, we detected the total number of observation days $N_{j>3}$ with $j = 3.5, 4, 4.5, 5$, normalized to N_s. It should be noted that in the calculations, assessments such as 3+, 4−, 4+, and 5− were considered equal to 3.5 and 4.5, respectively. Thus, the calculation was performed using the formula

$$< N_{j>3} >= k \frac{N_{j>3}}{N_s},$$

where the normalization coefficient $k = 10$ was used for greater convenience in presenting the results as a histogram. We note that, in our opinion, the normalized indicator of image quality in days better reflects the dynamics of changes in light of statistical patterns, as it corresponds to the probability of a positive event, i.e., has a clear mathematical meaning.

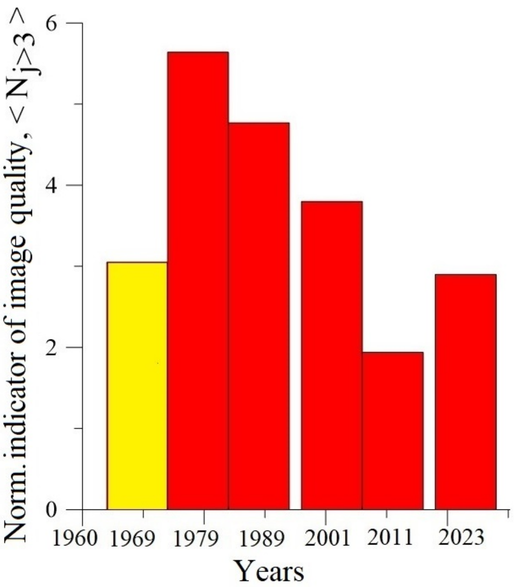

Fig. 1. Changes in the normalized indicator of image quality $< N_{j>3} >$ between 1969 and 2023. Yellow color corresponds to the results obtained with the STT-1.

As seen in Fig. 1, the normalized indicator of image quality has deteriorated since 1979. A sharp decline from 2001 to 2011 is attributed to untimely maintenance works. Only after the aluminizing of mirrors in 2015 and 2019, the value of the indicator $< N_{j>3} >$ significantly increased, becoming compared to the value in 1969.

Table 3. Number of observation days and image quality assessments for different observers during April–September 2023.

Observer number n	Number of days N_n	Total assessment J_n	Average assessment $< J_n >$
1	22	64.5	2.93
2	22	72.0	3.27
3	19	50.0	2.63
4	33	112.0	3.39
5	15	45.0	3.00

We also compared the image quality assessments made by different observers in 2023. The period under investigation included 111 observation days with corresponding image quality assessments by different observers, each assigned a number n (Table 3). The table shows the number of observation days N_n, the total (J_n) and average ($< J_n >$) image quality assessments for different observers n during April–September 2023. To calculate the average assessment $< J_n >$ for each observer, we first summed all the assessments obtained by the observer n during the season (April–September), regardless of the value of j. Then, we divided the resulting sum J_n by the corresponding number of observation days N_n, i.e.,

$$< J_n >= \frac{J_n}{N_n}.$$

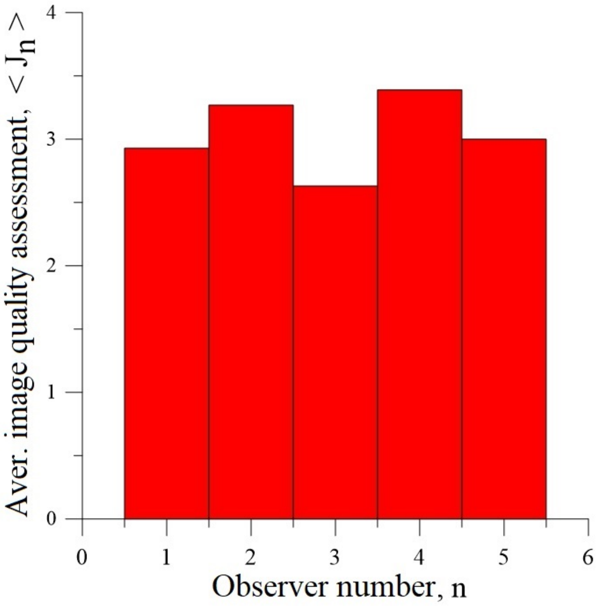

Fig. 2. Dependence of the average image quality assessment $< J_n >$ on the observer number n for April–September 2023.

As seen in Fig. 2, despite a small number of observation days per observer in 2023, the average assessments $< J_n >$ agree well with each other. This indicates not only the observers' responsible attitude toward measurements but also the validity of the statistical approach used.

4 Conclusions

The main conclusions of the work are as follows:

1. The quality of solar images from 1969 to 2023 shows a tendency to deteriorate, but since 1979, the image quality has remained relatively high (at the level of 1969).
2. The image quality assessments made by different observers in 2023 agree well with each other.
3. To obtain high-quality images, it is necessary to conduct timely maintenance and repair works, including aluminizing the telescope mirrors at least once per five years.

It should also be emphasized that the quality assessments of images obtained in 1969 require careful consideration, as the measurements were conducted with the STT-1 equipped at that time with another primary mirror with a diameter of 400 mm.

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