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Article

Astronomical Seeing at Maidanak Observatory during the Year 2018

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Abstract: Results of a four-month campaign of astronomical seeing measurements at Maidanak astronomical observatory (MAO) are presented. A differential image motion monitor (DIMM) was used for seeing estimations during the period from August to November 2018. The observation was organized within the framework of a site testing for a new telescope which is going to be installed at the observatory. The median value of seeing for the entire period was determined as 0.70 arcseconds, which agrees well with the results of the period 1996–2003. The comparison of monthly values showed that some monthly median values differ from the seasonal trend of the previous period.

Keywords: astronomical seeing; terrestrial atmosphere; optical turbulence; differential image motion monitor

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1. Introduction

The performance of ground-based astronomical observatories is limited by the terrestrial atmosphere. Astronomical seeing is one of the key parameters characterizing overall turbulence of the atmosphere above the observatory. The optical efficiency of telescopes depends largely on the astronomical seeing.

Maidanak astronomical observatory (MAO, longitude 66°56 E, latitude 38°41 N, 2600 m above sea level) is located at the south-east of the Republic of Uzbekistan. It is the main observational facility of the Ulugh Beg Astronomical Institute (UBAI), Uzbekistan Academy of Sciences. There are seven telescopes with 50-cm to 1.5-m apertures in the observatory [1]. Observations of different astronomical objects are carried out at MAO: gravitational-wave optical counterparts within the framework of the GRANDMA collaboration; gamma-ray bursts (GRB), gravitationally lensed systems (GLS), blazars, supernova, variable stars, exoplanets, and minor planets [2–8].

Optical properties of the atmosphere have been studied at MAO since it was founded in the late 1960s. The previous site testing campaign began in 1996 within the framework of the international collaboration led by the European Southern Observatory (ESO) [9]. Results of site testing studies at Maidanak Observatory in Uzbekistan in this period and a comparison to leading observatories showed that atmospheric parameters place Maidanak Observatory among the best international astronomical sites for high angular resolution observations [10].

The amount of clear night-time hours for Mt. Maidanak is about 60% of available yearly dark time—in absolute units this corresponds to 2000 h. The summer observing capacity of Mt. Maidanak is two times (more than 90% in July) higher than in winter (up to 50% in February).

The monitoring of astronomical seeing was carried out at Maidanak observatory during 1996–2003 using ESO DIMM [11] which was previously used for site testing of ESO observatories of La Silla and Paranal in Chile. The statistics of the whole timeseries revealed that the mean value of seeing is 0.76 arcseconds, the median is 0.71 arcseconds. The best monthly median seeing, 0.62 arcseconds, was observed in November [12].

In 2017, a project with a new 4-m telescope was initiated in Uzbekistan. Obviously, the first candidate for the place of installation was Maidanak Observatory. This acted as a new motivation to start the monitoring of astronomical seeing and other atmospheric parameters at MAO.

During the monitoring, it was planned to identify the following:

- The current value of astronomical seeing;
- Whether the astronomical seeing has changed or not;
- How much the astronomical seeing has changed;
- Causes of astronomical seeing changes;
- The monitoring of astronomical seeing on several hills at the Maidanak Observatory;
- The selection of a suitable location for the telescope;
- The increase of the efficiency of the telescope.

2. Materials and Methods

The light from the stars passes through the Earth's atmosphere, and the wave front coming in the same phase reaches the Earth's surface in different phases. As a result, the diffraction pattern of the stars formed in the telescope changes. The resolution θ of a telescope limited by atmospheric turbulence, as defined by the Strehl criterion, is θ [11]:

$$\theta = \left(\frac{4}{\pi}\right)\left(\frac{\lambda}{r_0}\right). \quad (1)$$

Here, r_0 is Fried's parameter, and λ—is the wavelength. Fried's parameter can be measured from the image motion using a small telescope [11]. Astronomical seeing is measured by the FWHM of the intensity of the star profile, which is the best angular resolution (in arcseconds) that can be achieved by an optical telescope in a long exposure time. Taking into account the Earth's atmosphere, the value of astronomical seeing is defined as ε_{FWHM} and is determined according to the following formula:

$$\varepsilon_{FWHM} = 0.98\frac{\lambda}{r_0} \quad (2)$$

One of the most effective methods of measuring astronomical seeing is the differential image method realized in a DIMMs [13]. In our case, it is based on a Celestron-11 telescope with a 279 mm primary mirror and a focal length of 2800 mm (Figure 1). Two circular masks are installed on the Schmidt corrector of the telescope. The masks are of 5 cm in diameter and the distance between the centers is of 19 cm. A 195-arcseconds wedge prism is installed on one of the holes, which creates the second image of the stars. A Santa Barbara instrument group's (SBIG) ST-5C camera is used as a detector on the focal plane of the telescope.

Due to atmospheric turbulence, image motion occurs—the distance between two images changes in two directions. The principle of the DIMM is to determine the relative displacements of centroids of two CCD-images along the x (longitudinal) and y (transverse) directions. The differential image motion variations of the set of the 200 dx and dy measurements are used to calculate $\varepsilon_{\mathrm{FWHM}}$ according to [13]. This determines the value of astronomical seeing in units of arcseconds. The smaller the motion of the star (the smaller the astronomical seeing), the more suitable the atmosphere of the observatory. In the world's leading astronomical observations, the value of the seeing is in the order of 0.6–0.8 arcseconds.

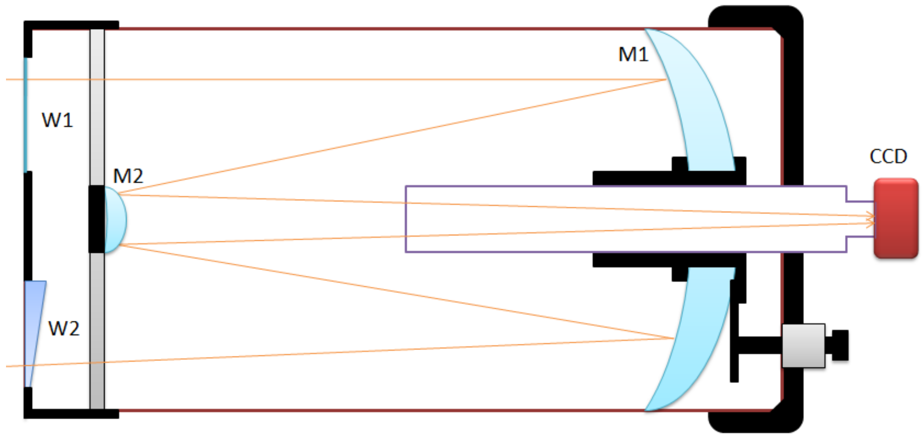

Figure 1. Optical scheme of the DIMM. M_1-main optical mirror, M_2-secondary hyperbolic mirror, W_1-first slit, W_2-second prismatic slit.

The DIMM we used at Maidanak Observatory in 2018 is the modified version of the instrument used in 1996–2003. During 1996–2003, we used ESO-DIMM [11] with the camera SBIG ST-5, a serial port camera. Since the speed of data transmission in the serial port was limited, the time required for one exposure was about 4 min for 40 images in 2 different exposures. In 2007, we replaced the camera with a more rapid one—ST-5C with a parallel interface but having the same pixel size and parameters. We used software based on Cerro-Tololo Inter-American observatories' (CTIO) Robodimm [14]. Despite the software being different, we used the same method described in [11] and updated in [13].

In order to have a good signal-to-noise ratio, bright stars are observed close to the zenith to have the air mass be at its smallest. A particular star is observed for a maximum of 4 h—two hours before and after culmination. A part of the list of stars selected for observation is given in Table 1. It lists the names, magnitudes, and equatorial coordinates of some of the bright stars that were observed.

Table 1. A partial list of the observed stars.

Star	Apparent Magnitude (m)	Right Ascension (α, 2000)	Declination (δ, 2000)
α And	2.05	$00^h08^m23^s.25$	$+29^\circ05'25''.55$
β Peg	2.48	$23^h03^m46^s.45$	$+28^\circ04'58''.02$
α Cyg	1.33	$20^h41^m25^s.91$	$+45^\circ16'49''.21$
α Lyr	0.09	$18^h36^m56^s.33$	$+38^\circ47'01''.29$
α Ari	2.00	$02^h07^m10^s.29$	$+23^\circ27'45''.94$

One of the most important aspects of measuring astronomical seeing is choosing the optimal exposure time (in milliseconds). It must be big enough to have two bright images of the same star with the highest possible signal-to-noise ratio in order to measure the centroids of images accurately. At the same time, the exposure time should be as short as possible to "freeze" the atmosphere. To overcome this situation, an "interlaced exposures" method is used—first DIMM takes exposure τ_1 (say, 5 ms) and τ_2 (double of τ_1—10 ms). Then, using two different exposure times, it "extrapolates" seeing to 0 exposure time using Equation (3), also described in [13].

For each exposure time, the differential displacements of the centroids of the images in x and y coordinates are measured. The variance of the set of the data is used for the estimations of the values of ε_1 and ε_2 in two exposures τ_1 and τ_2. Then, using the following expression, we can find the value of seeing ε_0 [15]:

$$\varepsilon_0 = 0.5(c_1\varepsilon_1 + c_1^{7/3}\varepsilon_2), \tag{3}$$

where $c_1 = (\varepsilon_1/\varepsilon_2)^{3/4}$. To reduce the statistical noise, factor c_1 is smoothed over time using a moving average method and then used in (3) to correct individual measurements [15].

In order to calculate one seeing value for a set of 200 measurements, the differential motions (dx and dy) are recorded in every exposure time.

3. Results

In early August, 2018, the DIMM device was installed on the same six-meter-high platform where it was used in the previous period. Monitoring of astronomical seeing using the DIMM telescope began on August 4 and continued until November 20.

On the basis of the observations at the Maidanak Observatory, the values of astronomical seeing obtained from 4 August to 20 November were processed and analyzed. Here, the astronomical seeing are calculated for the wavelength of as λ = 500 nm and they are reduced to zenith.

Figure 2 shows the whole timeseries of the astronomical seeing results obtained at the Maidanak Observatory.

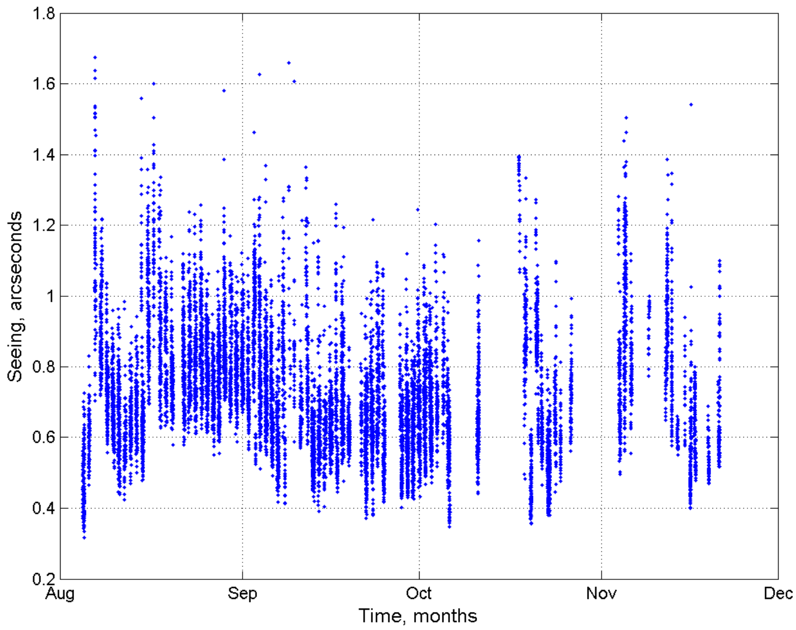

Figure 2. Astronomical seeing measured in August–November, 2018.

The cumulative distribution of astronomical seeing is shown in Figure 3. The blue color shows the cumulative distribution of astronomical seeing obtained in 2018. The dashed line shows the cumulative distribution of astronomical seeing obtained in 1996–2003. As can be seen from this graph, the median value of astronomical seeing for 2018 is 0.70 arcseconds and for 1996–2003 it was 0.71 arcseconds [12].

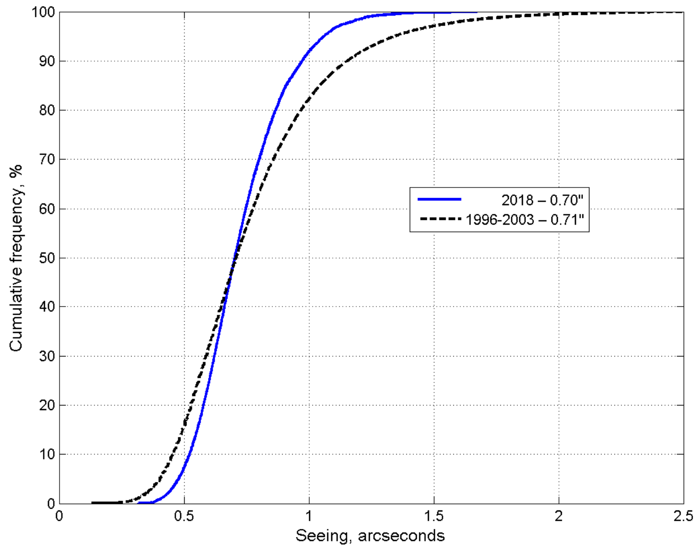

Figure 3. Cumulative distribution of astronomical seeing for the period August–November, 2018 and from 1996 to 2003.

The Table 2 shows the average, median values of astronomical seeing for each month, as well as values at the 25% and 75% percentile. The median value of astronomical seeing is 0.77 for August, 0.66 for September, 0.65 for October, and 0.75 for November. The value at 25% of all points obtained is 0.60 arcseconds. The value at 75% is 0.83 arcseconds. To find out how good or bad these astronomical seeing indicators are and how much they have changed, we compared the astronomical seeing results obtained using the same DIMM instrument in 1996–2003.

Table 2. Astronomical seeing statistics for each month for Maidanak Observatory.

Months	25%	Median	75%	Average
August	0.67	0.77	0.87	0.78
September	0.58	0.66	0.77	0.69
October	0.56	0.65	0.78	0.68
November	0.61	0.75	0.91	0.78
Total	0.60	0.70	0.83	0.73

A comparison of results obtained in two different periods at the Maidanak Observatory is presented in Table 3. This table shows the monthly median values of astronomical seeing obtained during the periods 1996-2003 and 2018. According to the first period data, the best value for astronomical seeing was in November (0.65 arcseconds), however our dataset shows that October has better seeing than November in this particular year. Overall, the median value of astronomical seeing at the Maidanak Observatory was found to be 0.70 arcseconds against 0.71 arcseconds in 1996–2003. The comparison shows that median values for both of the periods agree, the difference is negligible (0.01 arcseconds). However, in the particular year 2018, the median monthly seeing is higher in August (0.05 arcseconds) and in November (0.10 arcseconds), but slightly better in September and October.

Table 3. Median values of astronomical seeing obtained at the Maidanak Observatory in 1996–2003 and August–November 2018.

Months	1996–2003 (ε_{FWHM}, Arcseconds)	2018 (ε_{FWHM}, Arcseconds)	Difference
August	0.72	0.77	+0.05
September	0.70	0.66	−0.04
October	0.69	0.65	−0.03
November	0.65	0.75	+0.10
Total	0.71	0.70	−0.01

4. Conclusions

Overall statistics of astronomical seeing measured in this campaign are in good agreement with those of the period 1996–2003. Since the measurements carried out include the period where seeing is good (September–November) it was expected that the median value would be lower than the 0.70 arcseconds, but this was not the case in 2018.

Due to the short duration of the measurement campaign in 2018, it is not possible to draw a complete conclusion. In order to find the reasons of the seasonal changes, a continuous monitoring of this parameter is required. This requires regular observations of at least one full year or more.

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