Monitoring and Analysis of the Optical Observation Environment at Nanshan Station (Postprint)

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Abstract

To analyze the optical observing environmental conditions at Nanshan Station, long-term monitoring of atmospheric seeing, night sky brightness, and meteorological data was conducted at Nanshan Observatory using instruments such as SBIG and SQM-LE. Based on screening and organizing a large amount of monitoring data, monthly and yearly statistical analyses were performed. The results show that the annual average seeing at Nanshan Station monitored using the SBIG seeing monitor is 1.74" , the night sky brightness is 21.7 mag arcsec^{-2}, the annual average temperature is 3.4°C, the annual average relative humidity is 57.3%, the wind speed is mainly distributed in the range of 2-3 m/s, and the main wind direction is southwest. These parameters indicate that the optical observing environment at Nanshan Observatory is favorable and can meet the observational environmental requirements for medium and small telescopes. The measurement results can serve as a reference for other optical sites.

Full Text

Preamble

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Monitoring and Analysis of Optical Observing Conditions at Nanshan Observatory

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Abstract

To analyze the optical observing environmental conditions at Nanshan Observatory, we conducted long-term monitoring of atmospheric seeing, night sky brightness, and meteorological data using SBIG seeing monitors and SQM-LE night sky brightness meters. Based on the screening and organization of extensive monitoring data, we performed monthly and annual statistical analyses. The results show that Nanshan Observatory has an annual average seeing of 1.74 , night sky brightness of 21.7 mag/arcsec^2, annual average relative humidity of 57.3%, and annual average temperature of 3.4°C. Wind speeds are predominantly in the range of 2–3 m/s, with the main wind direction being southwest. These parameters indicate that Nanshan Observatory has good optical observing conditions that can meet the environmental requirements for small and medium-sized telescopes. The measurement results can serve as reference data for other optical sites.

Keywords: optical observing conditions; atmospheric seeing; night sky brightness; meteorological parameters

1. Introduction

To obtain high-quality optical stellar images, telescopes must not only be large in aperture with excellent design and precise manufacturing, but also be installed at sites with favorable optical observing environments. The factors that determine the quality of an optical observing site can be divided into two main categories: (1) atmospheric seeing and night sky brightness; and (2) atmospheric water vapor content, air temperature, relative humidity, wind speed, and wind direction. Atmospheric seeing is a crucial parameter for evaluating the quality of an optical observing site, representing the combined effect of atmospheric turbulence on starlight.

When a point source passes through a circular aperture optical system, the resulting image is not ideal. Due to the diffraction limit, it becomes a Fraunhofer diffraction pattern consisting of a central bright spot surrounded by diffraction rings. Before reaching ground-based telescopes, starlight must pass through Earth' s turbulent atmosphere. Constant changes in atmospheric density and temperature cause variations in atmospheric refractive index, which distort the optical wavefront. Consequently, the stellar image becomes unstable in both density and position, no longer maintaining a stable Fraunhofer diffraction pattern. The diffraction rings are disrupted, the central bright spot becomes larger and blurred, and the entire image moves and twinkles irregularly and rapidly. Monitoring atmospheric seeing at a site is therefore an important indicator for evaluating telescope site quality, observing efficiency, and data quality.

Analyzing temporal and seasonal variations in seeing ensures optimal telescope operation. Internationally, many excellent astronomical sites have been selected, such as Mauna Kea and Paranal in Hawaii, and La Palma, where seeing is below 0.5 . A site with annual average seeing around 1 can be considered excellent.

Night sky brightness is another critical parameter for evaluating optical site quality, directly affecting the limiting magnitude and observation precision. Its sources include natural light above the atmosphere (unresolved starlight, diffuse galactic light, zodiacal light, etc.) and artificial light sources such as urban illumination. Solar activity also significantly influences long-term variations in night sky brightness. During periods of intense solar activity, night sky brightness increases. While natural sky brightness is unavoidable, light pollution is anthropogenic. Monitoring night sky brightness at a site enables quantitative analysis of human-caused impacts and helps protect astronomical observatories. For night sky brightness measurements, excellent sites in the visible band achieve values of 21.5–22.0 mag/arcsec^2. Sites with values greater than 21.5 mag/arcsec^2 can be considered good.

Meteorological factors objectively affect observations. Temperature variations influence near-ground airflow, thereby affecting seeing. Appropriate temperature ensures normal operation of optical observing systems. Relative humidity not exceeding 60% and stable wind speed and direction are also important prerequisites for optical observations.

Nanshan Observatory is located in Gangou Township, Urumqi County, at an altitude of 2,080 m. The local climate is typical temperate continental, with no extreme winds year-round. Since beginning optical observations in 2010, no extreme weather has occurred in summer or winter. Multiple optical telescopes are operational, including a wide-field optical telescope system completed in 2010 for time-domain astronomy and space debris observation research. To support optical observations, an optical environment monitoring system was installed at Nanshan Station in 2010, including a seeing monitor, night sky brightness meter (Sky Quality Meter-LE, SQM), fish-eye cloud camera, and an automatic weather station for measuring temperature, relative humidity, wind speed, and wind direction. This paper focuses on statistical analysis of these long-term monitoring data to provide quantitative assessment of Nanshan Station' s optical observing environment.

2. Observation Principles and Methods

2.1 Atmospheric Seeing

Various physical quantities characterize seeing. Early methods used photographic trailing, where the variance σ from parabolic fitting of star trail trajectories represented atmospheric seeing. Modern observatories use equipment such as SBIG and DIMM to measure atmospheric coherence length r_0, with seeing expressed as the full width at half maximum (FWHM) of stellar image brightness. Smaller σ or FWHM indicates better seeing.

The relationship between FWHM and atmospheric coherence length r_0 is:

$$FWHM = 0.98\frac{\lambda}{r_0}\sec^{0.185}(\psi)$$

where λ is wavelength,   is zenith angle, and r_0 is the atmospheric coherence length. The refractive index structure constant C ^{2} is primarily determined by temperature fluctuations:

$$r_0 = \left[\int_0^{\infty} C_n^2(h)\,dh\right]^{-3/5}$$

where h is station altitude. The refractive index structure constant relates to temperature structure constant C ^{2}, pressure P, and temperature T through:

$$C_n^2 = (79 \times 10^{-6}\frac{P}{T^2})^2 C_t^2$$

Among the many parameters affecting optical astronomical observations, atmospheric seeing measurement is relatively complex with various methods. Early seeing observations used the Danjon method of directly observing star image degradation and grading the turbulence level. This method was later proven defective as it ignored image motion and focused only on image degradation. Telescope trailing measurement, widely used in the northern hemisphere, employs Polaris as the target star. The trailing method can directly calculate FWHM, providing atmospheric seeing. By measuring relative motion of single star images through two small apertures on the pupil plane, the DIMM (Differential Image Motion Monitor) method, proposed by Hartmann and later expanded by Stock, enables real-time measurement of atmospheric turbulence intensity. This is currently one of the more precise seeing measurement methods. In 1986, Sarazin and Roddier developed seeing monitors based on this principle. The SBIG seeing monitor measures r_0 using the trailing method without tracking errors, ensuring measurement validity, though it cannot yet achieve long-term unattended monitoring.

Nanshan Observatory uses an SBIG ST-402ME seeing monitor with a 150 mm focal length and f/5.3 focal ratio. The entire system is installed in a weatherproof metal box with a transparent window facing north. In the northern hemisphere, Polaris serves as the target star, remaining within the instrument' s field of view during observations. Computer programs directly obtain real-time zenith seeing FWHM values. Long-term monitoring generates extensive seeing data for statistical analysis. The seeing observation period covered in this paper is from 2010 to 2016.

2.2 Night Sky Brightness

Nanshan Observatory began using a Unihedron SQM-LE night sky brightness meter in 2010. This device is widely used for regional light pollution monitoring, with an absolute accuracy of $±$10% after calibration and minimum sampling time of 80 seconds. The device dimensions are 3.6 × 2.6 × 1.1 cm. Night sky brightness in mag/arcsec^2 relates to absolute brightness F (cd/m^2) through:

$$mag/arcsec^2 = 12.41 - 2.5\log_{10}(F)$$

Observatories can obtain long-term night sky brightness monitoring data, including cloudy and clear nights, as well as moonlit and moonless nights. To obtain more objective statistics, we first selected completely clear nights. Daily observation records show that weather conditions such as clouds and snow significantly affect results. Moonlight is the primary cause of increased visible band sky brightness. This paper selected clear-night data by combining meteorological logs with daily data quality. Bessel' s formula was used to eliminate gross errors by removing excessively high values, and only the maximum daily values were averaged to represent the site' s night sky brightness over a period, essentially avoiding moonlit night data influence. The night sky brightness data record period is from 2010 to 2016, with no distinction between clear and cloudy conditions in monitoring. The sampling interval was set to 1 minute.

2.3 Meteorological Data

For meteorological data monitoring at Nanshan Station, we selected an automatic weather station compliant with meteorological observation standards. This equipment is widely used in meteorology, water conservancy, and marine environmental monitoring, collecting data on temperature, humidity, wind speed, wind direction, and solar radiation with stable operation and high precision. Measurement resolutions are 0.1°C for temperature, 0.1% for humidity, and 0.1 m/s for wind speed. This weather station was installed at Nanshan Observatory, with humidity sensors at 1.5 m height and wind speed/direction sensors at 10 m height. Data collection intervals were set to 1 minute for all parameters.

3. Results and Analysis

3.1 Seeing Statistics

Statistical analysis of extensive seeing data collected at Nanshan Station shows the main distribution interval for atmospheric seeing. The seeing monitor collects data every minute, with computer records storing median values per minute. [Figure 1: see original paper] shows the statistical distribution of seeing at Nanshan Observatory, with 74,000 data points collected. Seeing better than 1.5 accounts for 28.7% of observations.

[Figure 2: see original paper] presents monthly statistical mean variations. After May, monthly mean seeing shows an improving trend, while March conditions suddenly deteriorate. Meteorological records reveal that March has more cloudy days, with a mean seeing of only 2.02 , whereas October' s mean is 1.51 . The seeing monitor is sensitive to weather factors, so obtaining precise statistics requires selecting data from optimal weather conditions. The overall trend shows autumn seeing is better than spring. The worst monthly mean occurs in March, while the best appears in October.

[Figure 3: see original paper] shows monthly nighttime variations in seeing, with each hourly interval based on no fewer than 15 days of data. Nanshan Station' s seeing remains relatively stable throughout the night, though March shows degraded seeing during twilight transitions. This degradation likely results from greater temperature changes during day-night transitions causing near-ground air movement. The seeing monitor itself is sensitive to wind, which can produce artificially high values and degraded seeing conditions.

3.2 Night Sky Brightness Statistics

Based on meteorological observation records from 2010–2016 and daily night sky brightness data, [Figure 4: see original paper] shows the statistical distribution for clear-night data. Night sky brightness is mainly distributed between 21.4–22 mag/arcsec^2, with visible band mean values greater than 21.5 mag/arcsec^2. [Figure 5: see original paper] presents the recorded visible band night sky brightness from meteorological logs, with some measurements reaching 23 mag/arcsec^2. Such high values occur when clouds appear in the observed field or when winter snow covers the instrument. These data are treated as gross errors and eliminated using Bessel' s formula. The final statistics use the maximum daily mean value as 21.7 mag/arcsec^2, with lower values primarily caused by moonlight affecting visible band night sky brightness.

3.3 Meteorological Parameter Statistics

[Figure 6: see original paper] shows monthly temperature statistics for Nanshan Station from 2010–2016. The annual average temperature is 3.4°C, with a recorded maximum of 30.7°C and minimum of -31.0°C. Monthly mean temperatures closely match median values. Temperature differences between maximum and minimum are larger in spring and winter (14.1°C), while summer and autumn differences are smaller (-7.8°C). Winter average temperature is -7.8°C.

[Figure 7: see original paper] presents monthly relative humidity statistics. The annual average relative humidity is 57.3%, with summer average at 62.7% and winter average at 53.0%. Monthly average relative humidity closely matches median values. Nanshan has more summer rain, with other months below 60.8% humidity.

[Figure 8: see original paper] and [Figure 9: see original paper] show wind speed and direction data obtained from the automatic weather station. Wind speed is measured as the average per minute, with predominant wind directions from the southwest and west-southwest over 24 hours. Wind speed is mainly distributed in the 2-4 m/s range. Daytime average wind speed is 1.9 m/s, nighttime average is 1.8 m/s. The cumulative probability for wind speeds of 0.2-1.5 m/s is 7.80%, 1.5-3.3 m/s is 36.50%, 3.3-5.4 m/s is 53.20%, 5.4-10.7 m/s is 28.7%, and wind speeds above 10.7 m/s occur less than 0.6% of the time, indicating minimal severe wind events.

Wind Speed Distribution Cumulative Percentage

Wind Speed (m/s)	Cumulative Percentage
$ $0.2 (0)	7.80%
$ $1.5 (1)	36.50%
$ $3.3 (2)	89.70%
$ $5.4 (3)	99.40%
$ $7.9 (4)	99.90%
>10.7 (5)	0.04%

4. Conclusion

This paper statistically analyzes long-term monitoring results of seeing at Nanshan Station obtained using SBIG seeing monitors. The analysis yields a mean seeing value of 1.74 , with winter seeing (1.67) better than spring. Continuous 7-year night sky brightness measurements using SQM-LE meters show a statistical maximum mean value of 21.7 mag/arcsec^2, with seasonal variations. Compared with excellent international sites, Nanshan Station' s night sky brightness qualifies as good. Meteorological data from the automatic weather station reveal Nanshan Station is dry, with relative humidity below 60%, annual average temperature of 3.4°C, and wind speeds mainly distributed at 2-3 m/s with minimal severe winds above level 5. These conditions are suitable for construction and operation of small optical telescopes.

Although the SBIG seeing monitor and SQM-LE night sky brightness meter are not mainstream instruments for site monitoring in the astronomical community, the long-term continuous monitoring data obtained can still reflect Nanshan Station' s optical observing environment to a considerable extent.

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Note: Figure translations are in progress. See original paper for figures.