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Site testing campaign for the Large Optical/infrared Telescope of China: general introduction of the Daocheng site

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Abstract The Daocheng site is one of the three candidate sites for the Large Optical/infrared Telescope (LOT) of China. It was discovered by Yunnan Observatories during the survey of potential sites for the next-generation large-aperture solar telescopes of China. This paper describes the overview of the site, the observation platform and the monitor instrument. In addition, simple statistical results are presented (from November, 2016 up to December, 2017). Detailed data results can refer to the overview of LOT site testing and data analysis articles, which were published during the same period.

Key words: site testing — LOT — Daocheng site — observation platform

1 INTRODUCTION

The atmosphere turbulence reduces the image quality and resolution ratio of ground-based optical telescopes (Fried 1966; Roddier et al. 1982). Therefore, selecting astronomical sites with stable atmosphere turbulence and good seeing is extremely important to maximize the full capacity of telescopes.

In the early 2000s, Chinese scientists focusing on astrophysics society came to a consensus to survey sites in the western area of China prior to the development of their future large-aperture telescopes (Fang 2011). Ali, Oma, and Karasu are promising candidate sites that were discovered by the Site Survey Team of the National Astronomical Observatories during their survey which started in 2003 (Liu et al. 2010; Liu et al. 2012b). Daocheng and Namucuo lake were selected by Yunnan Observatories during their parallel solar site survey which started in 2011 (Liu et al. 2012a, 2016; Song et al. 2018; Li et al. 2017). All of these efforts have dramatically promoted the astronomical site survey in China.

In 2016, a site selection project for the LOT (Cui & Zhu 2016) was launched by the Center for Astronomical Mega-Science of the Chinese Academy of Sciences (CAMS-CAS). Based on a dataset accumulated during remote and local surveys, the short candidate list for LOT was narrowed down to Ali, Daocheng, and Muztagh-ata. All three are located in western plateaus, and all are over 4200 m above sea level. Three teams were assigned to monitor the meteorological and atmospheric parameters at the three candidate sites. The site survey group of the Yunnan Observatories is in charge of the monitoring stations at Daocheng site.

Since October 2011, the group has been measuring and collecting a series of site parameters in the Daocheng site region (Liu et al. 2012a, 2016; Wu et al. 2016; Song et al. 2019). During $2014-2015$, the fixed-point monitoring stations of No. 1 and 2 at Mt. Wumingshan (one mountain at the Daocheng site) have been set up in succession, and continuous on-site measurement has been started. In October 2016, the site testing campaign for LOT was officially started at Mt. Wumingshan (Mt. WMS).

In the current article, we present the overview of the Daocheng site and give a brief description of the result of the campaign. An overall depict of the site and the site-

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monitor instruments will be provided in the following two sections. In Section 4 universal meteorological message: temperature, wind speed and also wind direction are presented. Section 5 presents the statistics of the atmospheric optical parameters with the Differential Image Motion Monitor (DIMM). Section 6 will illustrate a summary and will give final comments. The detailed data results can refer to the overview of LOT site testing and data analysis articles, which were published during the same period.

2 GENERAL SITE DESCRIPTION

Daocheng site (Mt. WMS, longitude $100°05'$ E, latitude $29°08'$ N) is located in the Grand Shangri-La area of southwest China, more specifically, between Daocheng County and Xiangcheng County, as shown in the yellow pushpin in Figure 1. This area is regarded as a particular conjunction part of the Hengduan Mountains, and the famous magnificent Shangri-La (southeastern part of the Tibetan Plateau), thus becoming China's special location. It has been selected as one of the most potential regions for hosting China's next-generation ground-based large telescopes. The highest altitude at Daocheng site is more than 5000 meters. However, its unique topographic, geological and geographical characters are suitable for the settling of large telescope clusters. The mountain area is a flat high plateau, rarely found in the west of China. There is a thin layer of highland grass on the mountain surface, which can greatly reduce the dust on the ground. Figure 2 shows a local configuration as the typical topographic feature for Mt. WMS (Wu et al. 2016).

The operation of a low-cost logistic network, excellent geographical and climatic features (e.g. low cost of operation, high relative evaluation and good atmosphere conditions), are provided at this site. The overall elevation of Mt. WMS region is as large as about 2000 m. There are a number of villages and towns nearby with altitudes of $2800 - 3800$ m within one hour's drive from the monitoring stations, which is helpful for building one low-altitude transit station convenient for material storage, personnel accommodation and other supporting facilities for the observation equipment. Figure 3 gives a relief map of the surrounding areas of Mt. WMS. It can be seen that the altitude drop of surrounding areas to Mt. WMS is relatively large.

Daocheng County has convenient transportation conditions and it has been connected directly with several major cities by the national highways and provincial highways. From the Aden Daocheng Airport, there are direct routine flight lines available to connect it with famous cities, such as Chengdu, Chongqing, $\mathrm{Xi'an}$ and Hangzhou, etc. There are several high-voltage electrical transmission lines along the road winding through Mt. WMS from east to West. This electricity supply will be very convenient in the future (Li et al. 2017).

To facilitate the monitoring of the conditions of the site parameters at Mt. WMS, two monitor stations were built for the site testing. Figure 4 shows No. 1 monitor station, and Figure 5 presents No. 2.

The straight-line distance between the two monitor stations is 7 km. Each observation station has set up a monitoring platform, and the monitoring instrument is installed on the platform. The power supply of the equipment is provided by the solar power system. To avert turbulent flow at layer of the surface border, the elevation of monitoring platforms is set as 5 m for No. 1 monitoring platform and 7.5 m for No. 2 monitoring platform.

For each monitor platform, except for the atmosphere turbulence monitoring equipment, an automatic weather station is built to collect the ground level meteorological statistics. Meanwhile, an all-sky camera is devised to record the images of the cloud statistics and to evaluate the light pollution.

3 MONITORING INSTRUMENTS

It is generally understood that statistically credible statistics of on site features are obtained during routine observations over a long time period (not less than two to three years). The best solution for the assignment is to install an automated monitoring platform without the intervention of regular observers.

A set of automated instrumentation and software have been developed for the accumulation of data such as seeing, meteorological parameters, cloud data, etc. A total of nearly 20 monitoring devices were installed at Stations 1 and 2, as shown partly in Table 1. Some of them can work in the daytime to measure the astronomical factors related to the solar observation, such as the seeing, the atmospheric integral water vapor, the sky brightness. The others are night instruments for night seeing measurements and calibrations. Seven devices are used for continuous monitoring of meteorological and atmospheric parameters, such as night sky brightness, dust particle density, 24-hour cloud cover, low-layer atmospheric turbulence, regular meteorological parameters. Figure 6 shows the main monitoring instruments, which are set on a few pillars on the top ground of the No. 2 station building. Some of the same types of devices can run simultaneously at the two monitoring stations for the purpose of comparison.

For the LOT's site testing campaign, the main devices are DIMM, Sky Quality-Meter, All-sky Camera, Meteorological Station, etc.

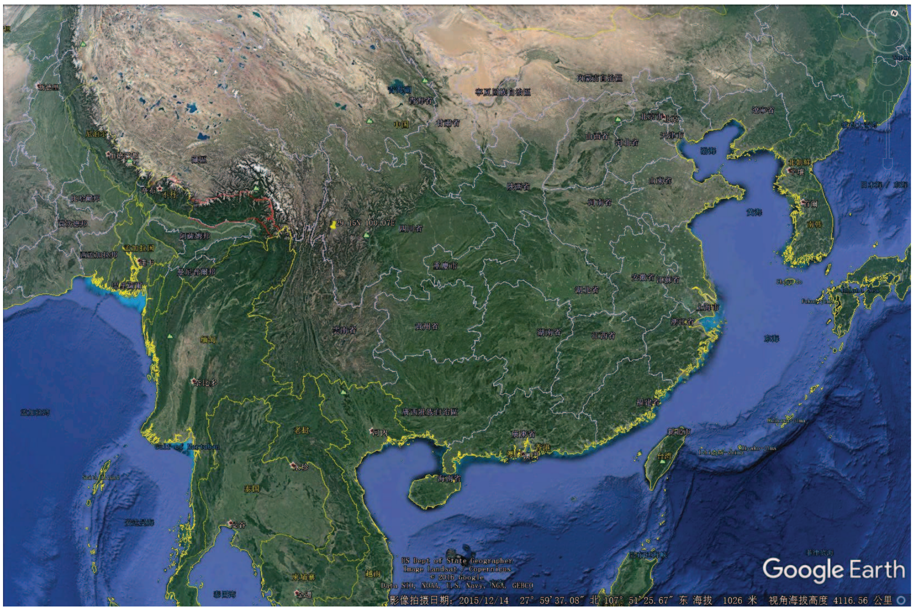

Fig. 1 Approximate location map of Mt. WMS. The *yellow pushpin* in the figure shows the location of Mt. WMS on Google Earth.

Fig. 2 A local configuration as the typical topographic feature for Mt. WMS with an altitude of 4800 m.

Table 1 Main Instruments Deployed at the Monitoring Stations

No	Instrument	Measurement/Mode
1	DIMM (Differential Image Motion Monitor)	night-time seeing/semi-auto
2	S-DIMM (Solar Differential Image Motion Monitor)	day-time seeing/semi-auto
3	All-sky Camera	cloud cover/auto
4	Multi-Wavelength Solar Photometer	day-time PWVC, aerosol index/auto
5	Micor-T Tower	C_T^2/semi-auto
6	Water Vapor Monitor	day-time PWVC/semi-auto
7	Sky Quality-Meter	night sky brightness/auto
8	Cloud Sensor	cloud condition/auto
9	Dust Particle Counter	particle counting/auto, night time
10	Meteorological Station	meteorological/auto
11	Lunar Scintillometer (LuSci)	night-time $C_n^2(h)$/semi-auto

3.1 DIMM

The DIMM is designed for night-time seeing measurement, which uses a single telescope with two apertures (one aperture is fitted with an optical wedge prism) to separate two images of the same star on the camera. The Fried parameter (seeing) can be obtained by measuring the correlation of motion between these two star images (Martin 1987; Sarazin & Roddier 1990; Tokovinin & Kornilov 2007).

For the comparison testing, we used two DIMMs with different telescope aperture. The first of them is named as NIAOT-DIMM, which designed by Nanjing Institute of Astronomical Optics & Technology (NIAOT). The NIAOT-DIMM consists of a 200mm-diameter Ritchey-Chrtien telescope (GSO-8-RC), a motorized equatorial

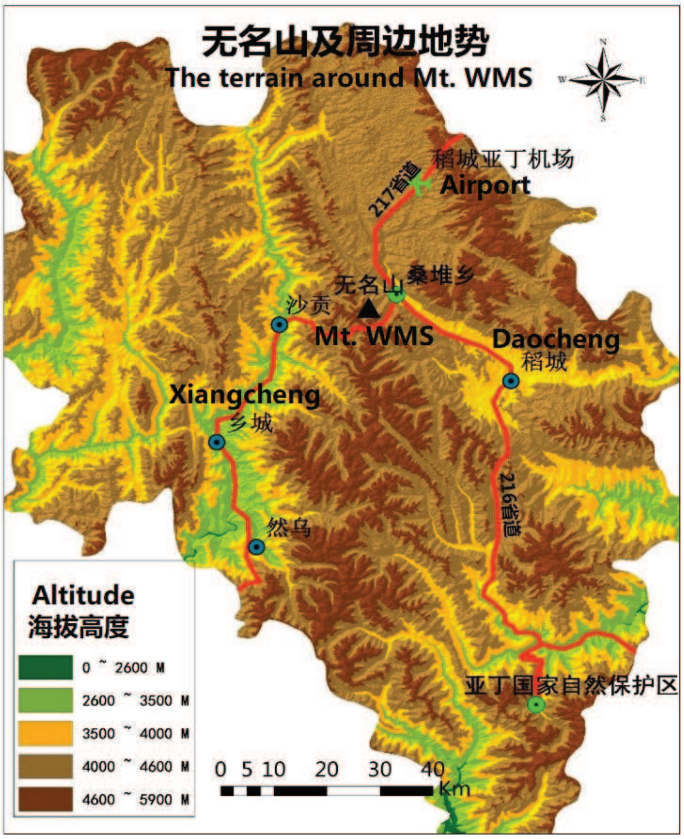

Fig. 3 Relief map of Mt. WMS and its surrounding areas.

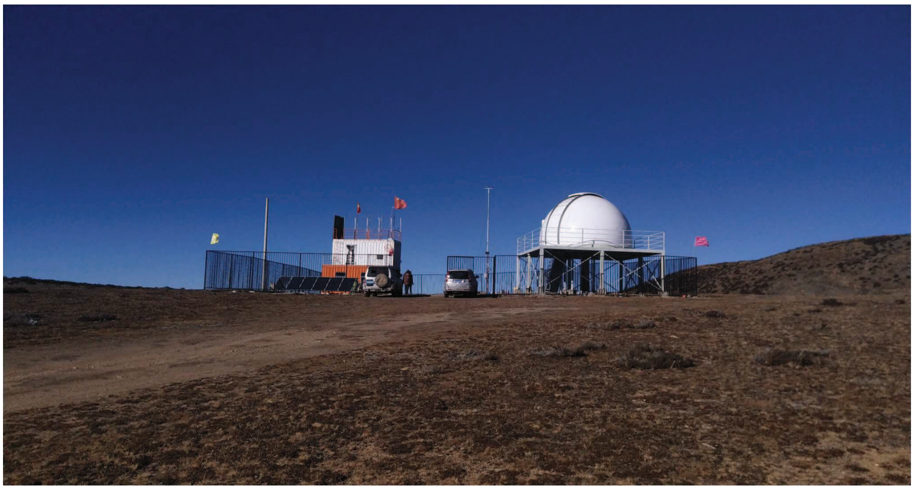

Fig. 4 Mt. WMS monitoring station No. 1.

mount (AP-1200), an aperture mask involving two sub-apertures (the distance between of the two sub-apertures is 140 mm, and the diameter of sub-apertures is 50 mm) and a CCD camera (Basler 1240). As shown in No. 3 of Figure 6, the NIAOT-DIMM can automatically measure and collect time series of data, but we need to manually start their systems.

The second is French DIMM (F-DIMM), which was purchased from the French ALCOR SYSTEM company by the CAMS-CAS (seen No. 4 of Fig. 6). The F-DIMM instrumental parameters are summarized in Table 2. This is automatic monitoring equipment that does not require manual intervention.

We have performed cross-calibration tests for both DIMMs. For each F-DIMM comparison, tests were conducted at the Xinglong Observatory for a week before being assigned to each site. Figure 7 is a statistical plot of the results of our comparative tests. The error between the two

Fig. 5 Mt. WMS monitoring station No. 2.

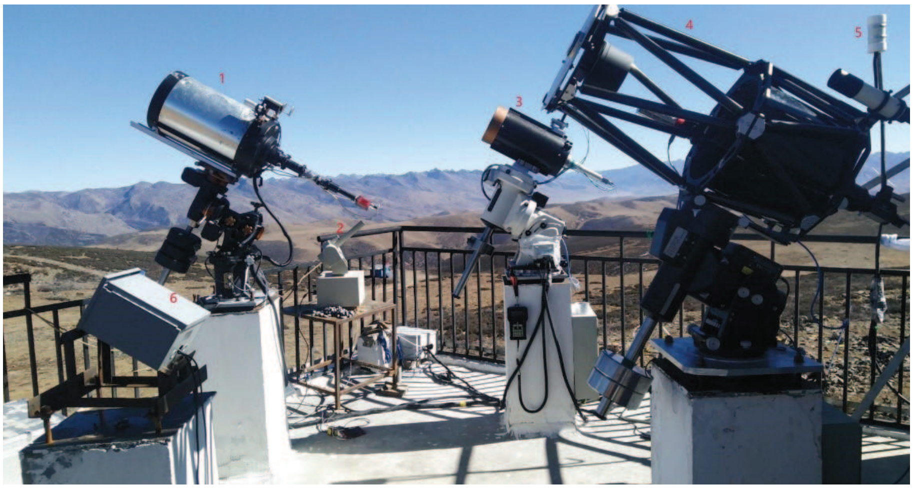

Fig. 6 Part of the site monitoring instruments on station 2. (1) Solar-DIMM, (2) Multi-Wavelength Solar Photometer, (3) NIAOT-DIMM, (4) French-DIMM, (5) Sky Quality-Meter.

Table 2 Technical Specifications and Parameters of F-DIMM

Telescope	
Model	GSO, 12″ RC
Aperture	304.8 mm
Focal length	3048 mm
Mount	
Model	GM 200
mask	
diameter	D=50 mm
separation	d=220 mm
CCD	
Model	DMK 33GX174
Exposure time	$<$ 10 ms
Pixel size	5.86 μm×5.86 μm
Number of images used for one seeing data	1000
calculated wavelength	500 nm

sets of DIMMs is less than 0.02 arcsec, which meets our requirements. The seeing data in this paper are based on NIAOT-DIMM.

3.2 Sky Quality-Meter

The instrument that we use at Mt. WMS is a Unihedron Sky Quality Meter (U-SQM), a device for measuring night sky brightness parameters, which is regarded as a low cost and pocket scale night sky brightness photometer, with the main specifications of the U-SQM as follows:

1. The Half Width Half Maximum (HWHM) and full Width Half Maximum (FWHM) is $\sim 10°$ and $\sim 20°$, respectively. The sensitivity to a point source $\sim$ 19° off-axis is a factor of 10 lower than on-axis. When point light source $\sim 20°$ and $\sim 40°$ are off axis, their brightness is 3.0 and 5.0 magnitudes fainter.
2. Operates from 5 VDC adapter, Ethernet connectivity.
3. The largest and the least light sampling time is 80 s and 1 s, respectively.
4. If specifications vary, they will not be further noticed.

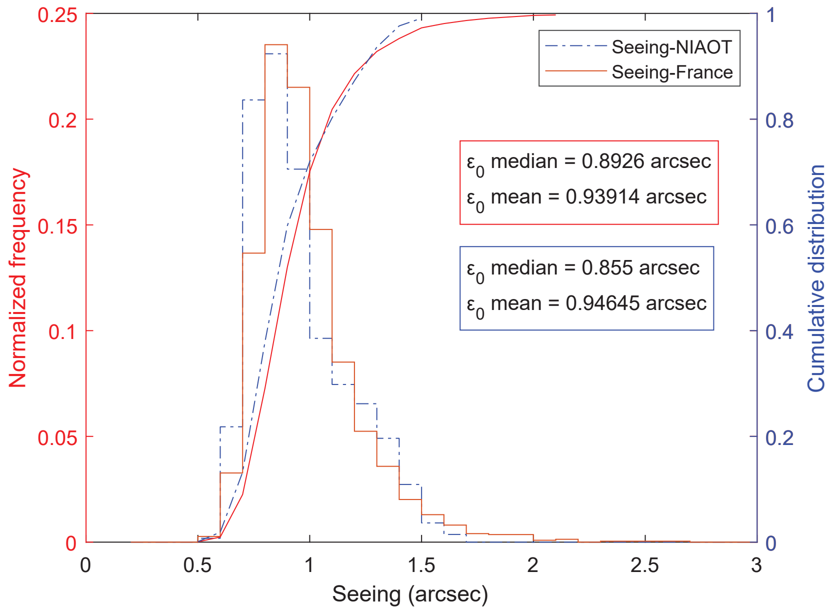

Fig. 7 Histogram and cumulative distribution of comparative tests at Mt. WMS.

3.3 All-sky Camera

The all-sky camera (ASCA) images the sky in real time by a camera and the 180° fish-eye lens. By analyzing the sky images, the changes in the amount of cloud can be obtained. The all-sky camera adopts the camera of Canon 60D and Sigma-4.5mm fish-eye lens. When a USB cable is connected to the computer, a sky image will be automatically captured every 5 minutes. Figure 9 shows the sample image shoot by the ASCA.

3.4 Weather Station

Each site station is installed with a Huayun CAWS-600 automatic weather station. This device is fully automated and it provides six-element meteorological data (wind-direction, wind-speed temperature, pressure, humidity, and rainfall) for constant monitoring. The weather station at No. 1 site is installed on a 10-meter-high weather mast. The weather station at No. 2 site is installed on a 22-meter-high tower. The weather station automatically collects the weather data every minute and saves it in real time. Remote data sharing can be achieved through the GPRS network.

4 WORKING FLOW OF THE MONITORING TASK

To effectively fulfill the hard site survey work on Daocheng site, the site survey team was divided into five departments according to their duties: the Monitoring Group, the Database Group, the Data Analysis Group, the Operation and Maintenance Group, and the Management Group (Li et al. 2017; Liu et al. 2018). Each department should complete the three main tasks, that is, monitoring and data pre-processing, operation and maintenance, and process management, as shown in Figure 8.

The monitoring group are in charge of the operation of the two monitoring stations on Mt. WMS and the branch in the downtown in Daocheng. We have two databases, one is placed in the Yunnan Observatories of the Chinese Academy of Sciences in Kunming and the other is placed in CAMS-CAS in Beijing. The Database Group completes the warehousing, database and backup tasks. The data services are mainly used by the internal departments, especially for the Data Analysis Group to provide downloading services for real-time and historical monitoring data. The Data Analysis Group shoulders the task of obtaining scientific research achievements. The development, installation and maintenance of each monitoring equipment and the servo system are the responsibility of the Operation and Maintenance Group. The Management Group is responsible for the overall construction and management of the site survey data flow.

5 METEOROLOGY OF THE DAOCHENG SITE

5.1 Clear Night Sky

The number of clear nights is an important parameter for evaluating the quality of astronomical observations at a site. The clear night sky measured by the ASCA. The sky images were selected according to the local twilight. As

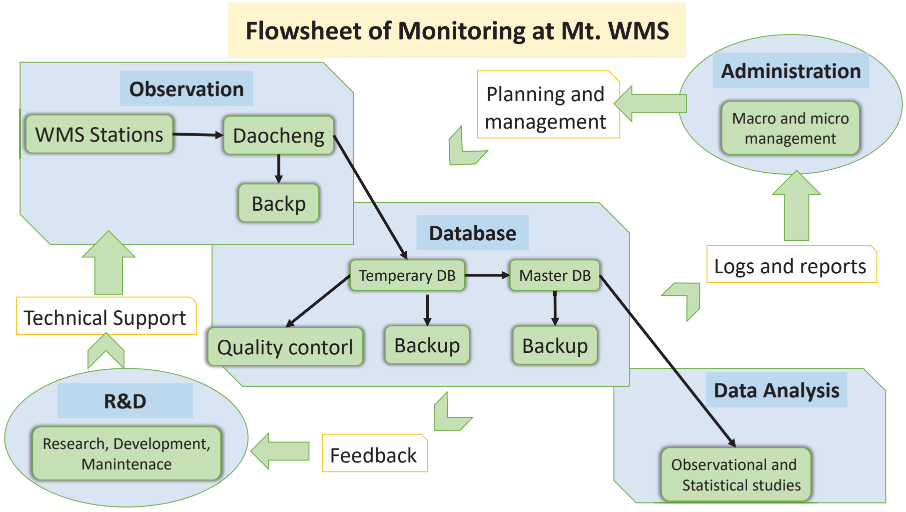

Fig. 8 Working flow of the monitoring task.

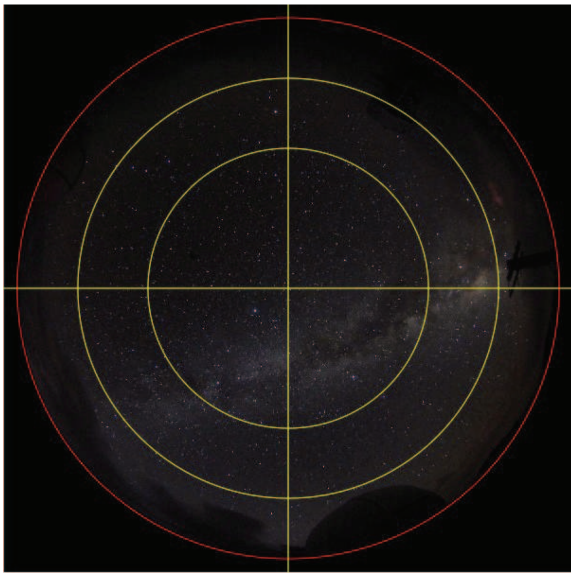

Fig. 9 Example of an all-sky camera frame. The *interior circle* ($0°$ to $45°$) and the *exterior circle* ($44.7°$ to $60°$).

shown in Figure 9, through to the bright stars scaling, the image is divided into inside and outside two laps, the zenith angle is $44.7°$ and $65°$, respectively. Finally, cloud volume is divided into four stages by visual interpretation:

1. Clear: There are no clouds in the target part, ignoring clouds outside the target part.
2. Outer: Clouds are visible in the exterior circle, but not in the interior circle.
3. Inner: Clouds are visible in the interior circle, but not in the exterior circle.
4. Cloudy: Over 50% of opaque clouds are within the target part.

The seasonal tendencies (with excellent winter months) are much more prominent at Daocheng site as shown in Figure 10. The ratio of clear nights is 53.7% (More detailed data analysis can refer to the data analysis papers). A maximum clear sky season for Daocheng site is from October to March of next year, with about 85% of possible clear time.

5.2 Temperature

Temperature data were measured by the automated weather station (AWS). The median value on clear nights is about $-2°$C, which is much more representative for the high-altitude observatories, and the low temperatures reduce the typical precipitable of atmospheric water vapour. The yearly average temperature at Daocheng site is about $0.5°$C.

In Figure 11, we show the average day-time and night-time temperatures for several months. For reference, the 1st and 3rd quartile (Q1, Q3) of the distribution of each month are plotted.

Local turbulence near the ground largely depends on the temperature contrast between day-time and night-time. At Daocheng site, the temperature difference (from one hour before to one hour after sunset) is small and amounts to about $-2.1°$C.

5.3 Ground Wind

Ground wind data were also measured by AWS. This is a very important parameter for the astronomical observation. The direction and strength have a great influence on near-surface turbulence. From the AWS, there will be one wind parameter measurement for every one minute. The measurement is 24 hours, non-stop. The monthly median values of wind-speed are shown in Figure 12. It is worth noting that the wind is relatively stable at night all year round.

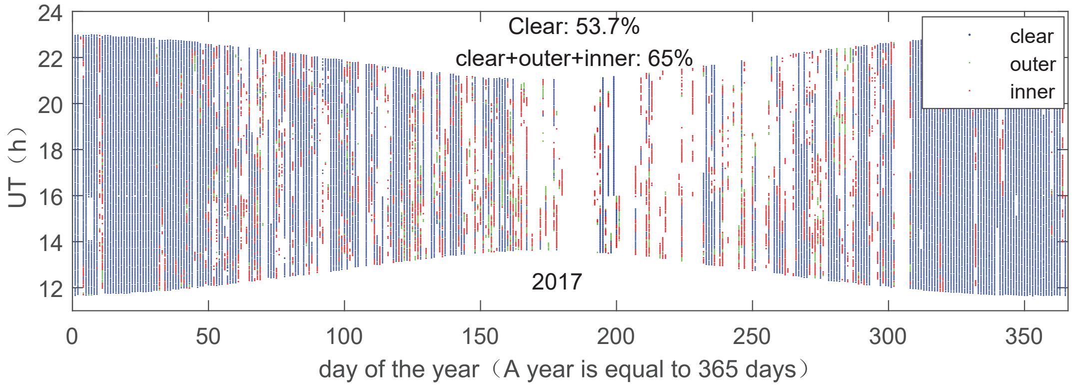

Fig. 10 General situation of the clear night at Daocheng Site, the data is from November, 2016 up to December, 2017.

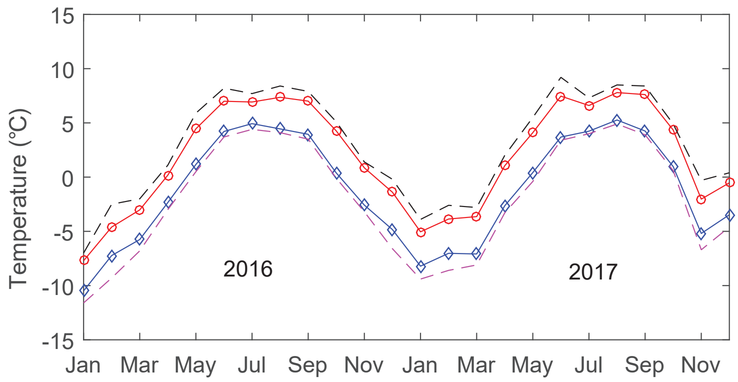

Fig. 11 The evolution of median night-time (*blue diamond*) and daytime (*red filled circles*) temperatures in each month (from 2016 up to 2017). *Dashed lines* track the Q1 (*black*) and Q3 (*magenta*) of the distributions in each month.

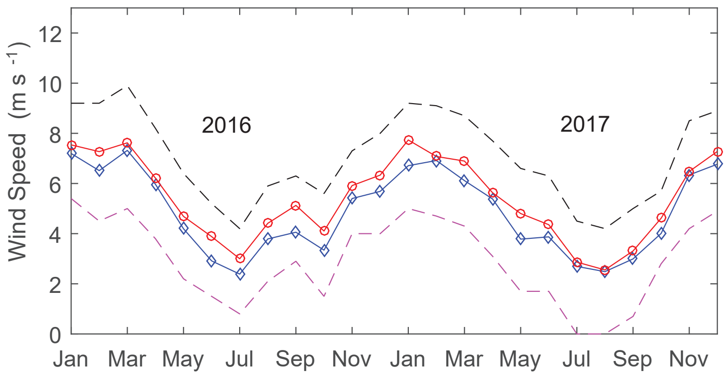

Fig. 12 The evolution of median night-time (*blue diamond*) and daytime (*red filled circles*) wind-speed in each month (from 2016 up to 2017). *Dashed lines* track the Q1 (*black*) and Q3 (*magenta*) of the distributions in each month.

Figure 13 shows the statistics of wind-speed, where the red line is day-time and blue line is night-time. The median value of wind-speed is appropriately 5.0 m s^{-1} in the day-time and 4.9 m s^{-1} at night-time. At the same time, Less than 1% of situations the wind-speed is stronger than 16 m s^{-1}.

The dominant wind-direction of the site is southwest. The wind rose of the wind is shown in Figure 14. The sampling frequency and sampling period of wind-direction is the same with wind-speed. Obviously, preferred wind-directions are associated with the massive relief properties.

6 OPTICAL TURBULENCE MEASUREMENT

The optical turbulence (seeing) data was measured with DIMM. By the LOT preparatory team's requirement, continuous seeing monitor began from 2016 November 1. The

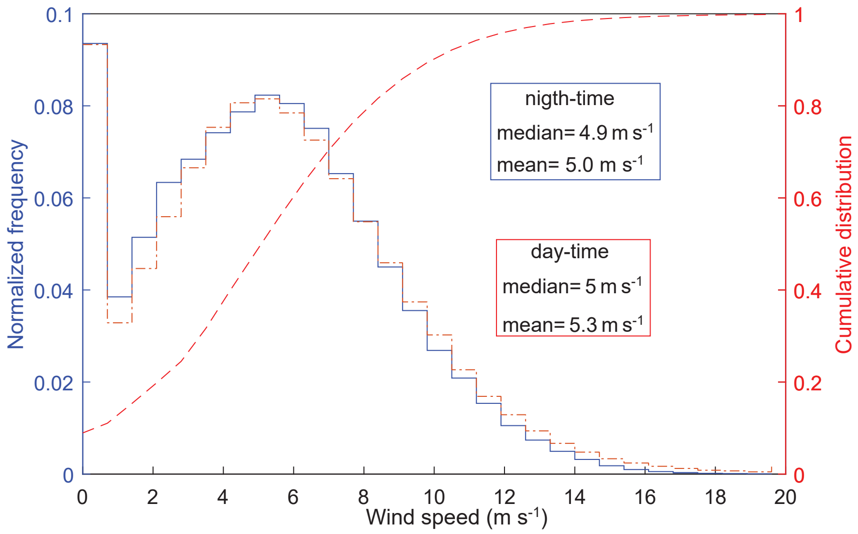

Fig. 13 Histogram and cumulative distribution of wind-speed at Mt. WMS. The *red dashed line* represents the day-time statistics and the *blue line* represents the night-time statistics.

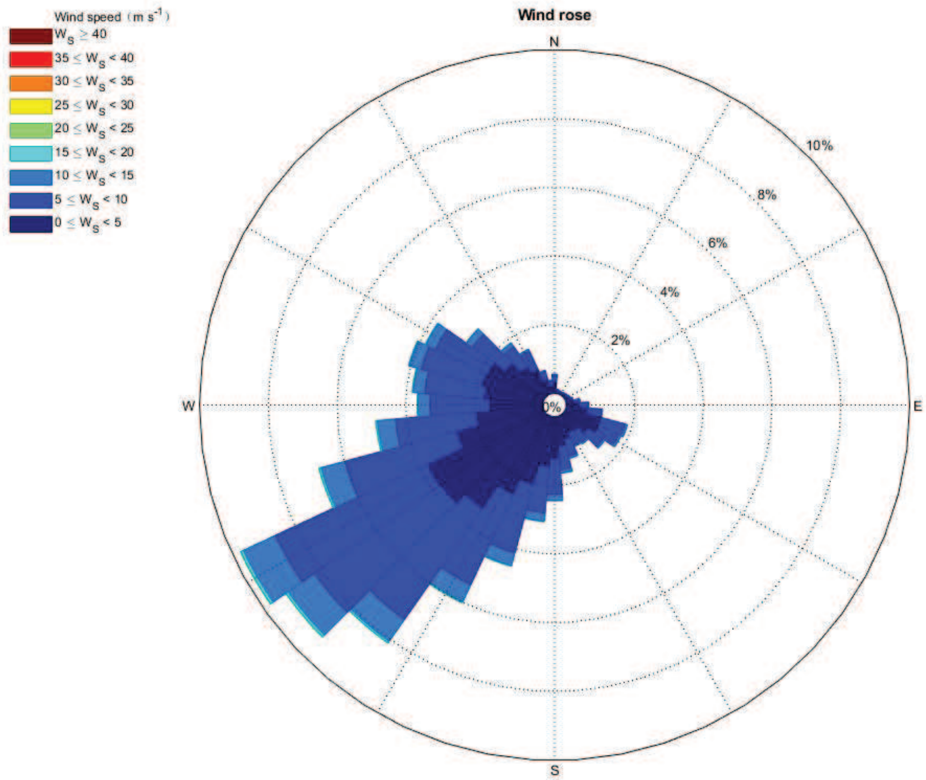

Fig. 14 Daocheng site wind-rose measured at 10 m above ground.

DIMM that we used outputs one seeing measurement every minute.

The seeing data acquired during the time from November 2016 to December 2017 are demonstrated in Figures 15–17. Most of them were collected by the NIAOT-DIMM.

Figure 15 shows the boxplot for each night against its acquisition date. Each box represents values in the range of Q1 to Q3, the red line represents the median value, and the dashed line represents the maximum observed on that day. Figure 16 shows the histogram of cumulative frequency and seeing values (the median value of seeing is

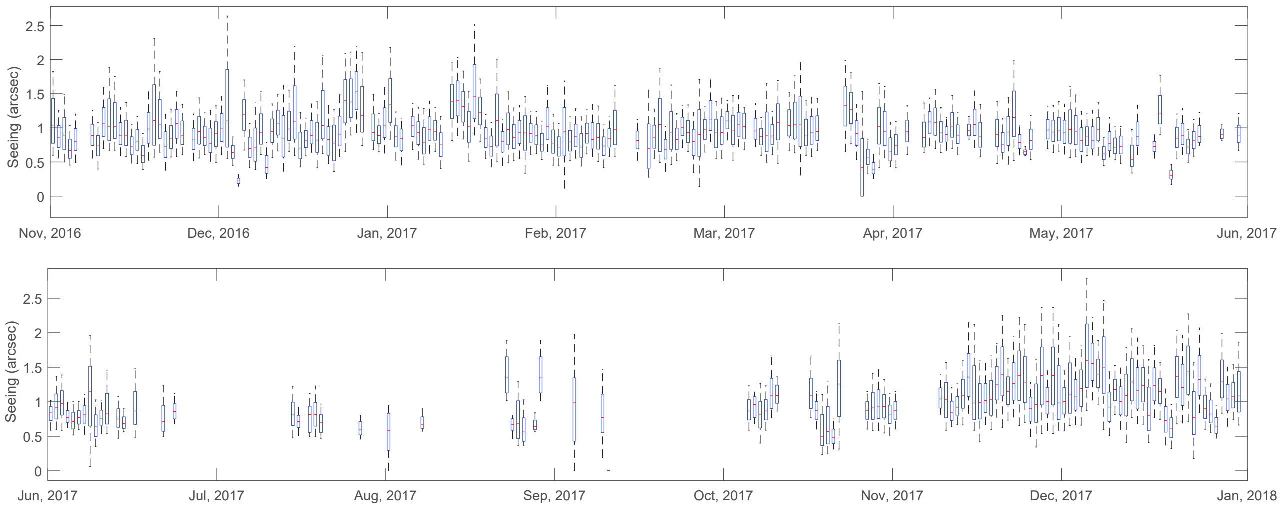

Fig. 15 Boxplot for each night against its acquisition date. Each box represents values in the range of Q1 to Q3, the *red line* represents the median value, and the *dashed line* represents the maximum observed on that day. (a) is the measurement results from November 2016 to May 2017, and (b) is the measurement results from June 2017 to December 2017.

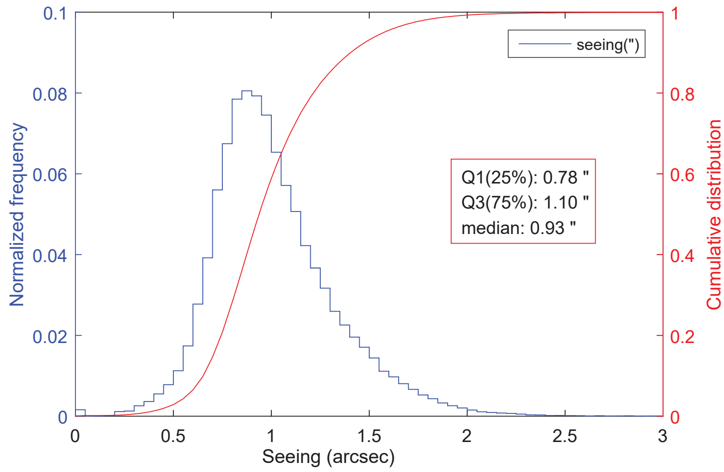

Fig. 16 Statistical distribution of the seeing at Daocheng site form November 2016 to December 2017.

about 0.93 arcsec). Figure 17 demonstrates the boxplot of 14 months of measurements. It can be seen that the seeing at Daocheng site is very stable.

7 CONCLUSIONS

With the joint efforts of various departments, the monitoring stations at the Daocheng site have been collecting various site data successfully since their operation a few years ago. The high-quality and continuity of the collected data provide a scientific, objective and quantitative basis for the comprehensive evaluation of Daocheng site as a candidate site for day and night astronomical observations. Multiple departments in the fixed-point monitoring team have clear division of labor and they work together to perform the collection, transmission, storage and analysis of the monitoring data, and also provide efficient operation, maintenance and logistics for monitoring. The mission of the fixed- point monitoring is to carry out the work with quality and quantity assured. In addition, the data security is ensured and the equipment and personnel are provided with reliable technical support and logistical supplies. The valuable experiences accumulated, as well as the cohesive cooperation between the nuclei and extensive teams, have laid a solid foundation for further construction and development of the astronomical observations at Daocheng site. The effectiveness of the developed is verified by the basic site characteristics.

The current statistic results are based on only two years of observation data. It is generally acknowledged that astroclimate parameters are influenced by long-term cycles and tendencies. So continued monitoring and more

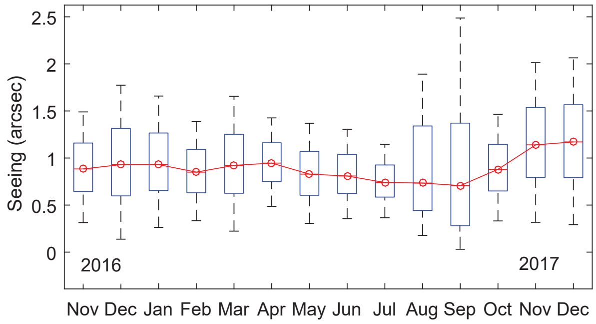

Fig. 17 Monthly statistics of the seeing at Daocheng site form November 2016 to December 2017. In terms of, the median, Q1, and Q3 values of seeing are presented. Each box represents values in the range of Q1 to Q3, the *red line* represents the median value, and the *dashed line* represents the maximum observed in that month.

extended site astronomical characterization (the altitude wind-speed profile and turbulence profile) are very necessary. For the subsequent monitoring, the measurement of the layered atmosphere turbulence ($C_n^2(h)$) and the vertical profile of the wind speed will be strengthened. A measurement platform at No. 1 site has been built and a telescope with 50 cm diameter has also been installed. The measurement of the layered atmosphere turbulence will be achieved in the near future.

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