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Site testing campaign for the Large Optical Telescope at the Ali site

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Abstract The Large Optical/infrared Telescope (LOT) is a ground-based 12 m diameter telescope which is proposed to be built in western China. The site selection for LOT in China began in 2016, and Ali was listed as one of the three candidate sites. Remote studies and local surveys have been carried out for more than 15 years in western China, and the results show that Ali is a promising site with comprehensive quality in terms of atmospheric and supporting conditions. An overview of the site testing campaign at the Ali site from 2016 to 2019 is presented. After the two years of data collection, the overall median seeing value is found to be 1.17 arcsec, the observable nights are 81.71% and the good observable nights are 71.76%. The weather conditions as follows, the median night temperature value is $-5.18°$C, the median night relative humidity value is 41.25%, the median night atmospheric pressure value is 540.92 hPa, the median night wind speed value is 7.41 m s^{-1} and the mainly wind direction is southwestern (SW). The median night sky background value is 22.07 mag$V$. We also discuss the wind speed at different locations on-site, the possibility of light pollution and the effect of wind speed on differential image motion monitor (DIMM) seeing measurements.

Key words: large optical telescope — site testing — Ali site — cloudiness — seeing

1 INTRODUCTION

The Large Optical Telescope (LOT) project was initiated in China in 2016 (Su et al. 2016, 2017). Site selection is an important part of this project. Three candidate sites were evaluated during a long-term monitoring after remote studies and sufficient discussions under the organization of the LOT site committee. These sites are named Ali, Daocheng (Song et al. 2020) and Muztagh-ata (Xu et al. 2020a,b,c). Our interest is focused on the Ali site, which is the final result of an astronomical site survey project conducted over 15 years in western China since 2003 (Yao 2005), in order to identify appropriate sites for constructing large and medium-size optical telescopes.

The Ali site is located in southwestern Tibet, as shown in Figure 1. Southwestern Tibet is unique for astronomy because of longitudinal location and high altitude, and the Ali site is very promising. SCIENCE reported the Ali site in Sept. 2012 as a world-class observatory being developed on the 'Roof of the World' (Stone 2012). The site is located at N$32°19'$ and E$80°01'$, with an altitude of 5100 m. The altitude of vast flat land nearby is around 4300 m. The distance from G219 road to the Ali site summit is less than 10 km, and there is a new road to the summit, with a pavement width of 6.5 m and slant of less than 7 degree. Figure 2 shows the map around Ali site. The nearest airport is Ali Kunsha airport (at 30 km) with daily scheduled flights to Lhasa, and flights offered twice per week to Kashi, Xinjiang, making it possible to fly from Ali to Beijing within one day. The site is only 25 km away from a nearby town, Shiquanhe (with 20 000 inhabitants). As the capital of the Ali area, it is the political, economic and cultural center in western Tibet.

Figure 3 displays a full view of the Ali site, and some domes have been installed for site testing instruments. As a site that is being developed with several facilities, a supply of 315 KW of electric power and fiber network lines have been completed. The local government of the Ali always gives very strong support to development of the Ali site. They have provided huge sums of money to build the roads to the summit and connect wires for power lines and fiber-optic cables for the Ali site, and to set up the nearby Ali Night Sky Park and issue site protection regulations.

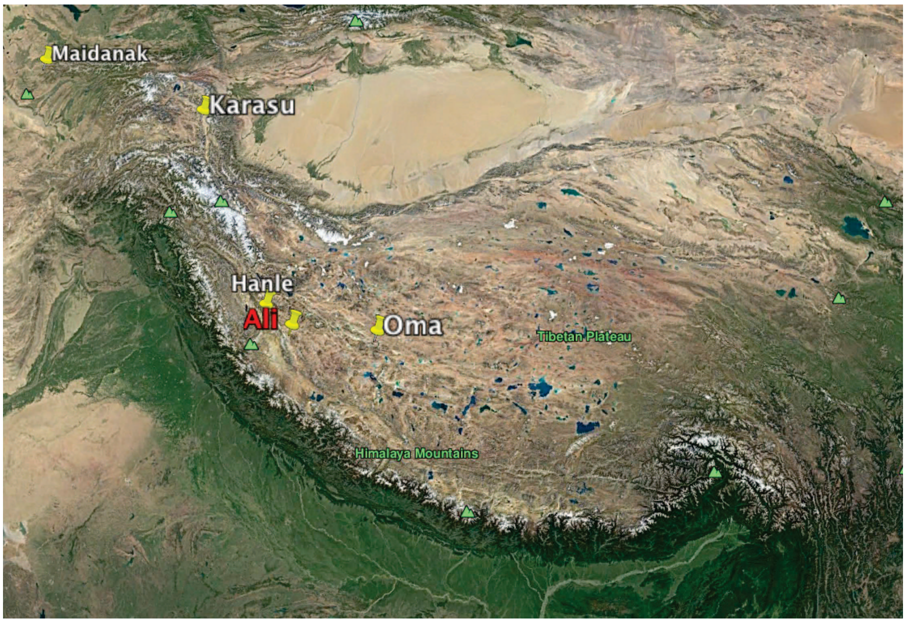

Fig. 1 The location of the Ali site.

Fig. 2 The map around the Ali site.

Although the Ali site is not too far from the Shiquanhe town, light pollution is not obvious below the 65 degree zenith angle observing limit (Skidmore et al. 2008). Detailed analysis will be presented in Section 5.2. There is no cultural or archaeological significance at Ali site to the local people. The seismic peak ground acceleration is an important indicator to evaluate for telescope construction. The Ali site is located in the southwestern Tibetan Plateau, which is a vast elevated plateau spanning central Asia and east Asia. The geological structure is quite stable, and it is far from any seismic zones. Among the remote studies, geological research has been conducted for the Ali site, and earthquake searches have been made for the site via the International Seismological Center network and compared with the other observatories. In the period of $1964-2001$, there was no earthquake greater than 6 mag in Ali and only once did a greater than 5 mag earthquake occur, while 16 greater than 5 mag and 1 greater than 6 mag earthquakes affected Mauna Kea, and 41 greater than 5 mag and 4 greater than 6 mag earthquake happened at Paranal.

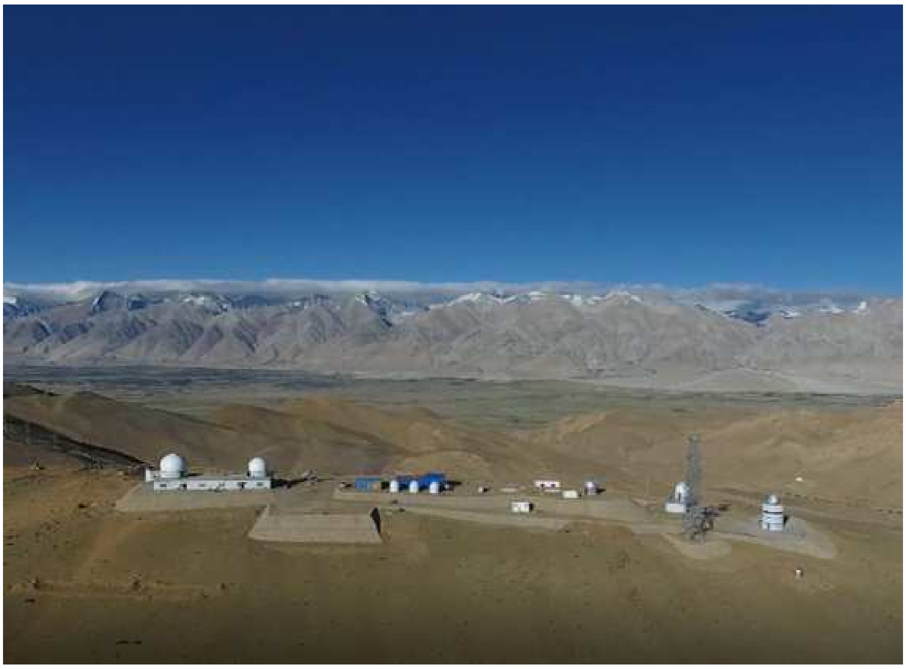

Fig. 3 Overall view of the Ali site and related facilities.

The 50 yr horizontal ground peak acceleration with 10% probability of being exceeded at Ali site is 0.10 g, while it is 0.40 g at Mauna Kea and 0.06 g at La Palma.

In this paper, we present an overview of the site testing campaign for LOT at Ali site. In this campaign, the seeing, cloudiness, meteorological parameters and sky background were measured and preliminary results are presented. In Section 2, we briefly review the history of site survey in western China, remote studies and local surveys that were carried for site selection, and the current state and future prospects at the Ali site. Section 3 introduces the instruments for LOT site testing, and the layout of these instruments on-site. In Section 4, we present the measurements and preliminary results in this campaign from March 2017 to March 2019, although some results are not calibrated. Section 5 discusses some issues of general concern, including the wind speed at Ali site, the possibility of light pollution from the nearby town and airport, and the effect of wind speed on differential image motion monitor (DIMM) seeing measurements. Section 6 summarizes the site testing campaign for LOT at the Ali site.

2 HISTORY AND CURRENT STATE

To initiate a site survey in the vast land of western China, the site survey project has been carried out since 2003. Remote studies have been conducted to search for good sites, by investigating archival databases of satellite and ground weather stations. Figure 4 shows the spatial distributions of cloudiness in night (2:00 BT), which employ the databases of 2425 from climatological stations operating during $1961-2008$ (Qian et al. 2012). Figure 5 presents the results of the annual average astronomical seeing distribution throughout 2010 over China with a mesoscale meteorological model (Wang 2012). Results from these remote studies indicate that the Ali site is located in an area with less cloudiness and better atmospheric seeing compared to others.

Based on remote studies and local surveys, two candidate sites, Karasu on the Pamir plateau and Oma on the Tibetan plateau (Fig. 1), were selected in 2005 (Yao et al. 2008), to make the first phase site testing measurements. The site testing results show that the Oma site has better atmospheric conditions than the Karasu site, especially in terms of cloudiness (Yao et al. 2012). This is also consistent with the results of the remote study in Figure 4. However, the Oma site has poor living conditions and it is very difficult to connect electricity and access the internet. For the detailed site characterization of long-term and telescope projects, a new site named Ali was identified and construction began in 2011. One of the main advantages of this site is that it is near the central town of Shiquanhe, thus the site can be easily maintained.

The site testing campaigns at Ali site are divided into two phases. In the first phase, intermittent site testing measurements were undertaken in the period of $2011-2015$ under poor support conditions (Yao et al. 2015a). Cloudiness, seeing, wind speed and optical turbulence profile are regarded as the most important parameters to evaluate the site (Liu et al. 2012). The second phase site testing measurements have been performed continuously

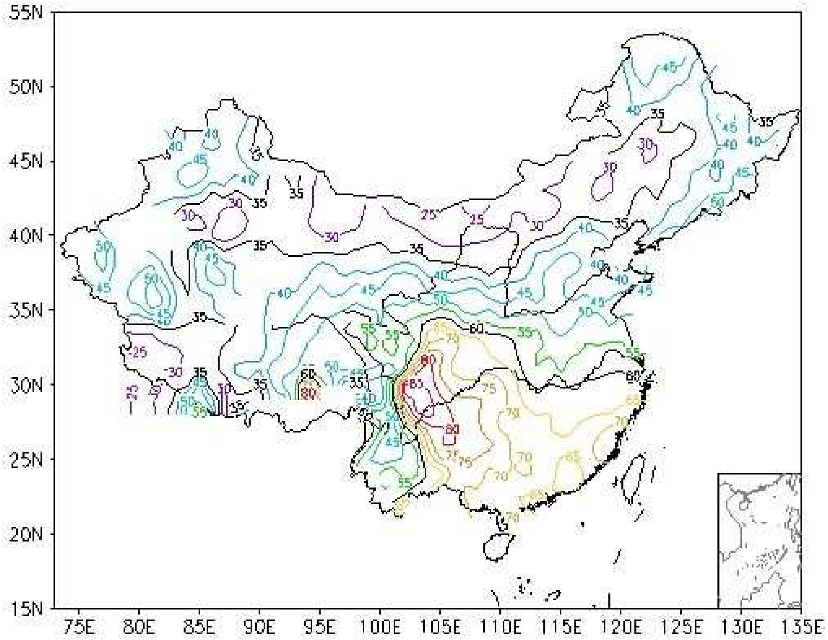

Fig. 4 The distribution of cloudiness (unit: 1%) at 2:00 (BT) from ground weather stations (1961 − 2008) (Qian et al. 2012).

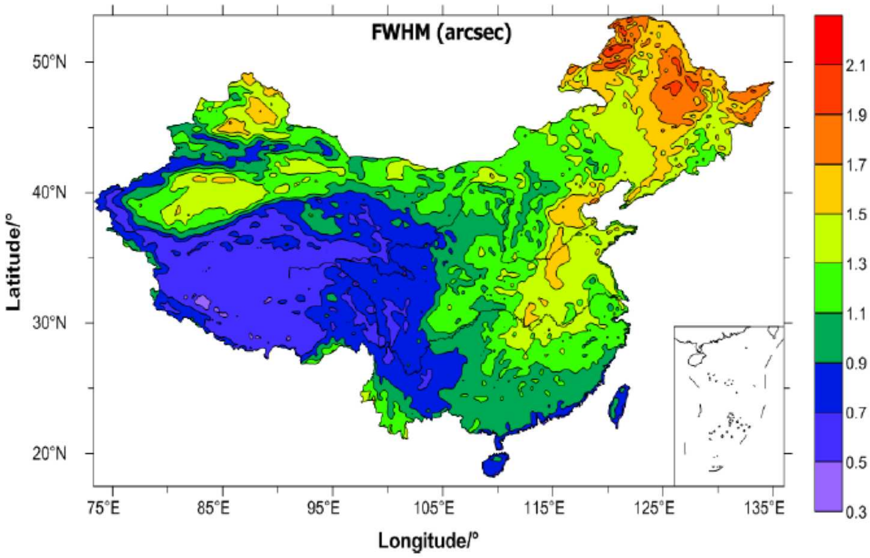

Fig. 5 The distribution of seeing over China in 2010 with the Weather Research and Forecasting (WRF) model (Wang 2012).

with improved facilities since March, 2016, and the continuous measurement results can more accurately characterize the site and seasonal variations. The following instruments have been employed, such as Low Humidity And Temperature Profiling Radiometers (LHATPROs) for precipitable water vapor (PWV), Surface layer NOn-Doppler Acoustic Radar (SNODAR) and ultrasonic anemometer for profiling the surface layer of optical turbulence, dust particle counter for atmospheric transparency. Such instruments have provided more comprehensive site characteristics (Liu et al. 2015b).

The report from the East Asian Core Observatory Association (EACOA) review committee gave a positive evaluation for Ali site in 2012, and thought that “the southwest Tibet is very promising site for astronomy.” In 2016, the Thirty Meter Telescope (TMT) project listed the Ali site as a candidate site. In 2017, the international review panel of LOT identified Ali B has the best performance, and the low velocity of wind at 200 mb in summer allows one to expect periods of excellent seeing along with high performance in Ground-Layer Adaptive Optics (GLAO) observing mode.

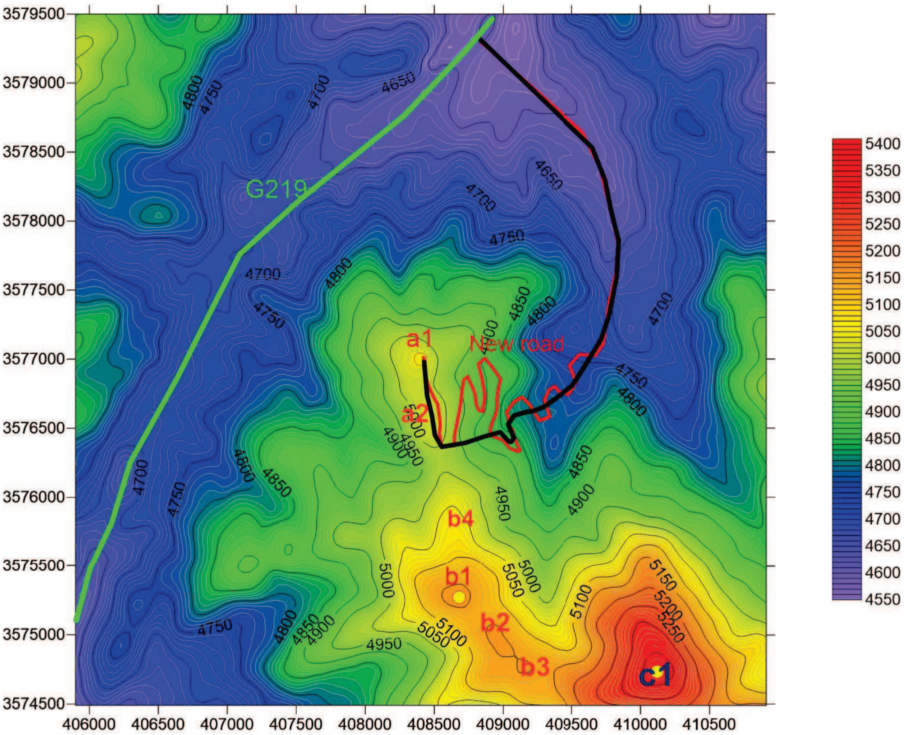

Fig. 6 The topographic map of the Ali site.

Fig. 7 The instruments of atmospheric conditions monitoring for LOT on-site.

The excellent observation conditions of the Ali site also attracted many projects. Due to the exceptional optical conditions, time domain astronomy projects flourished at Ali site. The Las Cumbres Observatory Global Telescope Network (LCOGT) planned to install two 1 m optical telescopes at Ali site, to achieve full-time observation coverage in the Northern Hemisphere, and Ali will be an important node in the LCOGT global network. The Sino-Japan 50 cm optical telescope for gravitational wave counterparts, the Taidou project of Nanjing University was also under construction. Benefiting from high atmospheric transmission rate at Ali, quantum communication experiments had been carried out and obtained fruitful results (Ren et al. 2017). The extremely low PWV conditions at Ali (Kuo 2017) provide one of the few observatories in the world for the Cosmic Microwave Background (CMB) project (Xin

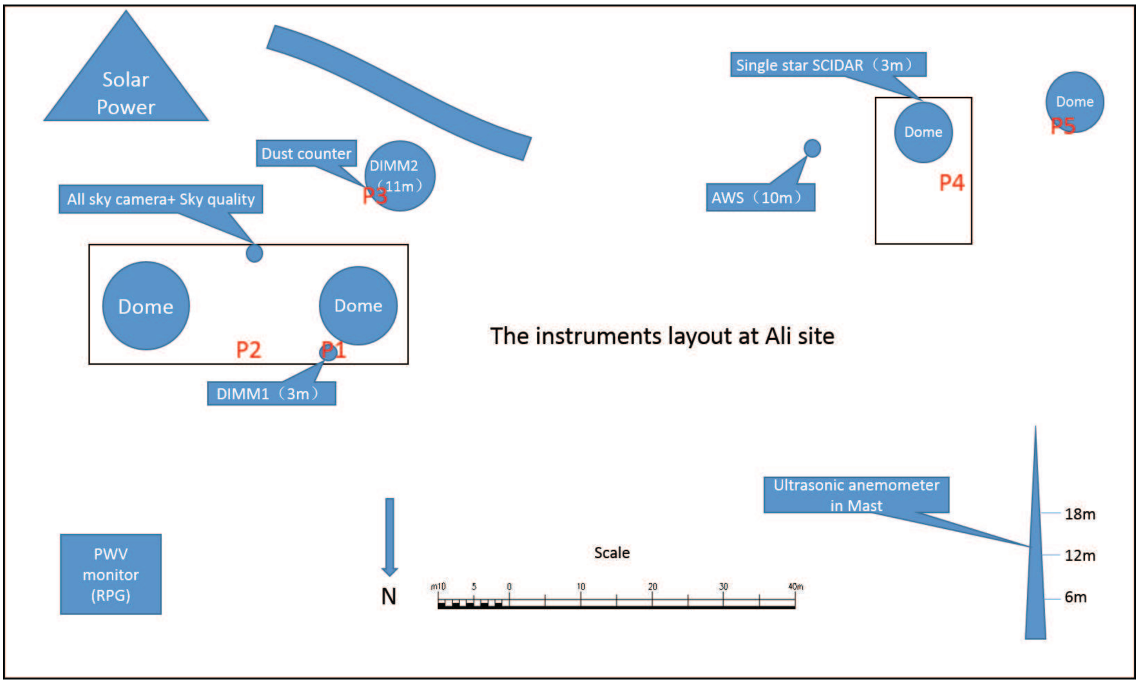

Fig. 8 The layout of instruments at the Ali site.

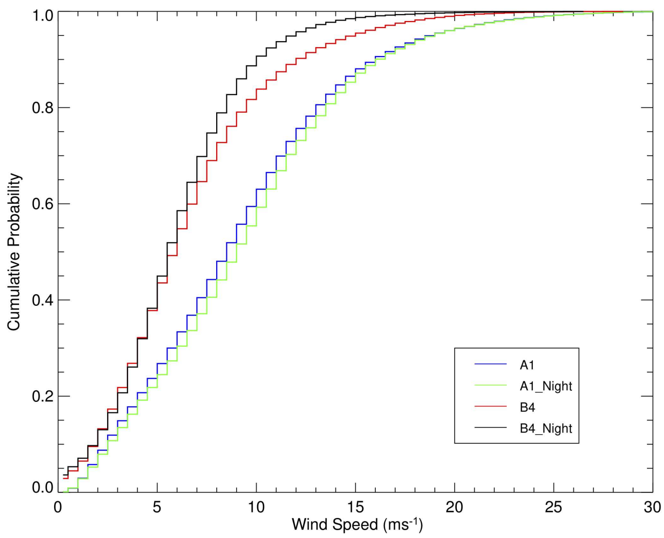

Fig. 9 Comparison of wind speeds at different locations on-site.

2016; Li et al. 2018a). The Ali CMB polarization telescope is already under construction in order to probe primordial gravitational waves and will start observation in 2020 (Li et al. 2018a).

3 INSTRUMENTS AND LAYOUT

According to the requirement of the LOT site committee, the astronomical seeing, cloudiness, meteorological conditions and sky background, are listed as the parameters of site monitoring. A DIMM has been considered as the standard for measuring atmospheric seeing (Sarazin & Roddier 1990). We have developed an automatic DIMM system named Ali DIMM for the seeing monitoring (Liu et al. 2010, 2015a). The instrument consists of a 25 cm LX200GPS Meade telescope and a front mask with two 5 cm apertures, separated by 20 cm. A Lumenera SKYnyx 2.0M CCD camera is attached to the telescope focal plane for fast sampling of star images, with a 640×480 format and pixel size of 7.4 μm. The exposure time is fixed at

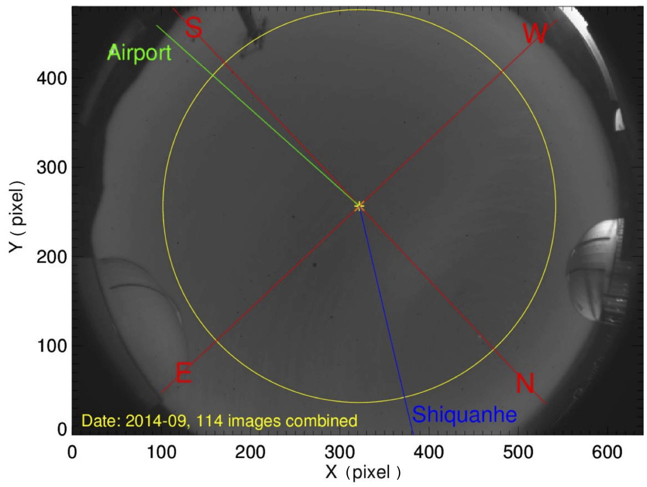

Fig. 10 A combined image with 114 all sky photos from September 2014.

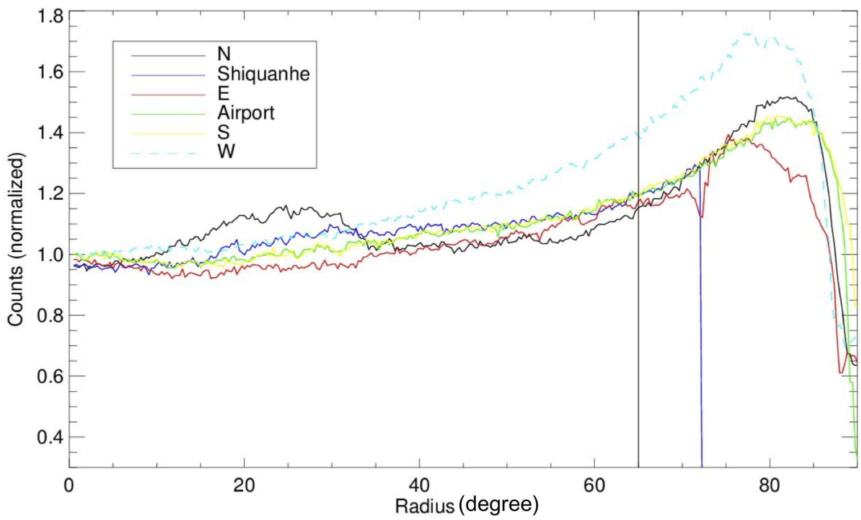

Fig. 11 Photometric results of the combined image from the horizon to the zenith.

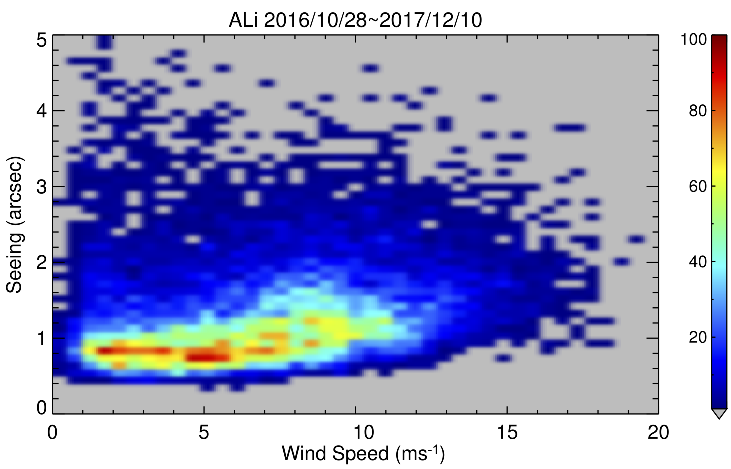

Fig. 12 Analysis of seeing dependence on wind speed.

10 ms, and $650 - 1000$ data sets are obtained each night. The effect of exposure time on seeing measurements had been discussed (Liu et al. 2010). DIMM seeing measurements are sensitive to the exposure time, and it is very important for accurately understanding the seeing evaluations and comparisons with various measurements.

The weather station CAWS600, a commercial automatic weather station (AWS) made by Huayun Co., Ltd was employed for monitoring meteorological parameters. The AWS can measure the wind speed and direction, air temperature, relative humidity and barometric pressure. The data from the AWS are downloaded once every two minutes. Figure 6 is a topographic map of the Ali site, in order to study the wind speed at different locations, we set up the same AWS at points A1 and B4 respectively. The SQM-LE is a monitor for night-time sky brightness from the Unihedron Co., Ltd, which measures the darkness of the night sky to provide readings of magnitudes per square arcsecond. The Full Width Half Maximum (FWHM) of the angular sensitivity is about 20 degree, and the minimum light sampling time is one second. An all sky camera is employed during site testing for cloud observation. The camera employs a Canon 700D and specific fish-eye lens, especially using accurate photometric data from SQM-LE via LAN for controlling exposure time, ensuring the all sky image is very clear. Figure 7 is a photo of all the instruments installed on-site. The detailed parameters of above instruments and calibrations are presented in another article (Wang et al. 2020).

The layout of all the instruments at the Ali site are shown in Figure 8. The DIMM first be installed at P1 near the 6 m dome, in order to avoid the influence of strong wind, then it was moved to the P2 position for calibration with another DIMM. Finally, we built a 10-meter tower and started DIMM measurements at P3. The AWS was installed on a wind rod with a 10 meters height above the ground, and the data can be transmitted with a mobile phone card. The all sky camera and sky quality monitor were installed on a platform of 3 meters height above the ground.

4 MEASUREMENTS AND RESULTS

The instruments at Ali site for LOT site testing were prepared in October, 2016, and the measurements started the following November. Here we present the results of the measurements at the Ali site, and the statistical analysis uses the dataset from March 2017 to March 2019.

In Table 1, we list the parameters, instruments, datasets, and results of the site testing campaign at the Ali site from March 2017 to March 2019. The median seeing is 1.17 arcsec. It should be noted that the seeing measurements in many places as mentioned in Section 3, the above results are only the summary statistics with the measurements of each place without any calibration. Due to complexities in the calibration method, the calibration of seeing will be published in a forthcoming article. The observable nights with the statistical method defined by the TMT site team (Skidmore et al. 2008) are 81.71%, about 300 nights in one year, and the good observable nights are 71.76%. The median wind speed is 7.41 m s^{-1}, with the main direction being from the southwest; the median temperature is $-5.18°$C, the median relative humidity is 41.25% and the median atmospheric pressure is 540.92 hPa. The median sky background in V band is 22.07 magnitudes per square arcsecond. The detailed measurement results and analysis are available in other papers (Feng et al. 2020; Cao et al. 2020).

5 DISCUSSION

5.1 Comparison of Wind Speed in Different Locations

As is well known, higher wind speed is one of the climate characteristics of a plateau. The meteorological data on the Ali site also demonstrate this feature. However, we also found that the wind speeds of different locations are quite different at the Ali site. As Figure 6 shows, in order to study the wind speed at different locations, we set up the same AWS at both points A1 and B4. The site testing campaign for LOT was carried at position A2, the quantum communication project was also located at position A2 and the telescope used for CMB observation will be installed at position B1. Position B3 was recommended by the international review panel of LOT as a more promising location for LOT.

Figure 9 displays the statistics of wind speed measurements at two locations from 2013 to 2017. The blue line and green line are the wind speed of all and the wind speed at night respectively at the A1 position. The median wind speed of all is 8.7 m s^{-1}, and the median value of wind speed at night is 9.2 m s^{-1}. The black and red lines are the wind speed of all and the wind speed at night respectively at the position B4. The median wind speed of all and wind speed in night are 6.0 m s^{-1} and 5.8 m s^{-1} respectively. The probability of the wind speed velocity at position B4 being less than 14 m s^{-1} is 98%, as the same level at Mauna Kea (97% $<$14 m s^{-1}). Next, we will numerically simulate the whole summit with Computational Fluid Dynamics (CFD) software, try to reveal the wind speed and direction of each position at the Ali site.

Table 1 Results of site testing campaign at the Ali site from March 2017 to March 2019. The observable night and the good observable night were defined with the method that can be found in Skidmore et al. (2008).

Parameters	Instruments	Dataset (nights)	Results (median)
Seeing (arcsec)	Ali DIMM	457	1.17
Cloudiness	All Sky Camera	697	
observable nights (%)			81.71
good observable nights (%)			71.76
Weather Conditions	AWS	675	
Night temperature (°C)			–5.18
Night wind speed (m s^{-1})			7.41
Night wind direction			*SW*
Night relative humidity (%)			41.25
Night Atm. pressure (hPa)			540.92
Sky background (mag$V$)	SBM	603	22.07

5.2 Possibility of Light Pollution and Protection of Dark Sky

The nearest city at the Ali site is Shiquanhe town, which is 25 km away. Although the permanent population of Shiquanhe town is only 20 000, there is still a risk of potential light pollution. In order to analyze the possibility of light pollution, we employed all sky photos taken at night, which were obtained by the SBIG A340 – an all sky camera made by Diffraction Ltd. A method was adopted to extract light pollution information from all sky images (Skidmore et al. 2011). As shown in Figure 10, a 10th percentile median image was created by 114 moonless night photos during September 2014, in order to remove contamination from astronomical sources. The position of the yellow asterisk marks zenith, the Kunsha airport is almost in the south direction and Shiquanhe is located in the northeast direction. The sky within a zenith angle of 65 degree is important to astronomical observations (Skidmore et al. 2008), which was marked with the yellow circle.

We conducted a photometric study on the direction of concerned using the combined image. Figure 11 displays the photometric results in different directions from the horizon to the zenith. The cyan line obviously rises with the increase of the zenith angle, which is caused by buildings that are currently under construction at the local site. The black and blue line is raised in the range of 15 to 35 degrees, which is due to the Milky Way star field. Shiquanhe is plotted with blue line and the Kunsha airport is plotted with a green line. No pollution was detected from both directions of Shiquanhe and the airport, and we found that the night sky at the Ali site is perfect except for temporary light pollution from the local site.

A site protection office under the official group and local astronomical society are organized. The office can coordinate with various levels of government and promote related activities (Yao et al. 2015b). The site protection program has been carried out in five aspects: site monitoring, technical support, local government support, specific organization and public education. An official lead group towards development and protection of astronomical resources has been established by the Ali government; one of its tasks is to issue regulations against light pollution, including special restrictions on the airport, mining and winter heating, and to supervise lighting inspection and rectification. The Ali Night Sky Park has been constructed, provides a popular place and observational experience. At the same time, it also raises public awareness on the importance of protecting dark sky.

5.3 Effect of Wind Speed on DIMM Seeing Measurements

It is well known that the seeing measurement not affected by telescope vibrations under the principle of differential image motion measurements (Sarazin & Roddier 1990). However, when the telescope is dithered at high frequencies due to strong wind, the image will be blurred by telescope vibrations. It will lead to the seeing value being worse than the really seeing. The above situation is the same effect as bad optical quality (Skidmore et al. 2009). Figure 12 shows the relationship between measured seeing and wind speed for two years period between 2016 and 2017. We see some dependence of seeing on the wind speed, especially when the wind speed is greater than 6 meters per second. Due to the telescope of DIMM-Ali, with an equatorial mount that was converted from an altazimuth mount without a counterweight, there is a significant effect on DIMM seeing for wind speeds up to 6 m s^{-1}. Therefore, the seeing measurement results with DIMM-Ali should be larger than the actual seeing, so DIMM-Ali should be improved to resist higher wind speeds. Even the TMT-DIMM with robust hardware provide reliable measurements in much higher wind speed. There is still an effective limit for measuring wind speeds down to 12 m s^{-1}.

6 SUMMARY

Over the last 15 years, a site survey project in western China has been carried out, in order to find the excellent candidate sites for larger and medium-size optical telescopes. The final candidate sites were narrowed down to the area in south-west Tibet, based on remote studies with satellites and the ground weather stations throughout China. Because of convenient support conditions, the Ali site was selected for long-term monitoring in order to verify previous research results.

In this article, the site-testing campaign for LOT at Ali site was summarized under the organization and management of the Astronomical Mega-Science Center, Chinese Academy of Sciences (CAS). The selection and layout of instruments were introduced. The results of observable nights and the nighttime median values of atmospheric seeing, sky background, air temperature, relative humidity, wind speed and barometric pressure were presented from March 2017 to March 2019. The preliminary monitoring results indicate that the Ali site is suitable for the construction of large optical and infrared telescopes. In order to obtain long-term evaluation parameters, site monitoring will continue to be performed.

Several issues of general concern at the Ali site were discussed in Section 5. The wind speed in different locations be compared, the possibility of light pollution from Shiquanhe town and Kunsha airport be analyzed, and the effect of wind speed on DIMM-Ali measurements be discussed. A numerical method based on the WRF model was employed to derive the atmospheric parameters in the surrounding area of Ali. The results of the WRF calculation have been verified well with observations at Ali site *in situ*, which will be published in another paper.

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