Astronomical Observing Conditions at Xinglong Observatory from 2007 to 2014

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ABSTRACT. Xinglong Observatory of the National Astronomical Observatories, Chinese Academy of Sciences (NAOC), is one of the major optical observatories in China, which hosts nine optical telescopes including the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) and the 2.16 m reflector. Scientific research from these telescopes is focused on stars, galaxies, and exoplanets using multicolor photometry and spectroscopic observations. Therefore, it is important to provide the observing conditions of the site, in detail, to the astronomers for an efficient use of these facilities. In this article, we present the characterization of observing conditions at Xinglong Observatory based on the monitoring of meteorology, seeing and sky brightness during the period from 2007 to 2014. Meteorological data were collected from a commercial Automatic Weather Station (AWS), calibrated by China Meteorological Administration. Mean and median wind speed are almost constant during the period analyzed and ranged from 1.0 to 3.5 m s⁻¹. However, high wind speed (≥15 m s⁻¹) interrupts observations, mainly, during the winter and spring. Statistical analysis of air temperature showed the temperature difference between daytime and nighttime, which can be solved by opening the ventilation device and the slit of the dome at least 1 hr before observations. Analysis resulted in average percentage of photometric nights and spectroscopic nights are 32% and 63% per year, respectively. The distribution of photometric nights and spectroscopic nights has a significant seasonal tendency, worse in summer due to clouds, dust, and high humidity. Seeing measurements were obtained using the Differential Image Motion Monitor (DIMM). Mean and median values of seeing over 1 year are around 1.9" and 1.7", respectively. Eighty percent of nights with seeing values are below 2.6", whereas the distribution peaks around 1.8". The measurements of sky brightness are acquired from the Sky Quality Meter (SQM) and photometric observations. Analysis shows that sky brightness at the zenith is around 21.1 mag arcsec⁻² and becomes brighter with a larger zenith angle. Sky brightness increases due to the light pollution of the surrounding cities, Beijing, Tangshan, and Chengde. Significant influence toward the direction of Beijing, at an altitude of 30°, can increase the sky brightness up to 20.0 mag arcsec⁻². Sky brightness reduces after midnight, mainly because of the influence of city lights and the artificial acts. The above results suggest that Xinglong Observatory is still a good site for astronomical observations. Our analysis of the observing conditions at Xinglong Observatory can be used as a reference to the observers on targets selection, observing strategy, and telescope operation.

1. INTRODUCTION

Xinglong Observatory (117°34'39" East, 40°23′26" North; see Fig. 1) of the National Astronomical Observatories, Chinese Academy of Sciences (NAOC), is located 120 km northeast to Beijing, at an altitude of about 900 m, south of the main peak of the Yanshan Mountains. It belongs to the typical monsoon, with northwest monsoon in winter and southeast monsoon in summer. Temperatures range from −20°C in winter to 30°C in summer. It contains nine optical telescopes, including the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) (Cui et al. 2012) and the 2.16 m reflector. As one of major optical observatories in China, it is important to give its observing conditions in detail as a reference for astronomers. Previous research and references on the observing conditions at Xinglong Observatory have been mainly mentioned at Yao et al. (2012); these measurements could not reflect the seeing value from DIMM with monthly variations and the sky brightness variations with different altitude and azimuth systematically. In this article, we will focus on three important characterizations of an optical observatory: the meteorology, the seeing, and the sky brightness.

For ground-based astronomy, the fractions of clear nights, seeing, and sky brightness are important parameters to evaluate the quality of an observing site (Patat 2003). Many astronomical observatories in the world have given detailed studies of these
parameters. Singh et al. (1989) monitored the sky and atmospheric conditions at Leh, including the photometric and spectroscopic hours, meteorology, seeing conditions, and extinction coefficients. Taylor et al. (2004) presented the sky brightness (UBVR bands) and the seeing measurements of the Mount Graham International Observatory, which contained the Vatican Advanced Technology Telescope (VATT), the Heinrich Hertz Submillimeter Telescope, and the Large Binocular Telescope (LBT). The Thirty Meter Telescope (TMT) site-testing group suggested a detailed list of atmospheric parameters which should be measured, including weather-related characteristics (e.g., fraction of cloud cover and photometric conditions, air temperature, and ground-level humidity), turbulence-related characteristics (e.g., overall seeing, isoplanatic angle), and other characteristics (e.g., dust, sky brightness, and atmospheric transparency) (Schöck et al. 2009). The site-testing group for the future European Extremely Large Telescope (E-ELT) also selected a list of key parameters which should be measured ideally, including turbulence-related features, meteorological conditions (e.g., wind speed and direction, relative humidity, air temperature, atmospheric extinction, cloud cover and dust), and other parameters (e.g., sky brightness, sodium layer) (Vernin et al. 2011). Astronomical site evaluation in the visible and radio range of an IAU technical workshop presented a systematic introduction on atmospheric turbulence, site surveys, and forecasting, etc. A detailed description was given by Vernin et al. (2002).

The definition of clear nights is judged by the quantitative proportion of cloud coverage or the time duration of no clouds through the whole night; the criteria of the percentage of cloud coverage at various world observatories are different from each other. Ehgamberdiev et al. (2000) defined “clear time” at the Maidanak Observatory as cloud coverage smaller than 25%. Singh et al. (1989) labeled nights with at least six uninterrupted hours of photometric sky conditions as “clear nights.” Cloud coverage is a crucial parameter for determining the useful time in an astronomical observatory. The clear nights are judged mainly on a visual basis during earlier days; however, this method is only suitable for the sites where there are assistant observers, but not for identifying future candidate sites. A new methodology which can quantify the fraction of clear nights by the satellite images for La Palma and Mt Graham in Cavazzani et al. (2011) presented the ground-based data as a reference simultaneously. This measurement was demonstrated for monitoring the methodology at astronomical sites successfully in Erasmus & Sarazin (2002). Using satellites for cloud coverage analysis has also been applied and demonstrated in other works (Erasmus and Maartens, Operational forecasts of cirrus cloud cover and water vapor above Paranal and La Silla observatories, Purchase Order 52538/VPS/97/9480/HWE,
Seeing is vital to high-precision imaging and high-spatial-resolution photometry for ground-based astronomy. Astronomical seeing refers to the optical inhomogeneities in the Earth’s atmosphere (Young 1974), which is usually measured by using Differential Image Motion Monitor (DIMM); this is now commonly used to measure seeing. Sarazin & Roddier (1990) described the DIMM theory for the first time; DIMM seeing was measured by the variance of the differential motion of two sub-aperture images of a star. A detailed description of DIMM with design, data processing, and calibration was given by Vernin & Munoz-Tunon (1995). Main advantage on seeing calculation by DIMM is that the tracking errors are subtracted automatically; however, the defocus (www.alcor-system.com/us/Dimm Software/defoc.pdf), spot saturation (Varela et al. 2004), and the optical quality of telescope could also introduce important errors in seeing calculation by DIMM. During the study on theory of DIMM, more accurate coefficients (e.g., CCD noise and exposure time) have been taken into consideration by Tokovinin (2002). This theory and instrument has been widely used in astronomical sites all over the world (e.g., Il’Yasov et al. 1999; Ziad et al. 2005; Floyd et al. 2010). Sky brightness is crucial for optical observatories, as it restricts not only the limitation of telescope, but also the sample frequency for given targets and the signal-to-noise ratio (S/N) for same telescope with certain exposure time. In order to protect the astronomical quality and prevent light pollution, the sky law for the protection on the island of La Palma and the area of Tenerife has been passed by the Spanish government since 1988. Many observatories in the world have given studies of sky brightness. Massey & Foltz (2000) measured the sky brightness over Mount Hopkins and Kitt Peak with spectrophotometry, then converted to broadband measurements for the zenith. They also gave the variations with different directions corresponding to the surrounding cities in a time span of a decade. Leinert et al. (1995) and Sánchez et al. (2007) presented the measurements of sky brightness with optical spectrophotometric data and photometric-calibrated data at Calar Alto observatory, which has the largest telescope in continental Europe. Patat (2003) and Patat (2008) provided the sky brightness with the influence of the time span and the solar activities at Cerro Paranal, which is the site of the Very Large Telescopes (VLT). Aubé et al. (2014) evaluated the sky brightness of two candidate Argentinian observation sites for Cherenkov Telescope Array with Sky Quality Meters (SQM) and the spectrometer for night aerosol detection.

### Table 1

**MONTHLY STATISTICS ON 24 HRS DATA INTERVAL OF WIND SPEED AND AIR TEMPERATURE DURING 2007–2014**

| Month   | Ndata | Max (°C) | Min (°C) | Median (°C) | Mean (°C) | Std | Max (m s⁻¹) | Median (m s⁻¹) | Mean (m s⁻¹) | Std |
|---------|-------|----------|----------|-------------|-----------|-----|-------------|----------------|--------------|-----|
| January | 169,641| 8.9      | −22.0    | −8.2        | −8.18     | 4.70| 23.4        | 1.8            | 2.25         | 2.01|
| February| 158,937| 11.1     | −21.7    | −4.9        | −4.72     | 5.35| 24.5        | 1.8            | 2.40         | 2.22|
| March   | 174,292| 22.6     | −15.3    | 0.9         | 1.33      | 5.72| 24.4        | 2.3            | 3.03         | 2.63|
| April   | 168,748| 26.1     | −5.3     | 8.8         | 8.88      | 5.32| 23.4        | 2.4            | 3.08         | 2.45|
| May     | 174,205| 33.4     | 0.6      | 16.1        | 16.23     | 4.90| 27.6        | 2.3            | 2.94         | 2.43|
| June    | 160,408| 31.4     | 9.2      | 19.2        | 19.38     | 4.03| 21.6        | 1.6            | 2.02         | 1.58|
| July    | 155,463| 33.7     | 12.8     | 21.7        | 22.02     | 3.27| 23.0        | 1.4            | 1.78         | 1.31|
| August  | 151,235| 32.7     | 11.5     | 20.6        | 20.94     | 3.37| 16.0        | 1.4            | 1.69         | 1.28|
| September| 166,691| 29.5     | 3.8      | 16.0        | 16.16     | 4.07| 18.1        | 1.4            | 1.79         | 1.45|
| October | 160,894| 23.4     | −3.9     | 10.0        | 9.94      | 4.58| 20.5        | 1.6            | 2.18         | 1.92|
| November| 167,998| 20.2     | −14.1    | 1.2         | 0.95      | 5.08| 25.7        | 1.8            | 2.41         | 2.28|
| December| 170,232| 12.3     | −21.6    | −6.4        | −6.68     | 5.06| 25.0        | 2.0            | 2.66         | 2.49|
This paper consists of five sections. § 1 gives a brief introduction. We describe the meteorology of Xinglong Observatory in § 2. § 3 presents the seeing data, which is measured by DIMM. In § 4, we describe the sky brightness at Xinglong Observatory and its variations. § 5 presents the summary and conclusions.

2. METEOROLOGICAL ANALYSIS AT XINGLONG OBSERVATORY

We present a statistical analysis on air temperature, wind speed, wind direction, relative humidity, and fraction of photometric nights and spectroscopic nights in this section. All the meteorological data were collected from the Vaisala HydroMetTM System MAWS110; this is a commercial automatic weather station (AWS) which includes sensors for air-temperature, humidity, pressure, wind speed, and wind direction. These sensors were installed on towers 10 m above the ground and calibrated by the China Meteorological Administration. Air-temperature sensor gives an accuracy of \( \pm 0.2 ^\circ \text{C} \). Accuracy of wind speed is \( \pm 0.2 \text{ m s}^{-1} \) with the range from 0.4 \( \text{m s}^{-1} \) to 60 \( \text{m s}^{-1} \). Accuracy of the wind direction is \( \pm 2 ^\circ \). Relative humidity gives an accuracy of \( \pm 2\% \) below 90\%, and \( \pm 3\% \) above 90\%. This system is especially designed for unattended operations requiring high reliability and accuracy at sites with the mains power and with battery backup. The MAWS110 uses a field-proven and high-accuracy data logger and advanced software; all the meteorological data are sampled every 2 min by software from the AWS.

2.1. Air Temperature

Air temperature is an important parameter in operating the telescope and its detector, e.g., charge-coupled device (CCD). It is known that CCD generate thermal electrons (also known as dark current), related to its operating temperature. In order to set the temperature of CCD, cooling is essential. Type of CCD, cooled with thermoelectric coolers, is influenced by air temperature.
We have analyzed the distribution of air temperature based on monthly basis and calculated the maximum, minimum, mean, and median values that are shown in Figure 2. The air temperature occupies the range, 9.2° C to 33.7° C, and shows higher in summer compared to other seasons. (In this article, we defined local seasons at Xinglong Observatory by grouping calendar months as follows—spring: March, April, and May; summer: June, July, and August; autumn: September, October, and November; and winter: December, January, and February.) Monthly differences between maximum value and minimum value have the same tendency, but mean value and median value of air temperature are almost same. The measurements based on 24 h, daytime, and nighttime analyses along with number of data (Ndata) are summarized in Tables 1, 2 and 3, respectively. Statistical analysis of air temperature showed the temperature difference between daytime and nighttime, which can be solved

![Figure 3](image1)

**Fig. 3.**—Air temperature trend examples during nighttime of four seasons, spring, summer, autumn, and winter are shown with time, respectively. The time indicated in UT. Standard deviation are noted.

![Figure 4](image2)

**Fig. 4.**—Daily mean of air temperature during nighttime and its standard deviation for the whole year of 2013 are shown.
by opening the ventilation device and dome slit at least one hour before the start of observations.

The airflow due to temperature difference influences the stability of atmosphere in the dome, which degrades the quality of images. In order to know the stability of the air temperature along the night, we select air temperature data between astronomical twilight of four nights from different seasons as an example. We have plotted the air temperature and its standard deviation with universal time (UT); Figure 3 shows that air temperature gradients are almost stable during the nighttime. Also, we have collected nighttime temperature data for whole year in 2013 as an example, and analyzed based on daily mean and its standard deviation, which are presented in Figure 4. The analysis suggested that the nighttime temperature at Xinglong Observatory is almost stable, which indicates the site is suitable for astronomical observation.

2.2. Wind Speed and Direction

Wind speed is crucial in performing astronomical observations and telescope operation, as it influences the support structure and driver system of telescopes. As a safety precaution, observations are not allowed if the wind speed exceeds the defined upper safety limit. The slit of the dome should be closed and the telescope should be back to the parking position. Various safety limits of wind speed at different sites are mentioned in Radu et al. (2012); 15 m s\(^{-1}\) is the typical maximum safety limit of the meteorological study in Murdin (1985). According to the local climate, Xinglong Observatory follows 15 m s\(^{-1}\) as the safety limits of wind speed.

In order to understand the influence of wind speed and wind gusts on astronomical observations and telescope operation, we have obtained the data of wind speed using AWS from 2007 to 2014. Such a long period of 8 years of data allowed us to analyze the effect of wind speed on daytime, nighttime, and also a 24 hr basis. The time criterion for nighttime data analysis is between astronomical twilight. We have ignored the “spurious data” (the data points that are abnormal and far away from the adjacent data points) in our analysis. We have obtained the monthly distribution of nighttime wind speed above 15 m s\(^{-1}\) and measured the maximum, minimum, mean, and median values. We have performed the analysis for all the seasons, shown in Figure 5, and found that the fraction of wind speed above 15 m s\(^{-1}\) in winter (especially in November and December) and spring have more influence on observing time. These percentages imply the lost observing time due to high wind speed. We have noticed that the recorded maximum wind speed is around 27.6 m s\(^{-1}\) (this value is instantaneous), which is important to be noted for further precautions and improvement of the facility.

We have analyzed the data of annual wind speed and its direction from 2007 to 2014 and shown the results in Figures 6 and 7. We find that most of the time, wind speed is under 4 m s\(^{-1}\), and the peak value of distribution is around 2 m s\(^{-1}\) during these years. Wind directions are mainly concentrated on East and West, which is influenced by the monsoon climate. We do not find other obvious regularities in the wind direction. Here we have summarized the monthly maximum, median, mean, and its standard deviation of wind speed with 24 hr, daytime, and nighttime in Tables 1, 2 and 3, respectively. Notice that the mean and median wind speed are almost constant during the period analyzed and ranged from 1.0 m s\(^{-1}\) to 3.5 m s\(^{-1}\), which are encouraging values for astronomical observations.

2.3. Relative Humidity

Moisture and water condensation are the extreme negative results from higher relative humidity, which affect astronomical observation and facilities. Condensation is a serious issue not only for telescope operation by damaging the light sensors and electronic equipment, but also degrades the quality of observed astronomical data (Radu et al. 2012). Higher humidity allows dust particles on exposed air to settle down on mirrors, which will decrease their reflectivity. Jabiri et al. (2000) and Lombardi et al. (2007) suggested that the observations should be stopped when the relative humidity goes beyond 90%. Lombardi et al. (2009) reported the safety limits on relative humidity between 80% and 85% for the Paranal Observatory, located on the coast of the Atacama Desert (Chile). After taking into consideration of the above studies, Xinglong Observatory set safety limits according to the local climate, in which telescope operation is not allowed if the relative humidity exceeds 90% before observation or exceeds 95% during observation.

In order to understand the behavior of humidity at Xinglong Observatory, we have collected the relative humidity data from AWS for the whole year of 2013 and analyzed the maximum and mean value on daily basis. Daily maximum and mean of relative humidity data are shown in Figures 8 and 9, respectively. The error bars indicates the precision of measurements. We have noticed that the large fraction of humid time occurs in

![Graph showing monthly statistics of wind speed above 15 m s\(^{-1}\) from 2007 to 2014.](image-url)
Fig. 6.—Annual cumulative distribution of wind speed from 2007 to 2010 are shown in left panels. Fractional values and cumulative fraction of wind speed are indicated in left and right y-axis, respectively. Annual wind direction and frequency distributions are shown in right panels. The axis in left represents the frequency that corresponds to different directions, and the label in right represents the wind speed interval.
Fig. 7.—Left: Annual cumulative distribution of wind speed from 2011 to 2014. Fractional values and cumulative fraction of wind speed are indicated in left and right y-axis, respectively. Right: Annual wind direction and frequency distributions. The axis in left represents the frequency that corresponds to different directions, and the label in right represents the wind speed interval.
summer and is around 55%, maybe due to monsoon climate and rains. High humidity is one of the main factors for lost time in summer at Xinglong Observatory.

2.4. Photometric Nights and Spectroscopic Nights

The definition of a “photometric night” at Xinglong Observatory is cloud-free observations which last for at least 6 hrs, or the whole night in summer as nights are shorter. “Spectroscopic nights” means that observations are performed in both clear sky and partial cloudy conditions.

Data of photometric nights and spectroscopic nights are collected from the telescope observation logs wherein night assistants record the observing information of each night between 2007 and 2014. Note that the information in logs are judged mainly on visual experience and meteorological parameters during that time, and expected to have some uncertainties. We have gathered information from the observation logs of three telescopes (the 2.16 m reflector, the 0.85 m reflector, the 0.8 m reflector) at Xinglong Observatory and compared them through comprehensive analysis.

The annual statistics of photometric nights, spectroscopic nights, useful nights, and unuseful nights (nights that are not able to observe due to bad weather) from 2007 to 2014 are given in Table 4. The average fractions of photometric nights and spectroscopic nights are 32% and 63% per year, respectively. The number of useful nights is equal to the number of spectroscopic nights at Xinglong Observatory. In addition, we have calculated the annual useful and unuseful nights. Average number of useful nights and unuseful nights are 230 and 135 per year, respectively. Fraction of photometric nights and spectroscopic nights are approximately equal during these years, which means the weather conditions of Xinglong Observatory are almost constant and suitable for optical observations.

In addition to the annual analysis, we have analyzed the monthly statistics of photometric nights and spectroscopic nights from 2007 to 2014 and presented them in Figures 10 and 11, respectively. Seasonal distributions are obvious—autumn and winter are better in terms of fraction of photometric nights and spectroscopic nights. They have a declining trend toward spring due to dust and wind, and go to lowest levels in summer due to rains and high humidity. In order to analyze the relation between photometric nights and spectroscopic nights, we performed monthly average analysis of them from 2007 to 2014, and presented them in Figure 12. The fraction

![Graph](image-url)
of useful time shows similar tendency and fraction of photometric nights decreases to the level of 10% in summer.

3. SEEING MEASUREMENTS FROM DIMM

DIMM was first applied to measure seeing at Xinglong Observatory in 2007 (Liu et al. 2010), 12 nights of DIMM data were collected for the seeing measurements at LAMOST site. They obtained the median seeing as 1.1″. Previous measurements of DIMM only have a short time span and could not reflect the monthly variations of seeing systematically.

DIMM seeing has been monitored from 2013 at Xinglong Observatory systematically. The dome for DIMM is on the eighth floor, just outside the LAMOST focal panel building. Its roof can slide to one side when it is operational. This dome design takes fully into account the effects of wind, rain, snow and other environmental factors, and also taking into account the appearance of unity with LAMOST at the same time. This original DIMM was first deployed in 2011 using a portable 28 cm diameter Schmidt–Cassegrain telescope, with a focal length of 2800 mm, equipped with a AVT Gruppy F-033 7.4 μm pitch 480 × 640 pixel Sony ICX424 CCD camera. The altitude-azimuth telescope was reformed to an equatorial telescope for more stable tracking in the second year. The DIMM’s mask is made up of aluminum. There are two 50 mm apertures on the mask, one with prisms separated by 230 mm from the other subaperture. The control software and data reduction process are made to run on the Ubuntu operating system. All software mentioned above were developed in C++ and Python language. Bright stars close to zenith are optimized observed objects. The image processing pipeline has fully considered the star’s quality and position. CCD exposure time was set to 5 ms and each seeing value is measured by processing 800 images, and there are about 2 or 3 measurements for every minute.

We have obtained DIMM seeing data for the whole year of 2014, and analyzed them on a monthly basis. The cumulative distribution of each month, except July and August, is presented in Figure 13. As the DIMM is installed on the LAMOST building, and July and August are the maintained months for LAMOST, no data available in these two months. From the figure, we noticed the double-peak distribution in February and September, which may be due to unstable winds.

In addition, we present annual seeing distribution in 2014. Figure 14 shows 80% of nights with seeing values are below
FIG. 13.—Monthly cumulative distribution of seeing measurements from DIMM during 2014 is shown. Note that the data for July and August are missing due to telescope maintenance. Fractional and cumulative fractional values are mentioned in left and right of y-axis, respectively.
whereas the distribution peaks around 1.8″. Mean and median seeing are around 1.9″ and 1.7″, respectively. Figure 15 presents the median, mean, and standard deviation of the monthly seeing value, which shows that the seeing distribution has a seasonal tendency, and mean DIMM value is better in summer than winter, similar to previous studies on seeing distribution (Yao et al. 2012). Table 5 summarizes the data points used in analysis, median, mean and standard deviation of monthly seeing data. We found that number of data points during February, March and June are very few, which maybe affected the shape of the data distribution.

4. THE SKY BRIGHTNESS AT XINGLONG OBSERVATORY

The sky brightness at Xinglong Observatory during 1995–2001 was studied by Liu et al. (2003), and showed that the sky brightness of the North Pole field can reach up to 21.0 mag arcsec⁻². Yao et al. (2012) followed the same procedure and found that the sky brightness is consistent with 21.0 mag arcsec⁻². Huang et al. (2012) gave the sky brightness (in V-band) changed from 21.4 mag arcsec⁻² in 2005 to 20.2 mag arcsec⁻² in 2011. However, these data analyses did not consider the influence caused by different altitude and azimuth, as Xinglong Observatory is surrounded by a number of nearby cities with light pollution and artificial light sources. Study of the distribution with sky brightness and its variation on different directions due to light pollution plays a vital role for photometric telescopes at Xinglong Observatory.

In this section, we present the sky brightness of Xinglong Observatory from a Sky Quality Meter (SQM) and standard photometric measurements. The SQM is developed by the Unihedron company,³ which can measure the sky brightness in magnitudes per square arcsecond. This instrument has been widely used to measure the sky brightness for the GLOBE at Night program.⁴ The SQM is installed at Xinglong Observatory, fixed on the roof of an building which has no surrounding shade, pointing to zenith. Detail description of this SQM can be found in Yao et al. (2013).

SQM data are sampled every five minutes; in order to analyze the sky brightness variations with time and phase of Moon, we collect 1-month data as an example. Details are plotted in Figure 16. It shows that the sky brightness gets darker after midnight, mainly due to the influence of city lights and the artificial acts. The sky brightness is also influenced by the moonlight, so we need to keep a large angular distance with the moon, in order to have a good S/N on faint target observations.

With the development of surrounding urban regions, light pollution at Xinglong Observatory is getting more and more

³ http://www.unihedron.com/projects/darksky/index.php.
⁴ http://www.globeatnight.org/sqm.php.
serious. Although sky brightness at the Xinglong Observatory has been studied before, they only gave the brightness of the North Pole field or random area. In order to obtain the quantitative evaluation of the light pollution with different altitude and azimuth, we collect the data from TNT (an 0.8 m Cassegrain reflecting telescope) by pointing it to the certain position on photometric nights. These data included photometric standard stars (Landolt 1992) with different airmass.

As CCD of TNT is cooled by Liquid nitrogen, the dark current is about $0.00025 e^{-} s^{-1} pixel^{-1}$, which is negligible (Huang et al. 2012), so we have only corrected the bias and flat field for all object images. The entire data were reduced by following the standard procedure using various tasks in IRAF$^5$ and the Source Extractor software (Bertin & Arnouts 1996):

$$M - m = ZP - \kappa \chi$$

(1)

where $M$ is the catalog magnitude, $m$ is the corresponding instrumental magnitude, which is calculated by the formula of $m = -2.5 \log_{10}(\text{counts} / t_{\exp})$, $\kappa$ is the extinction coefficient, and $\chi$ is the airmass of image. We have followed the similar photometric procedure by Guo et al. (2014).

After the photometric calibration, we got the zero-point ($ZP$) of the instrument from the linear regression shown in Figure 17. The pixel scale of the detector is $0.516''$ pixel$^{-1}$. We have calculated the sky brightness using

$$M_{NSB} = ZP - 2.5 \log \left( \frac{\text{sky count}}{\text{scale}^2 t_{\exp}} \right),$$

(2)

where $ZP$ is obtained from the photometric calibration mentioned above. The term $\text{sky count}$ is the sky flux per pixel; we removed the influence of stars and cosmic rays and gave the median value of background as the $\text{sky count}$. The term $\text{scale}$ is calculated with the focal length of TNT and the pixel size of detector, e.g., $0.516''$ pixel$^{-1}$, and $t_{\exp}$ is the exposure time (in seconds).

We noticed that Xinglong Observatory is mainly surrounded by three cities (Beijing, Chengde, and Tangshan), and two counties (Xinglong and Yingshouyingzi), shown in Figure 18. According to our analysis, counties are very near to the observatory and have little influence compared with the cities. Beijing is located in the southwest direction from Xinglong Observatory, which corresponds mainly with azimuth of 240°. Chengde is located in the northeast direction, and Tangshan is to the southeast. We tested the influence of the light pollution with different altitude and azimuth, and the detailed distribution of sky brightness is shown in Figure 19. We find the sky brightness at the zenith is 21.1 mag arcsec$^{-2}$, which is comparable with the sky brightness of about 21.0 mag arcsec$^{-2}$ ($V$-band) measured by Liu et al. (2003) until 2001 and Yao et al. (2012) until 2011 at Xinglong Observatory. Light pollution from Beijing is more prominent, especially at altitudes of 30° and 40°, which could reach 20.0 mag arcsec$^{-2}$ at an altitude of 30°. The light pollution of Tangshan is prominent at higher altitudes, almost the same as Beijing. Our analysis of the influence of light pollution can be used as a reference to the observers when they use telescopes to observe faint objects at Xinglong Observatory.

5. CONCLUSIONS

We have made an attempt to understand the astronomical observing conditions at Xinglong Observatory, using data for a period of 8 years from 2007 to 2014, by performing the analysis of three important parameters: meteorological information, seeing, and sky brightness.

Annual statistics of air temperature show that it is almost constant during the period analyzed and ranged from 9.2° C...
to 33.7°C. Monthly statistics show that air temperature in summer is higher compared with other seasons, which can reach around 30°C in daytime and go down to 10°C in the nighttime. In order to stabilize the temperature and airflow at the beginning of observations, the ventilation device and the dome slit are opened at least 1 hr before the observation every day. We have also checked the variation of air temperature overnight through the analysis of annual nighttime air temperature and found that the temperature gradient is almost stable, which indicates better dome seeing and the quality of the images.

Annual statistics of wind speed show that it is under 4 m s⁻¹ most of the time, the peak value of distribution is around 2 m s⁻¹ during these years. Monthly statistics suggested that mean and median value of wind speed are almost constant during the period analyzed and ranged from 1.0 m s⁻¹ to 3.5 m s⁻¹. Analysis suggested that wind speed above 15 m s⁻¹, which is safety limit for operating telescopes at Xinglong Observatory, happened to be more during winter and spring. Humid time occurs mostly in summer and it is around 55%, due to the monsoon climate, which is main cause for lost time during summer. We found that it also extends a small fraction to autumn mainly during September.

Through the analysis of meteorological information at Xinglong Observatory, we find that the fraction of photometric nights and spectroscopic nights are almost constant from 2007 to 2014, without obvious variation. Average percentage of spectroscopic nights is 63% per year. Over 60% of nights are suitable for observation. Unuseful times are mainly distributed in summer, as it is the rainy season at Xinglong Observatory. Cloud, high humidity, wind, and dusts also influence observations. The average percentage of photometric nights is 32% per year. The distribution of photometric nights and spectroscopic nights show similar seasonal trend. Fraction of photometric nights decreases to the level of 10% in summer.
Seeing data was collected from DIMM. Annual statistics of seeing shows that median and mean seeing are around 1.7″ and 1.9″, respectively. Peak of seeing distribution is around 1.8″, 80% of the seeing is better than 2.6″. Seeing is seasonal dependent, and better in summer than winter.

Sky brightness data were collected from SQM and photometric observation. Sky brightness gets darker after the midnight from the SQM, which means the city lights and artificial acts have influence on the light pollution. We find that the sky brightness is influenced by the moonlight, so astronomers need to keep a large angular distance with the moon when observing faint targets. Standard photometric measurement by TNT with different azimuth and altitude on moonless night shows that sky brightness at the zenith is at the level of 21.1 mag arcsec⁻². However, it becomes brighter at large zenith angle due to the light pollution of surrounding cities. Light pollution from Beijing is prominent at the altitude of 30° and 40°, which could reach 20.0 mag arcsec⁻² at an altitude of 30°. Light pollution from Tangshan is prominent at higher altitudes, almost the same as Beijing.

Our detailed analysis on the above parameters showed that amount of useful time and the night sky brightness are almost consistent during the period, suggesting that the site is stable and suitable for optical astronomical observations. Our analysis toward the astronomical observing conditions at Xinglong Observatory can be used as a reference to the observers on targets selection, observing strategy, and telescope operation.

We are thankful to anonymous referee for his/her valuable comments and suggestions that lead to improve the manuscript. We thank the supports of the night assistants at Xinglong Observatory. We thank Bharat Kumar Yerra for his observant comments on the manuscript that lead to a better presentation. This work is partly supported by National Natural Science Foundation of China under grant No. 11373003 and National Key Basic Research Program of China (973 Program) No. 2015CB857002.

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