Postprint of the All-Day Information Collection System at Zhongshan Station, Antarctica

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Abstract

The Antarctic plateau possesses unique astronomical observation conditions. To conduct empirical research on the nighttime astronomical observation conditions at the Antarctic Zhongshan Station, the Yunnan Observatories of the Chinese Academy of Sciences specially developed a fully automatic all-sky information acquisition system featuring low-temperature resistance, automatic snow and frost removal, and other performance characteristics adapted to the Antarctic climate. This system can provide real-time all-sky cloud cover, sky background brightness, and all-sky images, and can push the information to a webpage for real-time display. This paper introduces the development of this system and the low-temperature resistance experiments conducted to adapt to the Antarctic climate. Subsequently, it statistically analyzes the all-sky information data from the two-year period of 2016-2017 at Zhongshan Station, preliminarily obtaining the observable hours, observable nights, sky background brightness, and temperature and humidity conditions at Zhongshan Station.

Full Text

The All-Sky Information Acquisition System at Antarctic Zhongshan Station

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Abstract: The Antarctic Plateau offers unique conditions for astronomical observation. To conduct empirical research on the nighttime astronomical observing conditions at Antarctic Zhongshan Station, the Yunnan Observatories of the Chinese Academy of Sciences specially developed a fully automated all-sky information acquisition system designed to withstand Antarctic climate conditions, including low-temperature resistance and automatic snow/frost removal. This system provides real-time all-sky cloud cover, sky background brightness, and all-sky images, with information pushed to a web interface for real-time display. This paper introduces the development of this system and the low-temperature experiments conducted to adapt it to Antarctic conditions. Subsequent statistical analysis of Zhongshan Station' s all-sky information data from 2016–2017 preliminarily yields the station' s observable hours, observable nights, sky background brightness, and temperature/humidity conditions.

Keywords: All-sky information; Infrared cloud meter; Cloud cover

0 Introduction

Theoretical and observational studies have shown that the Antarctic continent may host the best astronomical site resources on Earth, primarily for three reasons. First, the Antarctic atmosphere is thin, dry, and extremely cold, making it suitable for infrared and terahertz band observations. Second, the polar night enables uninterrupted time-series observations, which is significant for time-domain astronomy. Third, the extremely low atmospheric boundary layer provides excellent seeing conditions. China has successively established Great Wall Station, Zhongshan Station, Kunlun Station, and Taishan Station in Antarctica. Kunlun Station is located in the Dome A region, one of the best observing sites on Earth, where astronomers have installed multiple instruments including PLATO (PLATeau Observatory), CSTAR (Chinese Small Telescope ARray), SNODAR (Surface layer NOn-Doppler Acoustic Radar), and AST3 (Antarctic Survey Telescope).

Kunlun Station is situated at the highest point of the Antarctic continent at 4,087 m elevation, with extremely harsh climate conditions suitable only for summer scientific expeditions. Zhongshan Station is located on the edge of the Antarctic continent at an average elevation of 11 m, 1,250 km from Kunlun Station. The station has complete living facilities for both summer and winter expeditions, characterized by perennial low temperatures, large temperature variations, low humidity, and strong winds with distinct continental features. In 2015, the annual minimum temperature reached -40°C, with an annual average relative humidity of 59.8%. Zhongshan Station experiences polar day and polar night phenomena lasting approximately 55 days and 58 days, respectively. The station primarily conducts scientific observations and research in polar upper atmospheric physics, snow and ice, atmospheric science, oceanography, geology, geochemistry (meteorites), geography, and environmental monitoring. To meet future demands for Antarctic astronomical development and inland expedition trends, it is necessary to plan and construct an Antarctic astronomical operations support and testing base at Zhongshan Station. As one of the first nighttime astronomical observation devices operating at Zhongshan Station, the "All-Sky Information Acquisition System" will provide crucial empirical evidence for the planning and design of the Zhongshan Station astronomical base.

The all-sky information acquisition system integrates astronomically relevant all-sky information such as cloud cover, sky background brightness, and all-sky images, playing an important role in astronomical observations and site monitoring. Additionally, the all-sky images captured by the system can provide rich information including cloud cover and auroral morphology characteristics.

1 Overview of the Zhongshan Station All-Sky Information Acquisition System

The Antarctic Zhongshan Station all-sky information acquisition system was developed by the Lijiang Astronomical Observation Station of Yunnan Observatories beginning in July 2015. Assembly was completed by the end of August, followed by multiple low-temperature experiments and integrated testing. The system was successfully delivered to the Astronomical Research Office of the Polar Research Institute of China on October 10 and transported to Antarctica with the 32nd Chinese Antarctic Research Expedition. Installation was completed on March 20, 2016, on the red-roofed building at Zhongshan Station, after which data acquisition officially commenced.

[Figure 1: see original paper] Equipment Installed on the red roof of Zhongshan Station

The system enables real-time monitoring of all-sky cloud cover and sky background brightness at Zhongshan Station, captures real-time all-sky images, provides all-sky information monitoring functions, stores collected data to local hard drives, and simultaneously pushes data to a web display interface. The system achieves fully unattended operation with automatic snow and frost removal functions, allowing it to adapt well to Antarctic climate conditions. Since installation at Antarctic Zhongshan Station, the equipment has operated reliably without serious malfunctions.

1.1 System Design

The all-sky information acquisition system is centrally controlled by an industrial computer for data acquisition, storage, and publication, with external power and network supplied through two cables. Internal hardware components include a power supply, cloud meter, all-sky camera, sky brightness meter, and dual temperature acquisition modules. The system architecture is shown in [Figure 2: see original paper].

[Figure 2: see original paper] Architecture of All-Sky Information System

All-sky cloud cover acquisition uses a cloud meter independently developed by Yunnan Observatories. The design principle is based on the fact that clouds exhibit similar infrared radiation characteristics in the infrared band. Atmospheric warming primarily depends on absorbing long-wave radiation from the ground; more cloud cover in the sky absorbs more long-wave radiation, resulting in higher temperatures and smaller temperature differences with the ground. Using the MLX90614 ($±$0.5°C, -70°C to +380°C) infrared thermometer to obtain sky temperature T_s and surface ambient temperature T_a, the difference $T_d = T_a - T_s$ is calculated. Cloud cover fraction C is then computed using the cloud-clear formula $C = b - k \times T_d$. Here, T_d is defined as clearness, C is cloud cover fraction (with the sky area detected by the cloud meter considered as 10; if 10% of the area has clouds, $C = 1$; if 30% has clouds, $C = 3$), and b and k are constants related to the geographic environment and topography of the installation site. These constants are determined by manually identifying cloud cover fractions from captured all-sky images for the same detection range as the cloud meter, statistically analyzing the clearness at corresponding times to obtain the relationship between cloud cover and clearness (see), and then calculating b and k through least-squares fitting. [Figure 3: see original paper] shows the fitting diagram of the cloud-clear formula. During fitting, it was discovered that the applicable formulas differ significantly between daytime and nighttime, so separate fittings were performed for day and night.

Cloudcover and Clearness Correspondence Table

[Figure 3: see original paper] The Fitting Diagram of Cloudy Formula

The all-sky camera consists of a Canon 700D DSLR camera and a Sigma 4.5mm F2.8 fisheye lens, connected to the industrial computer via a MiniUSB cable for control and data transmission, with a 7.4V power supply for the camera. The all-sky camera monitors a zenith distance range of 90°, capturing one all-sky image every 5 minutes (360° × 180° field of view). Original images are stored on the control computer, and a thumbnail with text watermark and timestamp is generated and sent to the web display. The all-sky camera can adjust exposure parameters based on sky brightness values to capture clearer images. The Canon 700D shutter is rated for approximately 100,000 actuations, with spare DSLR camera components available for replacement.

The sky background meter uses the SQM-LE night sky brightness detector produced by Canadian company Unihedron, which continuously measures the sky background brightness in the visible band near the zenith. This instrument has been designated by the International Dark-Sky Association as one of the standard instruments for astronomical night sky background measurement, allowing its data to be compared with most astronomical observatories worldwide.

System Parameters

System parameters are shown in . The system uses DS18B20 ($±$0.5°C, -10°C to +85°C) digital temperature sensors as dual temperature acquisition modules for real-time monitoring of internal and external equipment temperatures. The internal thermometer is embedded in the enclosure, while the external temperature probe is completely exposed outside the enclosure. All hardware is mounted inside a PELI-1500 waterproof case (external dimensions 47 × 35.7 × 17.6 cm, internal dimensions 42.5 × 28.4 × 15.5 cm), as shown in [Figure 4: see original paper]. The enclosure contains two heaters and one cooling fan. One 100W heater with a rear-mounted fan is placed on the industrial computer, blowing air toward the camera lens. The fan operates continuously, while the heater is controlled by a heating controller. Another 150W heater is fixed on the enclosure lid next to the sky brightness meter. This heater model HV031 uses PTC heating elements with low thermal resistance, high heat exchange efficiency, and a service life exceeding ten years.

[Figure 4: see original paper] Schematic Diagram Inner Device

The enclosure top has a circular hole and rectangular opening. The circular hole is fitted with a hemispherical acrylic transparent cover with triple protection (waterproof, anti-condensation, anti-frost), allowing the all-sky camera to capture images through this transparent cover. The rectangular opening is fitted with a transparent glass cover through which the sky brightness meter can collect data. A small hole at the bottom houses a 12V cooling fan controlled by a fan controller. Four holes on the side accommodate sensors and connection cables, as shown in [Figure 5: see original paper], with temperature sensor, cloud sensor, 220V power cable, and RJ45 network cable arranged left to right. The waterproof case itself has excellent sealing performance and is not prone to condensation or frost. All hardware is fixed inside the waterproof case with screws for easy maintenance, removal, and replacement. All openings in the waterproof case are sealed with low-temperature resistant adhesive. The equipment was delivered with maintenance instructions, troubleshooting methods, and spare components including cloud meter, thermometers, DSLR camera, DSLR camera power module, switching power supply module, 220V and 12V fans, mounting screws, and other original parts for replacement.

[Figure 5: see original paper] All-Sky Information Acquisition Equipment

1.2 Low-Temperature Experiments

To adapt to Antarctic climate conditions, all components of the all-sky information acquisition system were selected for low-temperature resistance and underwent low-temperature testing. Low-temperature testing was conducted using the GDW-165 high-low temperature test chamber from Shanghai Pindun Company at the Precision Instrument Laboratory of Lijiang Astronomical Observation Station. Test results indicated that all system components and cables could operate normally at -45°C. After system encapsulation, the entire equipment underwent low-temperature experiments. During testing, the equipment was placed in the high-low temperature test chamber, connected to the internal industrial computer via remote desktop, and the acquisition program was run to monitor internal and external temperatures from the dual temperature acquisition modules in real time and to check for condensation or frost on the acrylic transparent cover through all-sky camera images. During experimentation, equipment was continuously adjusted: desiccant was placed inside, and heater and fan activation temperatures were regulated to control internal temperature and avoid condensation and frost. The final configuration set the internal heater controller temperature to 15°C (activating when internal temperature falls below 15°C) and the fan controller temperature to 20°C (activating cooling when internal temperature exceeds 20°C).

[Figure 6: see original paper] Left panel: GDW-165 High and low Temperature Test Chamber; Right panel: The Device is Placed in the Test Chamber

1.3 Data Storage and Publication

The all-sky information acquisition system automatically collects all-sky cloud cover, sky background brightness, and dual temperature data according to software parameters, saving them to TXT documents with one document generated daily and stored on the industrial computer hard drive. One all-sky image is captured every 5 minutes, with each image approximately 1.2 MB in size, stored with the capture time as the filename, resulting in about 346 MB of data per day. Through web services, site information and all-sky images are pushed to a webpage for real-time display, as shown in [Figure 7: see original paper]. The left panel shows current all-sky information at Zhongshan Station, while the right panel displays the real-time all-sky image captured by the all-sky camera. This enables local and local network access, viewing, and real-time monitoring of all-sky information.

[Figure 7: see original paper] Zhongshan Station All-Sky Information Acquisition System Webpage

2 Analysis of Zhongshan Station All-Sky Information

After installation at Zhongshan Station on March 20, 2016, the all-sky information acquisition system has continuously collected data, accumulating a large volume of all-sky information. This paper utilizes all-sky cloud cover, sky background brightness, aurora, and temperature data from 2016 and 2017, combined with relative humidity data for Zhongshan Station in 2016 provided by Mr. Yang Yong from Xiuning County Meteorological Bureau, for statistical analysis. Preliminary results include observable hours, observable nights, sky background brightness, and temperature/humidity conditions at Zhongshan Station. Located within the Antarctic Circle, Zhongshan Station experiences polar day and polar night phenomena. The polar night period for 2016–2017 was May 27 to July 15, while the polar day period was November 21 to January 21 of the following year.

2.1 Observable Time and Observable Nights

Observable time and observable nights are important metrics for evaluating optical astronomical sites. All-sky cloud cover can effectively reflect a site' s observable time, and the all-sky information acquisition system enables real-time monitoring of cloud cover at Zhongshan Station. Definitions of observable time and observable nights are not entirely uniform; here we adopt the standard of cloud cover ≤ 3 to count observable hours. For continuous observable time exceeding 3 hours during a night, it is counted as one observable night, and must also satisfy wind speed ≤ 15 m/s and relative humidity $< 90\%$. This paper considers only cloud cover and humidity factors. [Figure 8: see original paper] and [Figure 9: see original paper] show observable hours and observable nights at Zhongshan Station for 2016 and 2017. In 2016, observable hours totaled 772.2 hours with 93 observable nights; in 2017, observable hours were 437.38 hours with 51 observable nights. This paper counts observable time from astronomical twilight end to astronomical dawn beginning (solar altitude $\leq$ -18°). At Zhongshan Station, solar altitude is $\geq$ -18° from October to February of the following year, so observable time during these months is zero in the figures. Figures 8 and 9 show significant differences in observable hours and nights during April, May, and August between 2016 and 2017. Comparison of cloud cover and all-sky images for corresponding months between the two years revealed no equipment malfunction, indicating objective conditions. [Figure 10: see original paper] presents monthly average cloud cover statistics for Zhongshan Station in 2016 and 2017.

[Figure 8: see original paper] Observable Hours of Zhongshan Station in 2016, 2017

[Figure 9: see original paper] Observable Days of Zhongshan Station in 2016, 2017

[Figure 10: see original paper] Monthly Average Cloud Cover of Zhongshan Station in 2016, 2017

2.2 Sky Background Brightness

Sky background brightness, also called night sky brightness, is another important metric for evaluating optical astronomical sites, primarily affecting the limiting magnitude and signal-to-noise ratio of astronomical observations. Sky background brightness is typically expressed in magnitudes per square arcsecond (Mag/arcsec^2), with darker backgrounds having larger values. Excellent astronomical sites should achieve V-band sky background brightness of 21.5–22.0 Mag/arcsec^2. The SQM-LE sky background meter used in the all-sky information acquisition system has a central wavelength of 550 nm (V-band). The maximum sky background brightness measured at Antarctic Zhongshan Station (moonless, clear night) was 22.13 Mag/arcsec^2 on July 3, 2017, as shown in [Figure 11: see original paper], where fluctuations between 16:10 and 08:00 were caused by aurora activity as confirmed by all-sky images.

The sky brightness meter is installed inside the all-sky information acquisition system with its sensor facing the zenith, measuring zenith sky background brightness through the acrylic transparent cover. Since the transparent cover has some light-blocking effect, causing SQM measurements to appear darker, the initial installation measured the acrylic cover' s offset as -0.08 under various dark conditions. Therefore, the true maximum sky background brightness at Zhongshan Station is 22.05 Mag/arcsec^2. The mean and median nighttime sky background brightness values for the two-year period are 17.02 Mag/arcsec^2 and 18.6 Mag/arcsec^2, respectively, both corrected for the offset.

[Figure 11: see original paper] Sky Darkness of Zhongshan Station on 2017-07-03

2.3 Temperature and Relative Humidity

The all-sky information acquisition system is equipped with a dual temperature acquisition module that collects real-time internal and external equipment temperatures. The external temperature probe is located outside the equipment, and its readings can reflect current temperature conditions at Zhongshan Station to some extent. This paper provides a simple analysis of temperature variations at Zhongshan Station based on external temperature data; Zhongshan Station also operates a meteorological station compliant with China Meteorological Administration surface observation standards. [Figure 12: see original paper] shows monthly temperature variations at Zhongshan Station from March 2016 to 2017, while [Figure 13: see original paper] shows daily temperature variations. The average temperature for 2016–2017 was -10.6°C, with a maximum temperature of 19.1°C recorded in December 2016 and an extreme minimum temperature of -44°C recorded in September 2016. The monthly average minimum temperature occurred in June 2016 at -19.99°C.

[Figure 12: see original paper] Monthly Temperature Distribution at Zhongshan Station in 2016-2017

[Figure 13: see original paper] Daily Temperature Distribution at Zhongshan Station in 2016-2017

[Figure 14: see original paper] shows monthly relative humidity variations at Zhongshan Station in 2016. Relative humidity at Zhongshan Station is relatively low, with an annual average of 55.2% in 2016, a monthly minimum average of 46.6%, and monthly average relative humidity ranging between 46% and 65%.

[Figure 14: see original paper] Monthly Relative Humidity at Zhongshan Station in 2016

3 Summary and Outlook

The Antarctic Zhongshan Station all-sky information acquisition system integrates all-sky imaging, cloud cover, sky background brightness, and internal/external temperature acquisition functions. It is easy to install and transport, with automatic operation and snow/frost removal capabilities, making it significant for real-time monitoring of optical astronomical site all-sky information. Data transmitted since installation at Zhongshan Station demonstrate that the equipment can adapt to Antarctic extreme climate conditions and has accumulated substantial empirical data for the station. This paper has only analyzed data from 2016 and 2017, preliminarily determining Zhongshan Station' s observable time, observable nights, sky background brightness conditions, and temperature conditions, providing empirical evidence for subsequent astronomical observations at Zhongshan Station. Additionally, the system has captured numerous all-sky images from which further information can be extracted through subsequent image processing.

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