Different Diurnal Variation Processes of Sky Background Brightness at Lijiang and Namtso (Postprint)

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Abstract

Sky brightness background is a crucial parameter for evaluating the excellence of a coronal observation station, which directly determines whether a coronagraph can achieve long-term monitoring of coronal activities. The Sky Brightness Monitor (SBM) is a precision instrument for accurately measuring important atmospheric parameters such as daytime sky brightness background, atmospheric integrated water vapor content, and atmospheric extinction index. It is also the internationally standard instrument for coronagraph site selection and an important facility for solar site selection in western China. Before conducting statistical analysis using the accumulated data from the Namtso observation site and Lijiang observation station, we first performed an in-depth analysis of two sets of representative data, aiming to preliminarily investigate and understand the sky brightness background characteristics of the sites based on the temporal profiles of the representative data. First, we gradually explain the different variation processes of sky brightness background throughout a day from two aspects: actual climatic characteristics and derived sky brightness background; second, we establish an effective computational method to quantify and reveal the evolution characteristics of sky brightness at a site. The results from the two sites show that: (1) The sky brightness background at 530;nm for both Lijiang station at an altitude of 3200,m and Namtso observation site at 4700,m is relatively good, with minimum values reaching the order of magnitude of $10 \times 10-6$, which can guarantee routine coronal observations; (2) The sky background brightness at Namtso observation site and Lijiang observation station evolves differently over time. Lijiang observation station is not suitable for all-day observations, as the observing conditions in the morning are far superior to those in the afternoon. In contrast, the Namtso observation site has long observable hours (from 9:00 to 16:00), and coordinating with observation facilities at other stations can significantly improve the efficiency of ground-based monitoring of space weather. The analysis of results not only provides an analytical example for subsequent statistical analysis of Namtso’ s sky brightness background, but also demonstrates the expected characteristics of Namtso’ s sky brightness background.

Full Text

Introduction

The solar corona, the outermost layer of the Sun’s atmosphere, consists primarily of high-temperature, tenuous, highly ionized plasma with temperatures reaching millions of degrees Celsius [?]. Coronal mass ejections (CMEs) represent one of the most violent eruptive phenomena in the solar atmosphere and constitute a major source of hazardous space weather events. CMEs cause instantaneous expansion and ejection of material from the low corona; when propagating to near-Earth space, they typically disturb Earth’ s magnetic field, leading to geomagnetic storms, ionospheric storms, and auroral phenomena. These events induce drastic changes in space weather that affect human production and daily life, potentially causing satellite malfunctions, disrupting communications, power grids, and navigation systems, and threatening the lives of astronauts. Therefore, observations of the corona serve not only scientific purposes—studying the origin, triggering mechanisms, propagation, and evolution of CMEs—but also enable monitoring and early warning of space weather variations caused by large-scale solar activities.

French scientist Bernard Lyot successfully invented the coronagraph in 1930, ending the long-standing limitation of coronal observations to total solar eclipses [?]. Typically, the intensity ratio between the solar disk center and the adjacent sky background ranges from 10^4 to 10^6, making coronal observations extremely difficult outside of total eclipses and necessitating specialized instrumentation (coronagraphs). While coronagraphs can be employed for sky brightness measurements during site surveys, Lyot coronagraphs are expensive to manufacture and require additional supporting equipment, rendering them impractical for fieldwork. In 1948, Evans developed a small sky photometer (the Evans Sky Photometer, ESP) to measure sky background; however, this instrument had limitations including complex operation, lack of portability, single-band measurement capability, and manual control requirements [?, ?]. In 2004, Lin et al. [?] invented the Sky Brightness Monitor (SBM) for the Advanced Technology Solar Telescope (ATST) project. This instrument offered numerous advantages including portability, simultaneous four-band measurement, simultaneous imaging of both the solar disk and sky region on a charge-coupled device (CCD), and low cost. In the same year, Penn et al. [?] measured sky brightness at the Mees Solar Observatory (Haleakala) and the National Solar Observatory at Sacramento Peak (New Mexico), achieving minimum sky brightness values of $5 \times 10^{-6} I_\odot$ (where $I_\odot$ represents solar disk-center intensity) at both sites in the green line (530 nm). At the Sunspot Solar Observatory, sky brightness remained below $10 \times 10^{-6} I_\odot$ for approximately 5 hours, while at the Mees Solar Observatory this duration extended to about 6 hours.

In 2011, the Chinese solar physics community reached a consensus to initiate site selection efforts for the next-generation giant solar telescope [?, ?]. In 2012, Liu et al. [?] manufactured the first domestic SBM based on experience from the ATST project, with instrumental stray light coefficients superior to comparable international equipment. Since then, domestic SBMs have been deployed for preliminary surveys across various western Chinese sites, with measurement results published successively: a calibrated minimum of $15 \times 10^{-6} I_\odot$ in the blue band at Dashanbao, Zhaotong [?]; $50 \times 10^{-6} I_\odot$ in the blue band at Fenghuangshan, Kunming [?]; $117 \times 10^{-6} I_\odot$ in the blue band at Shizuishan, Ningxia [?]; $68 \times 10^{-6} I_\odot$ in the blue band at Qitai, Xinjiang [?]; and an overall sky brightness level of approximately $30 \times 10^{-6} I_\odot$ in the green band at Dali, Yunnan [?].

Despite years of field measurements, data accumulation, and meticulous processing, substantial datasets remain unprocessed. Benefiting from high-quality data from Lijiang Observatory (obtained by our team), Zhao et al. [?] developed an automated SBM data processing program that significantly reduced processing time, and subsequently published annual statistical results for Lijiang station in 2017 [?]. The present work adopts this program for analyzing data from both Lijiang Observatory and the Namco observation point. As first-round candidates in the western China site selection program, these two locations exhibit distinct sky brightness characteristics due to their different geographical settings. Section 2 describes the instrumentation and data processing methods, Section 3 presents in-depth analysis of representative data from Namco and Lijiang, and Section 4 provides a summary—that both Lijiang Observatory and the Namco observation point exhibit favorable sky brightness conditions, reaching the $10 \times 10^{-6} I_\odot$ magnitude and thus capable of supporting routine coronal observations.

This paper aims to provide thorough analysis, enrich the database on sky brightness scattering levels, and elucidate important representative datasets from different sites, thereby facilitating comprehensive future studies of prominent high-altitude candidate sites in China such as Lenghu, Daocheng, and Muztagh.

Instrumentation and Data Processing Methods

2.1 Instrument Description

The SBM structure is illustrated in Figure 1 [Figure 1: see original paper]. The instrument features a multi-band photometric system with four channels: blue (450 nm), green (530 nm), red (890 nm), and water vapor (940 nm), each with a 10 nm bandwidth. This configuration enables simultaneous monitoring of atmospheric parameters including sky scattering background, water vapor content, atmospheric extinction, and aerosol levels [?, ?]. In the visible band, the green line (530 nm) represents the strongest spectral line in the coronal spectrum, and subsequent data analysis primarily focuses on this band. The SBM comprises key components including the optical tube, CCD, ND4 neutral density filter, and equatorial mount. The ND4 filter consists of two neutral density filters each with an optical density of 2, providing approximately uniform attenuation across the visible and partial near-infrared bands. Mounted at the objective end via three supports spaced at 120° intervals, the ND4 filter reduces solar radiation intensity to enable simultaneous imaging of both the solar disk and adjacent sky region on the CCD. Three baffle rings of different sizes within the optical tube constrain the instrument' s beam and imaging field. These baffle rings, along with external occulters on the ND4 filter assembly, suppress diffracted light from the tube edges and scattered light from internal dust.

Sky glow, representing the brightness of the large sky area surrounding the Sun, is typically normalized to one-millionth of the solar disk-center intensity. Diffracted light from direct solar illumination far exceeds the sky glow in magnitude, making diffraction suppression critically important for SBM performance [**?**]. Positioned at the focal plane, the CCD can simultaneously acquire data for both the solar disk and sky glow while keeping readout values unsaturated, enabling direct radiometric comparison. The SBM employs an automatic tracking system with a multi-band CCD acquisition unit and MaxIm DL 5 software, allowing collection of more samples within the same time interval without relying on visual estimation by observers, thereby significantly improving data accuracy. The instrument specifications include a 5 mm aperture, 100 mm focal length, f/20 focal ratio, and a field of view of 2.8-7.8 solar radii, though the effective field is typically reduced due to diffraction effects [**?**].

The SBM serves as the current international standard instrument for coronagraph site selection. Lin et al. [**?**] conducted cross-calibration between the ESP and SBM instruments, measuring systematic errors between the two systems and finding discrepancies of only 2×10^{-6} to $3 \times 10^{-6} I_{\odot}$. Liu et al. [**?**] performed calibration tests comparing domestic and international SBMs, reporting absolute differences of $0.9 \times 10^{-6} I_{\odot}$ and relative differences of 16.6% across four bands when the average sky brightness was within $15 \times 10^{-6} I_{\odot}$—differences that fall within the instruments' systematic error ranges. Furthermore, measurement errors between SBMs of the same batch are minimal, ranging from 1×10^{-6} to $2 \times 10^{-6} I_{\odot}$. This demonstrates that our independently developed SBM can quantitatively evaluate site parameters.

Figure 1 SBM structure diagram. 1: ND4 filter; 2: External occulter; 3: Occulter support arms; 4: Baffle rings; 5: Objective lens; 6: ND2 filter; 7: Filter wheel; 8: CCD; 9: SBIG ST-402 camera.

2.2 Data Description

SBM data are shown in Figure 2 [Figure 2: see original paper], with image dimensions of 765 × 510 pixels. From inner to outer regions, the image displays the solar disk, ND4 filter, diffraction rings, sky area, and ND4 support arm projections. Both the sky region and sky glow region refer to the same area, with its radiative intensity collectively termed sky glow intensity. Typically, pixel values in the solar disk region reach approximately 30,000, largely dependent on exposure time settings by observers but generally not exceeding 60,000 (the CCD saturation value is 63,000). The ND4 filter aims to attenuate solar disk radiation by four orders of magnitude, requiring a transmission coefficient of 1×10^{-4} across all four bands. The filter numbers and transmission coefficients are listed in Table 1 ; both Lijiang Observatory and the Namco observation point utilize ND2 filters numbered 8 and 9.

Diffraction ring pixel values are typically lower than solar disk values but higher than those of the ND4 filter and adjacent sky regions. It is important to note that when the solar disk approaches the ND4 filter edge, diffraction rings often exhibit overexposure and saturation. Cases of large-area saturation should be discarded and not used for analysis. For small-area saturation, both sky glow intensity and solar center intensity will be underestimated, meaning sky glow intensity in that direction cannot be used for calculations. Conversely, when deviations are small, the opposite sky glow region may be used for computation. Finally, support arm projections and sky regions should be excluded from calculations; similarly, sky regions obstructed by trees or power lines must be masked and not used (rectangular region in the right panel of Figure 2).

Table 1 Calibrated transmission coefficients of ND2 filter samples

The data used in this study were collected at Yunnan Lijiang Observatory (date: 20110225) and Tibet Namco observation point (date: 20131023). The Lijiang dataset comprises 1,792 files totaling approximately 1.3 GB, with intervals of about 1 minute between files and a total duration of about 8.5 hours (Beijing time 08:28:53–16:51:18). The Namco dataset contains 10,425 files totaling approximately 7.6 GB, with intervals of about 10 seconds and a duration of about 7 hours (Beijing time 09:37:45 to 16:27:28). All data were acquired using the same SBM instrument with excellent overall quality and no saturation phenomena.

Figure 2 Left panel: SBM sample showing from inner to outer regions the solar disk, ND4 filter, diffraction rings, ND4 support arms, and sky area (arrow indicates). Right panel: arrow points to two power lines, and this region cannot be used for sky brightness calculations.

2.3 Calculation Methods

Sky brightness scattering level (hereafter sky brightness) is defined as the ratio of sky glow intensity to solar center intensity, representing the atmospheric scattering capability for solar radiation. The calculation follows [**?**]:

$$S = \frac{I_{\mathrm{sky}}}{I_{\odot}} \tag{1}$$

where S denotes sky brightness, $I_\odot$ represents the pixel value at the solar centroid (solar center algorithm details are available in [?, ?]), and I_{sky} is the sky region intensity measured over an annular region from 5.0 to 6.5 solar radii. This range avoids support arms and diffraction rings to minimize errors. Figure 3 [Figure 3: see original paper] shows the imaging geometry for a single SBM data file. The two circles obtained through image segmentation methods represent the solar disk and ND4 filter edges, with the small circle’ s central black point marking the solar centroid. The arc regions on both sides at 5.0–6.5 solar radii are used to calculate I_{sky}. Specific segmentation methods are described in [?].

Figure 3 SBM sample plane: inner and outer circles represent the edges of the Sun and ND4 filter, respectively. The two arcs indicate the calculation region for sky area.

2.3.1 Instrument Scattered Light Subtraction Pillet et al. [?] proposed that measured sky brightness includes inherent instrumental scattered light, expressed as:

$$S_\lambda(\hat{n}) = \frac{I_{\text{sky}}(\hat{n}, \lambda)}{I_\odot(\hat{n}_0, \lambda)} = \phi_\lambda(\hat{n}, \hat{n}_0)\kappa_\lambda M(\hat{n}) + B_\lambda \tag{2}$$

Lin et al. [?] employed a uniform curved atmospheric model, treating atmospheric mass as a function of zenith distance and atmospheric thickness, and simplified Equation (2) to:

$$S(Z) = B_\lambda + \alpha M(Z, t) \tag{3}$$

where $S_\lambda(\hat{n})$ represents the sky brightness in a given band along the observer’ s line of sight, normalized to solar centroid intensity; λ is wavelength; $\hat{n}$ and $\hat{n}_0$ are direction vectors pointing toward the sky region and the Sun, respectively; ϕ_λ is the atmospheric phase function at wavelength λ, representing the angular distribution of atmospheric scattering of solar radiation; κ_λ is the atmospheric absorption coefficient; B_λ is the instrument scattered light (wavelength-dependent); Z is zenith distance; t is atmospheric thickness; α equals $\phi_\lambda\kappa_\lambda$; and M is the atmospheric mass between the Sun and observer, expressed as:

$$M(Z, t) = \sqrt{R\cos Z + R^2\cos^2 Z + 2Rt + t^2} \tag{4}$$

where R is the sum of Earth’ s radius and altitude, though Earth’ s radius alone is typically used in calculations. Substituting Equation (4) into Equation (3) yields:

$$S(Z) = B_\lambda + \alpha\left(\sqrt{R\cos^2 Z + R^2\cos^2 Z + 2Rt + t^2}\right) \tag{5}$$

Equation (5) contains three unknown parameters (α, B_λ, t), making fitting difficult and prone to failure. Consequently, not all daily datasets can be used to subtract scattered light through fitting. B_λ represents the instrument' s inherent scattered light. Under clear, stable atmospheric conditions, B_λ obtained through fitting Equation (5) remains relatively stable and can represent the instrument's intrinsic scattered light. Currently, B_λ values for the SBM have been determined through fitting and published [?]: blue band: $0.77 \times 10^{-6} I_\odot$; green band: $0.81 \times 10^{-6} I_\odot$; red band: $2.12 \times 10^{-6} I_\odot$; water vapor band: $3.26 \times 10^{-6} I_\odot$. After years of use, B_λ inevitably increases; therefore, our team annually applies black coating to the interior of the SBM tube to ensure that internal scattered light levels do not increase significantly.

2.3.2 Calculation Method in This Study This study first calculates sky brightness using Equation (1), then subtracts the B_λ values published by Liu et al. [?] to obtain the true sky brightness. To further investigate atmospheric characteristics, the sky brightness is finally normalized to unit air mass.

Sky brightness is a function of atmospheric mass. Normalizing sky brightness (after scattered light subtraction) to unit air mass yields a physical quantity representing the atmospheric phase function and absorption function. The physical significance of this normalization is to describe the scattering and absorption processes of solar radiation above the observation site. Calculation of atmospheric mass in Equation (4) depends on the fitted parameter t from Equation (5); therefore, we adopt the empirical formula proposed by Kasten et al. [?] based on the ISO Standard Atmosphere model.

Following the derivation by Pillet et al. [?] and Lin et al. [?], atmospheric mass M fundamentally represents relative air mass, making the empirical formula fully applicable. The formula is [?]:

$$M(Z) = \frac{1}{\cos Z + a(b + 90 - Z)^{-c}} \tag{6}$$

For uniformly mixed gases, $a = 0.50572$, $b = 6.07996$, $c = 1.63640$ [?]. For the water vapor absorption line at 940 nm, $a = 0.0548$, $b = 2.6500$, $c = 1.4520$ [?]. This formula is applicable only for zenith angles less than 80° with an accuracy of 0.5%. Further details are available in [?, ?].

Analysis of Representative Data

3.1 Lijiang Observatory

Lijiang Observatory (100°01 E, 26°42 N) is located in Gaomeigu Village, Yulong Naxi Autonomous County, Yunnan Province. Situated at the junction of the eastern Hengduan Mountains and the Yunnan-Guizhou Plateau, it is a high-altitude region. Analysis of total and seasonal precipitation in Lijiang from 1951-2010 shows no significant increasing or decreasing trend [?]. According to meteorological site data from Ma et al. [?], cloud cover statistics at 02:00, 08:00, 14:00, and 20:00 during July 1995 to December 1996 revealed greater cloud coverage at 14:00 compared to the other three times, particularly pronounced during the dry season (November to April) with February showing the most significant difference. February' s mean daily temperature range was 11.5°C, with maximum and minimum values of 17.5°C and 3.9°C, respectively, indicating large diurnal temperature differences and severe daytime water vapor evaporation.

Figure 4 [Figure 4: see original paper] shows the temporal variation of sky brightness at Lijiang Observatory on February 25, 2011. The overall trend displays an initial decrease followed by an increase. Between 08:00 and 10:00, sky brightness drops sharply, with the green-line sky brightness (530 nm) decreasing from $20 \times 10^{-6} I_\odot$ to approximately $7 \times 10^{-6} I_\odot$. This rapid decrease directly correlates with the continuous reduction in atmospheric mass after sunrise, as described by Equation (6). Under clear skies, Rayleigh scattering dominates atmospheric scattering, with shorter wavelengths exhibiting greater scattering intensity. This is reflected in the figure where the blue band (450 nm, diamonds) appears highest, followed by the green band (530 nm, triangles), red band (890 nm, squares), and water vapor band (940 nm, asterisks). Notably, near 09:20 and 09:40, the red and water vapor bands show significant deviations from the overall trend due to ghost image artifacts. A 20-minute data gap between 10:10 and 10:30 resulted from instrument power replacement. Between 10:30 and 12:00, with the Sun near zenith, sky brightness reaches its minimum value for nearly 1.5 hours, indicating that Lijiang Observatory can potentially achieve optimal observing conditions around $6 \times 10^{-6} I_\odot$. The descent from maximum ($20 \times 10^{-6} I_\odot$) to minimum ($6 \times 10^{-6} I_\odot$) occurs relatively rapidly. Occasional jumps in the red and water vapor bands suggest initial changes in water vapor and cloud cover. After 12:00, sky brightness exhibits rising, falling, and rising again patterns, with data from different bands becoming mixed and showing an overall upward trend.

Before 12:00, atmospheric conditions remain very stable with only slight increases in sky brightness, consistent with the pre-12:00 data in Figure 4 where atmospheric scattering and absorption are stable, causing sky brightness to decrease with reducing zenith distance. After 12:00, atmospheric scattering and absorption become relatively chaotic, complicating the sky brightness behavior. Overall, on February 25, 2011, Lijiang Observatory exhibited stable morning atmospheric conditions with sky brightness falling below $10 \times 10^{-6} I_\odot$ after 09:30, suitable for coronagraphic observations. After 12:00, floating clouds degraded conditions, making observations unfavorable. This aligns with published Lijiang data characteristics [?]. The minimum sky brightness (530 nm) at Lijiang Observatory reached $6 \times 10^{-6} I_\odot$, remaining below $10 \times 10^{-6} I_\odot$ for approximately 3 hours. Consequently, Lijiang Observatory demonstrates favorable sky brightness conditions, achieving the $10 \times 10^{-6} I_\odot$ magnitude and capable of fulfilling routine coronagraphic observation tasks.

The sky brightness profile in Figure 4 fully demonstrates Lijiang' s climatic characteristics in February. Between 08:00 and 10:00, the observatory experiences dry, cloud-free conditions with rapidly decreasing sky glow values. From 10:00 to 12:00, large diurnal temperature differences cause gradual temperature increases, lifting surface water vapor and producing scattered fluctuations in the water vapor band. Beginning at 12:00, extensive floating clouds pass overhead, causing chaotic increases across all bands. Near 13:00, as clouds drift away, sky brightness decreases slightly. By 14:00, dense clouds formed by rising water vapor begin passing extensively, degrading monitoring conditions and causing sky brightness to surge. Observations ceased after 15:00. Meteorologically, the February 25, 2011 data best represent Lijiang Observatory's atmospheric scattering characteristics: stable morning decreases favor observations, while afternoon cloudiness proves unfavorable.

Figure 5 [Figure 5: see original paper] shows sky brightness per unit air mass versus time, reflecting atmospheric stability. The figure reveals that between 08:30 and 12:00, sky brightness per unit air mass remains relatively stable, indicating that atmospheric scattering and absorption processes are consistent, with sky brightness variations primarily driven by changing atmospheric mass.

Figure 4 Sky brightness variations at Lijiang station plotted against observation time.

Figure 5 Lijiang station: variation of sky brightness per unit air mass with time.

3.2 Namco Observation Point

The Namco observation point (90°53 37 E, 30°55 10.5 N) is located at the northern end of Namco Lake. Namco Lake, situated in the south-central Tibetan Plateau, ranks as China' s third-largest saltwater lake. The Namco basin lies within a sub-frigid monsoon semi-arid climate zone at the southeastern edge of the northern Tibetan plateau grassland region, exhibiting sensitivity to regional climate change with distinct wet and dry seasons. The monsoon period extends from June to October, influenced by warm, moist airflow from the Indian Ocean carried by the southwest monsoon, creating warm and humid conditions. The dry season from November to May is dominated by westerly circulation, characterized by cold and dry conditions [**?**]. The southern lake region features the Nyenchen Thanglha Mountains with perennial snow cover. Recent warming has caused glacier melting, resulting in lake expansion of 79.4 km^2 and water level rise of 4.8 m [**?**]. During October and November, Namco exhibits distinct lake-effect precipitation features, as maximum precipitation points connect with the lake, creating lower lake surface temperatures compared to land. Under westerly influence, downwind areas (eastern regions near Nyenchen Thanglha Mountains) show pronounced lake-effect precipitation characteristics [**?**]. Foehn winds form as air undergoes adiabatic descent, warming and drying in the process. Namco Lake' s basin topography readily generates foehn conditions. Statistical results from Xu et al. [?] indicate that cumulative foehn occurrences in October exceed those in September and November, meaning October frequently experiences morning foehn winds from the west and afternoon rainfall in the east, along with upper atmospheric circulation. Before eastern rainfall occurs, atmospheric humidity reaches critical thresholds forming floating clouds, with atmospheric circulation covering the lake surface.

Figure 6 [Figure 6: see original paper] presents sky brightness variations at Namco on October 23, 2013. The blue and green lines in both left and right panels are identical and largely overlap. The overall daily trend shows decreasing sky brightness with only occasional cloud passages. The minimum sky brightness occurs at 14:00, reaching $8\times10^{-6}I_{\odot}$. The descent from maximum ($30.2\times10^{-6}I_{\odot}$) to minimum ($8\times10^{-6}I_{\odot}$) proceeds gradually. Notably, the red and water vapor band profiles appear significantly higher than or coincident with the blue and green bands due to severe ghost image artifacts that increase measurement errors in long-wavelength bands by tenfold compared to short-wavelength bands.

Figure 7 [Figure 7: see original paper] shows a stereogram of the water vapor band (940 nm) with Sun and sky regions removed (left panel) and a planar view (right panel). Arrows indicate ghost images, with inner and outer red circles marking the solar disk and ND4 filter edges. The water vapor band exhibits severe ghost images that reduce solar center brightness, consequently decreasing the measured solar center intensity. Table 1 shows transmission coefficients of 0.0346 and 0.0344 for ND2 filters #8 and #9 in the water vapor band. Theoretically, the ND4 filter should attenuate solar radiation by four orders of magnitude, but the combination of filters #8 and #9 only achieves three orders of magnitude attenuation. Combined with ghost image effects, measurement errors in the red and water vapor bands far exceed those in the blue and green bands. Consequently, we exclude the red (890 nm) and water vapor (940 nm) bands from the Namco dataset. Although Lijiang Observatory used the same #8/9 ND2 filters, its red and water vapor bands perform normally because ghost image artifacts are less severe in the Lijiang data.

Examining the two short-wavelength bands (green and blue lines) in Figure 6, sky brightness reaches minimum values near solar noon. Due to direct solar heating, lake water vapor evaporates more rapidly, and under dry, warm conditions from westerly winds, rising vapor cools to form clouds. This results in a relatively short duration of minimum sky brightness, lasting approximately 1.5 hours. Influenced by Namco Lake’ s plateau climate characteristics, extensive floating clouds appear after 16:00, making coronagraphic observations unfavorable. Observers halted monitoring upon visual detection of extensive cloud passage. Figure 8 [Figure 8: see original paper] shows that sky brightness per unit air mass remains relatively stable, suggesting that Namco’ s sky brightness has reached its limiting value of $8\times10^{-6}I_{\odot}$. Overall, on October 23, 2013, Namco exhibited stable climate characteristics with gradual sky brightness decrease. The green-line (530 nm) sky brightness reached a minimum of $8\times10^{-6}I_{\odot}$, remaining below $10\times10^{-6}I_{\odot}$ for about 4 hours. Sky brightness per unit air mass maintained low levels for 2–3 hours before cloud appearance (Figure 8). Therefore, Namco observation point demonstrates favorable sky brightness conditions, achieving the $10 \times 10^{-6} I_{\odot}$ magnitude and capable of supporting routine coronagraphic observations.

Figure 6 Sky brightness variations at Namco station plotted against observation time (left: four bands; right: two bands).

Figure 7 Left: Stereogram of water vapor band (940 nm) with Sun and sky regions removed. Right: Planar view of left panel data; arrow indicates ghost image; inner and outer circles represent solar disk and ND4 filter edges.

Figure 8 Namco station: variation of sky brightness per unit air mass with time.

3.3 Sky Brightness Descent Rate

Figure 9 [Figure 9: see original paper] displays sky brightness temporal profiles for both Lijiang Observatory and Namco observation point. Sites with sky brightness at the $10 \times 10^{-6} I_{\odot}$ magnitude can conduct routine coronal observations, while those with sky brightness between 10×10^{-6} and $20 \times 10^{-6} I_{\odot}$ may also perform coronal observations. To quantitatively characterize the descent rate, we select data within the range from $20 \times 10^{-6} I_{\odot}$ (20 ppm) to the minimum value and fit them using:

$$y = A \times x^2 + B \times x + C \tag{7}$$

Fitting parameters are presented in Table 2 , with standard errors of 0.75 and 0.67. Parameter A represents the function’ s steepness—larger A values indicate faster sky brightness descent rates. Table 2 shows that Lijiang Observatory’ s descent rate exceeds that of Namco observation point. Further derivative analysis yields descent rate ranges of [0, 9.16] for Lijiang with an average descent speed of 4.58 $\text{ppm} \cdot \text{h}^{-1}$, and [0, 5.09] for Namco with an average descent speed of 2.545 $\text{ppm} \cdot \text{h}^{-1}$. During the descent phase, Lijiang Observatory’ s average sky brightness per unit air mass is 3.39 $\text{ppm} \cdot \text{airmass}^{-1}$, while Namco’ s is 7.78 $\text{ppm} \cdot \text{airmass}^{-1}$.

Figure 9 Sky brightness variation with time. Arrows indicate Lijiang Observatory and Namco observation point. Solid and dashed lines represent quadratic fits to sky brightness.

Table 2 Fitting parameters of sky brightness descending curve

3.4 Comparative Discussion

Analysis of the two representative datasets yields the following results: Lijiang Observatory’s minimum sky brightness (green line, 530 nm) is $6 \times 10^{-6} I_{\odot}$, lasting 1.5 hours, with sky brightness below $20 \times 10^{-6} I_{\odot}$ occurring only in the morning for 3.5 hours. In contrast, Namco observation point’ s minimum sky brightness (green line, 530 nm) is $8 \times 10^{-6} I_\odot$, lasting 1 hour, with sky brightness below $20 \times 10^{-6} I_\odot$ persisting for 5.5 hours from 10:30 to 16:00. Internationally excellent coronal observatories typically exhibit sky brightness below $10 \times 10^{-6} I_\odot$, while sites with sky brightness between 10×10^{-6} and $20 \times 10^{-6} I_\odot$ can accomplish routine coronal observations. Both Lijiang Observatory and Namco observation point achieve the $10 \times 10^{-6} I_\odot$ magnitude, qualifying them for routine coronal observations.

Notably, coordinated observations between Namco and Lijiang can provide up to 7 hours of continuous observability (09:00-16:00). Solar and interplanetary space monitoring and space weather early warning require multi-instrument, multi-location coordinated operations—a trend representing the future development direction both domestically and internationally. For example, Brazil’ s under-construction solar radio telescope will coordinate with the Daocheng radioheliograph to achieve continuous solar monitoring [**?**]. In the visible band, continuous solar monitoring also requires coordinated domestic multi-station observations to overcome Eastern Hemisphere time limitations. Namco observation point’ s sky brightness conditions satisfy requirements for coronagraph station construction, making it a potential candidate site. The current Meridian Project Phase II demonstrates a development trend toward networked, comprehensive ground-based monitoring, while western China monitoring stations remain sparsely distributed—presenting a development opportunity for Namco observation point.

The ideal sky brightness temporal profile features rapid descent and prolonged duration, reaching minimum values quickly and maintaining them for extended periods. We calculated descent rates from $20 \times 10^{-6} I_\odot$ to minimum values to characterize this behavior. Lijiang Observatory’ s average descent rate is 4.58 $\text{ppm} \cdot \text{h}^{-1}$ with average sky brightness per unit air mass of 3.39 $\text{ppm} \cdot \text{airmass}^{-1}$, while Namco’ s values are 2.545 $\text{ppm} \cdot \text{h}^{-1}$ and 7.78 $\text{ppm} \cdot \text{airmass}^{-1}$, respectively. Clearly, Lijiang Observatory’ s descent characteristics better meet expectations. Sky brightness per unit air mass reflects atmospheric scattering and absorption (including aerosols, water vapor, and particulate effects). Lijiang, located in China’ s cleanest Da 香格里拉 region, has lower atmospheric dust content than Namco, which lies in the arid, low-precipitation Tibetan Plateau region with relatively higher dust content. Consequently, Lijiang’ s air quality surpasses Namco’ s, as evidenced by its lower sky brightness per unit air mass. Namco’ s average sky brightness per unit air mass is 2.29 times that of Lijiang, meaning for identical solar radiation intensity, Namco’ s scattered radiation intensity exceeds Lijiang’ s by more than a factor of two, resulting in significantly higher sky glow intensity at Namco.

Regarding temporal profiles, Namco’ s sky brightness descends more gradually. Furthermore, afternoon sky brightness characteristics differ markedly between the two sites. Visually, Lijiang experiences observable cloud passage, while Namco appears cloud-free. Theoretically, Figures 5 and 8 show that Namco’ s sky brightness per unit air mass changes little between 14:00–16:00, indicating stable atmospheric composition, whereas Lijiang shows the opposite pattern—cloud appearance alters atmospheric composition (water vapor content), causing substantial sky brightness changes. Overall, Lijiang Observatory’ s morning observing conditions surpass afternoon conditions, making it more suitable for morning coronal observations—consistent with published statistical results [**?**]. Although Namco’ s sky brightness exceeds Lijiang’ s before 16:00, it remains suitable for coronal observations throughout this period.

Conclusion

The solar corona constitutes an important component of the solar atmosphere and represents a key focus of solar physics research and observation. Currently, domestic coronagraph technology is developing vigorously, and this development relies on station construction. Excellent site parameters not only determine telescope imaging quality but also serve as crucial criteria for evaluating terminal instruments and site construction. In the optical band, sky brightness is a vital parameter for assessing coronal observatory quality. Based on two representative datasets from domestic SBM observations (Lijiang Observatory and Namco observation point) and incorporating geographical locations and climate characteristics, this paper progressively analyzes different diurnal variation processes of sky brightness. Using quantitative descent rates and normalized sky brightness, we investigate site sky glow characteristics and understand the temporal profiles of both locations. We conclude that although Lijiang Observatory and Namco observation point exhibit different sky brightness (530 nm) variation patterns, both achieve minimum values at the $10 \times 10^{-6} I_{\odot}$ magnitude, demonstrating that both sites can meet routine coronal observation requirements. According to their sky brightness temporal profile characteristics, Lijiang Observatory is better suited for morning observations, with low, stable sky brightness values (minimum $6 \times 10^{-6} I_{\odot}$ lasting 1.5 hours). In contrast, Namco observation point is suitable for extended-duration coronal observations, maintaining low sky brightness for prolonged periods (sky brightness below $20 \times 10^{-6} I_{\odot}$ from 10:30 to 16:00). These two sites complement each other’ s strengths and weaknesses, providing up to 7 hours of continuous observability. For ground-based space weather monitoring requiring multi-instrument, multi-location coordination, Namco observation point holds significant value for visible-band solar and interplanetary space monitoring. Currently, with only limited Namco data published, subsequent work will focus on statistical analysis of Namco’ s sky brightness and comprehensive comparison with other stations.

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The Variations in the Sky Brightness of Lijiang and Namco throughout the Day

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ABSTRACT The sky brightness is an important parameter to evaluate the excellence of a coronal observatory, which directly determines whether the coronagraph can measure and monitor the coronal activity for a long time. The Sky Brightness Monitor (SBM) is a precision instrument for accurately measuring important atmospheric parameters such as the sky brightness, water vapor content, and atmospheric extinction. It is also a universal instrument for coronagraph site selection and an important equipment for solar site selection in western China. Before conducting statistical analysis on the accumulated data from Namco and Lijiang, this paper first performs an in-depth analysis using representative data from Namco and Lijiang. The aim is to preliminarily study and understand the characteristics of the sky brightness at the site based on the profiles of the representative data. Firstly, by considering the actual climatic characteristics and the normalized sky brightness, the paper gradually explains the different variations of the sky brightness throughout the day. Secondly, we establish an effective calculation method to measure and reveal the evolution characteristics of the sky brightness. The results show: (1) the sky brightness (green line, 530 nm) at the Lijiang station with an altitude of 3200 meters and the Namco site with an altitude of 4700 meters are both relatively good. The minimum values can reach the order of 10×10^{-6}, ensuring the feasibility of regular corona observations; (2) the sky brightness at the Namco site and the Lijiang station evolves differently over time. The Lijiang station is not suitable for all-day observations, with morning conditions being far superior to those in the afternoon. In contrast, the Namco site has a longer observation time (from 9:00 AM to 4:00 PM), and its cooperation with the observation equipment of other stations can significantly improve the efficiency of space weather ground monitoring. The analysis results not only provide a sample analysis for subsequent statistics on the sky brightness at Namco but also demonstrate the expected characteristics of the sky brightness at Namco.

Key words telescopes: site testing, astronomical instrumentation, methods: data analysis, techniques: image processing

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