An Analysis of the Seeing Conditions at Platform C of the Lenghu Site (Postprint)

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Abstract

This paper statistically analyzes the seeing data at the Lenghu site Platform C from 2018 to 2024, during which extensive construction modified the original landscape. The study focuses on the impacts of meteorological factors and building obstructions. The results reveal a progressive degradation in seeing as the monitoring setup passively changed: the median values were 0. 76 (the original location), 0. 83 during the Terrace, and 0. 99 at the new Dome (temporarily considered the permanent monitoring location). Once the instruments are fully deployed, wind speed and wind direction critically affect seeing quality, with optimal conditions occurring when the wind speed is 2–6 m s−1 and the wind direction is between 180° and 270°. However, in 2023 and 2024, the wind speeds decreased, and the prevailing wind direction shifted from southwest to northwest, correlating with poorer seeing. Computational Fluid Dynamics simulations reveal that the construction of the Wide Field Survey Telescope altered the local wind field, increasing turbulence around the Dome,especially when the winds blow from 225° to 255°. In contrast,Platform A,located in a higher and more open area,consistently maintained better seeing,particularly after midnight,likely due to fewer obstructions and lower nocturnal heat release.

Full Text

Preamble

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An Analysis of the Seeing Conditions at Platform C of the Lenghu Site

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Abstract

This paper statistically analyzes seeing data at Platform C of the Lenghu site from 2018 to 2024, a period during which extensive construction modified the original landscape. The study focuses on impacts from meteorological factors and building obstructions. Results reveal progressive degradation in seeing as the monitoring setup changed: median values were 0.76″ during the Terrace phase and 0.83″ at the new Dome (temporarily considered the permanent monitoring location). Once instruments are fully deployed, wind speed and direction critically affect seeing quality, with optimal conditions occurring at wind speeds of 2–6 m s^{-1} and wind directions between 180° and 270°. However, in 2023 and 2024, wind speeds decreased and the prevailing wind direction shifted from southwest to northwest, correlating with poorer seeing.

Computational Fluid Dynamics simulations reveal that construction of the Wide Field Survey Telescope altered the local wind field, increasing turbulence around the Dome, particularly for winds from 225° to 255°. In contrast, Platform A, located in a higher and more open area, consistently maintained better seeing, especially after midnight, likely due to fewer obstructions and lower nocturnal heat release.

Key words: site testing – methods: statistical – hydrodynamics – atmospheric effects

1. Introduction

Astronomical seeing refers to the distortion of radiation wavefronts from cosmic sources caused by fluctuations in air's refractive index (Giovanelli et al. 2001). It directly impacts astronomical image quality and spatial resolution, making it a key parameter in site selection and ground-based telescope performance (Tokovinin 2023). Since 1985, numerous international teams have evaluated sites for prestigious observatories, including Mount Locke in Texas (Barker 1987), La Silla and Paranal in Chile (Woltjer 1991), Maunakea in Hawaii (Bely 1987), and Roque de los Muchachos in La Palma (Munoz-Tunon et al. 1997). These evaluations play a vital role in determining suitable locations, as optimal seeing is necessary for high-quality observations.

The La Silla Observatory in Chile systematically records astronomical seeing through a fully automated Differential Image Motion Monitor (DIMM) and publishes monthly averages on the European Southern Observatory website (https://www.eso.com), providing invaluable data for site assessment and ongoing observations. Similarly, Van Kooten & Izett (2022) evaluated Maunakea's seeing conditions over 40 years using MASS-DIMM data, concluding that conditions remained relatively stable—essential for future observations. Likewise, Liu et al. (2015) analyzed seeing at China's Xinglong station from 1995 to 2001, documenting a range of 2″–5″ with notable seasonal variations. Furthermore, Feng et al. (2020) assessed seeing data from Ali, Muztagh, and Daocheng sites from March 2017 to March 2019, reporting values of 1.17″, 0.90″, and 1.01″ respectively, supporting selection of a 12 m optical/infrared telescope for western China. Lastly, Deng et al. (2021) investigated seeing at Saishiteng Mountain in Lenghu from October 2018 to December 2020, reporting a median seeing of 0.75″ that indicates the site's potential for future research.

An excellent astronomical observatory requires extremely stringent seeing conditions, which improve telescope operational efficiency and enhance precision and reliability of collected data and scientific results. As standard procedure, ongoing monitoring of atmospheric and meteorological parameters—especially seeing—provides essential support for advancing astronomical research.

Seeing represents the distribution and intensity of atmospheric turbulence, including properties of the ground surface layer, boundary layer, and free atmosphere (Giovanelli et al. 2001). Near-surface turbulence significantly influences seeing variations, closely related to ground-level wind shear and temperature gradients. It is also affected by local topography, vegetation, and buildings, exhibiting strong locality (Coulman 1985). Topographic changes alter local wind fields, while buildings and vegetation generate eddies and airflow disturbances through localized heating or shading. Atmospheric parameters such as temperature, relative humidity, and precipitable water vapor also affect seeing conditions (Jabiri et al. 2000). Human activities and ground conditions like roads and buildings intensify near-surface turbulence by modifying local heat fluxes, temperature gradients, and wind flow patterns (Blocken & Carmeliet 2004). Collectively, these factors contribute to seeing variations that affect astronomical observation quality.

Recent statistical analysis of Platform C seeing data revealed degradation as the landscape was gradually modified and equipment locations changed. This study aims to analyze factors affecting seeing variations, focusing on wind speed, wind direction, and building placement to determine whether the DIMM should be relocated.

The Lenghu site features several mountain ridges converging at a local summit of about 4500 m altitude. Following preliminary construction (the top was blasted and flattened), three major platforms were created for telescope projects: Platform A (4304 m), Platform B (4300 m), and Platform C (4200 m). Most site quality measurements were collected at Platform C, though some data were also taken at Platform A in the first half of 2024.

This paper is organized as follows: Section 2 introduces DIMM principles, seeing data processing methods, and preliminary results. Section 3 provides detailed analysis of factors affecting seeing, such as wind speed, wind direction, and building obstructions. Section 4 compares seeing data from Platforms A and C from mid-March to early June 2024, highlighting differences in seeing trends before and after midnight and the influence of local microclimatic effects. Section 5 examines seasonal seeing characteristics from 2022 to 2024, focusing on wind direction patterns and their impact on seeing performance, particularly for Platform C. Finally, Section 6 summarizes main conclusions and provides recommendations for future work.

2.1. Observation Site and Instrumentation

The Lenghu site is located at the summit of Saishiteng Mountain, east of the Altun Mountains and on the northern edge of the Qaidam Basin. Six years of continuous monitoring demonstrate Lenghu's exceptionally favorable climate for astronomical observations: 70% of nights throughout the year are clear and suitable for photometry, with median seeing of 0.75″. Nighttime temperature variations are minimal, averaging 2.4°C. Additionally, 55% of nights exhibit precipitable water vapor levels below 2 mm. The night sky is exceptionally dark with almost no light pollution (Deng et al. 2021). These conditions underscore Lenghu's potential as a premier astronomical site.

The Lenghu site hosts several observation platforms. Platform C, the first constructed, is at 4200 m altitude where the aforementioned parameters are monitored. Platform A, at 4304 m, has a meteorological station established this year to monitor environmental parameters. The straight-line distance between these platforms is approximately 1 km. This paper focuses on Platform C data and conditions, with measurements at Platform A included for reference.

Figure 1 presents a panoramic view of Platform C, and Table 1 shows the DIMM device positions during three observation periods. The DIMM was initially installed at the Original location (hereafter C1) in October 2018, when surroundings were open and unobstructed. Due to subsequent construction, the DIMM was relocated to the Terrace (C2). In February 2023, with new construction planned around the Terrace area, the DIMM was moved again to its current location (C3). The Dome containing the DIMM was mounted on a 10 m tower; locations are marked by numbers in Figure 1.

Seeing refers to degradation of image quality in ground-based telescope observations due to atmospheric turbulence, resulting in image blurring. The full width at half maximum of a point source's point-spread function quantifies seeing in angular units (arcseconds), reflecting integrated atmospheric turbulence along the entire light path, characterized by the refractive index structure constant (Roddier 1981; Tokovinin 2023). DIMM measurements have been widely used in site-selection campaigns and have become a standard assessment of integrated atmospheric optical turbulence (Zhu et al. 2023). This study employs a standard French DIMM device from Alcor-System, which measures wavefront slope differences between two pupils on a shared telescope mount (Sarazin & Roddier 1990). Measurements were calculated at an average wavelength of 550 nm and corrected to the zenith position (airmass unity).

2.2. Data Preprocessing

A total of 1,125,467 seeing records were collected between October 28, 2018 and June 24, 2024. To ensure data quality, records were cross-matched with system-recorded clear weather conditions (sky = 1), and outliers with seeing values above 3″ were excluded, as such values typically indicate poor observation conditions irrelevant for high-precision analysis. A rolling window of 10 data points was applied, using rolling averages and standard deviations to filter the data. A threshold of 1.5 standard deviations was selected based on detailed analysis, including testing multiple thresholds and validating against data continuity, ensuring accurate outlier identification without excluding valid data points. Seeing values exceeding this threshold were marked as outliers, and discontinuities were flagged where differences between consecutive data exceeded 0.5″, indicating potential anomalies. Further filtration retained only data collected during twilight and dawn periods for improved astronomical accuracy.

Given inconsistent intervals in data recording, time-weighting was applied using an exponential decay function with a time constant of approximately 20 s. The weight calculation formula is:

$$\text{weight} = \exp\left(-\frac{\Delta t}{\tau}\right)$$

where Δt is the time difference between adjacent data points, and τ is the time constant. We normalized weights to ensure they summed to 1. Furthermore, we excluded data with intervals over 300 s to minimize impact from irregular or anomalous time intervals on the final analysis. The weighting process had minimal impact on observed percentiles, affecting them by only 0.01″.

Data analysis based on different DIMM locations indicates gradual deterioration in seeing quality across observation phases. Median seeing values for C1, C2, and C3 were 0.76″, 0.83″, and 0.99″, respectively (see Figure 2 and Table 2). Cumulative distribution and percentile analyses further support this observation, with larger seeing values (indicating worse conditions) becoming more frequent during C3, underscoring its negative impact on seeing conditions.

3. A Comprehensive Analysis of Seeing Variability Factors

3.1. Wind Speed and Wind Direction

We processed wind speed data collected between 2018 and 2024, focusing on observations from astronomical twilight and dawn. We aggregated data monthly to capture wind speed variations during key observation periods. To explore location-specific wind speed characteristics, we categorized monthly average wind speeds by the three locations. As shown in Figure 3, overall wind speeds in 2023 and 2024 were lower than in previous years. Figure 4 presents monthly average wind speeds across each location, showing consistently lower speeds during C3. For safety and data quality, the remote-controlled DIMM dome opens only when wind speeds remain below 10 m s^{-1}. If wind speeds exceed 12 m s^{-1} for 3 minutes or reach 15 m s^{-1} for 1 minute, the system suspends observations.

In the wind direction analysis, we created wind rose charts for Platform C, dividing wind direction data into three locations (see Figure 5) and displaying annual distributions from 2021 to 2024 (see Figure 6). We also present proportions of wind directions ranging from 195° to 360° (in 15° intervals) for the three locations, as shown in Table 3. Analysis results indicate a shift in dominant wind direction from southwest to northwest, along with increased north winds. This could be attributed to differences in terrain slope at the three locations, leading to changes in local wind flow patterns. Additionally, we speculate that C3 may be affected by Wide Field Survey Telescope (WFST) obstruction. Further analysis of wind speed, direction, and seeing conditions reveals that optimal seeing occurs at wind speeds between 2 and 6 m s^{-1} and wind directions from 180° to 270° (see Figure 7).

3.2. Building Obstruction

In ground-based observatories, airflow interference between buildings impacts both microclimate and seeing conditions. When wind strikes a building's windward surface, it disrupts local wind fields and alters the microclimate. As airflow bypasses the building, strong vortices form on the leeward side. These vortices gradually weaken as they extend downwind, with the wake region typically reaching five to six times the building height. Consequently, these airflow disturbances modify the wind environment surrounding the telescope, increasing air turbulence and ultimately deteriorating seeing conditions (Li & Jiang 2022).

The WFST has a height of 21 m and dome diameter of 17.1 m, located approximately 19° west-southwest (WSW) of C3 at a distance of about 61 m. Construction began in May 2021 and ended in July 2023. To assess WFST's impact on seeing conditions, we categorized seeing data from 2018 to 2024 into three phases: pre-construction (October 2018–May 2021), during construction (June 2021–July 2023), and post-construction (August 2023–June 2024). Statistical analysis revealed median seeing values of 0.79″, 0.88″, and 0.98″ for these phases (Figure 8). It should be noted that variations in seeing values across different phases are primarily influenced by local topography, though natural atmospheric condition variations may also contribute.

Due to WFST's height and position, C3 lies within the WFST downwind wake disturbance area. These disturbances may alter the local wind field and microclimate, adversely affecting seeing conditions. We built a three-dimensional (3D) topology and WFST model (Figure 9(a)) and performed Computational Fluid Dynamics (CFD) simulations to study Platform C's wind environment. We chose a pressure-based solver for momentum equations and the k-omega Shear Stress Transport model for turbulence without the energy equation. Inlet velocity equals an average wind speed of 4 m s^{-1}, with wind directions ranging from 0° to 360° at 15° intervals.

To collect turbulence intensity data for cases with and without WFST, 2000 sampling points were distributed around C3 (Figure 9(b)). Median turbulence intensities are presented in Table 4, with corresponding scatter plots shown in Figure 10. Results revealed differences in turbulence intensity for wind directions of 225°–255°, consistent with prevailing west and southwest winds observed in the wind rose diagram for 2018–2024 (Figure 11), corresponding to WFST's location relative to C3. We present turbulence intensity plots around C3 with and without WFST for prevailing wind directions at 225°, 240°, 251°, and 255° (Figure 12). These results suggest the wind environment around C3 is influenced by WFST. Notably, turbulence intensity discussed here refers solely to mechanical turbulence. Although it does not directly intensify optical turbulence, the chaotic energy redistribution in this process can create more favorable conditions for thermal turbulence, thereby indirectly degrading astronomical seeing.

4. A Comparison with Platform A

We analyzed data from mid-March to early June 2024 to compare seeing between Platforms A and C. Platform A, approximately 100 m higher than Platform C, is in an open area without obstructions. The time series in Figure 13 shows that while trends on both platforms are similar before midnight, Platform A consistently outperforms Platform C after midnight. To explore this difference, we analyzed wind speed and direction data. Figure 14 shows minor differences between the two platforms, implying limited impact of macro-scale wind properties on visual clarity differences. However, the higher frequency of west winds on Platform A compared to Platform C (Figure 15) may suggest that Platform C is more sheltered by surrounding buildings.

Local microclimate effects, such as heat released by buildings at night that increases local air instability and near-surface turbulence, may be responsible for seeing deterioration at Platform C after midnight. In contrast, Platform A's more open environment experiences less thermal disturbance and thus maintains better seeing conditions.

5. Seasonal Characteristics

Figures 16 and 17 illustrate wind roses and seeing statistics for different seasons from 2022 to 2024 for Platform C. Results indicate the best seeing occurred in 2022, characterized by prevailing west or southwest winds in spring, summer, and fall, and northwest winds in winter. However, west winds became more prevalent only in fall and winter, which may have improved seeing during these seasons.

In spring 2024, comparison between Platforms A and C (Figure 18) shows both platforms were mainly influenced by north winds. However, Platform A had a higher proportion of west and southwest winds, which may have contributed to slightly better seeing. Overall, wind direction significantly impacts seeing quality, with west or southwest winds associated with better conditions. Local variations in wind direction further underscore its critical role in determining seeing quality.

6. Conclusion

We present a statistical analysis of seeing conditions at Lenghu site Platform C from 2018 to 2024, investigating influences of key meteorological parameters including wind speed, wind direction, and building-induced obstruction on seeing quality. Main conclusions are:

1. Analysis of 1,125,467 seeing records from the DIMM revealed progressive decline in seeing across different equipment locations. Median seeing values were 0.76″ for C1, 0.83″ for C2, and 0.99″ for C3, indicating that changes in the observational environment, particularly those associated with location development, may impact seeing quality. However, some measurements were taken at different times and locations, so variations in local topography and natural atmospheric conditions could influence the data. The absence of simultaneous multi-location measurements makes it challenging to pinpoint precise causes of observed degradation.

2. Wind speed and direction affected seeing quality. Optimal seeing occurred with wind speeds of 2–6 m s^{-1} and directions between 180° and 270°. In 2023 and 2024, lower wind speeds, particularly during C3, correlated with seeing quality decline. Wind rose analysis showed a shift from southwest to northwest winds, with more north wind, altering local observational conditions.

3. WFST construction modified the local wind field at the surface layer, causing changes in wind direction, reduced wind speed, and increased turbulence at the DIMM location. These factors degraded seeing quality for telescopes downwind of WFST. CFD simulations indicated wind disturbances of 225°–255°, aligning with observed data. Analyzing seeing data from different WFST construction phases showed median values of 0.79″, 0.88″, and 0.98″, respectively. Comparisons with Platform A, located in

a higher, more open environment, consistently showed better seeing, especially after midnight. This discrepancy is likely due to building-induced occlusion and nocturnal heat-driven turbulence.

4. To improve seeing quality in future observatories, efforts should focus on optimizing design and layout of both buildings and equipment to minimize disturbances in the local wind field. On April 27, 2024, the pillar supporting the telescope was raised to bring it closer to the free atmosphere, which slightly improved seeing data statistics. The actual seeing condition at Platform C is likely not deteriorating over time but is being modified by buildings. To better measure natural seeing conditions, a new location for the site quality monitoring system is recommended.

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