Reliability-qualified Nighttime Lights for Disaster Impact and Recovery in cloud-impacted tropical Regions

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Keywords: Observability; Data gaps; Temporal completeness; Spatial completeness; Disaster monitoring

Abstract

Daily satellite-derived nighttime lights (NTL) are increasingly used to monitor electricity disruption and recovery, but their application in humid tropical regions is constrained by persistent cloud cover and irregular observation. This study addresses this limitation by treating observability as a defining condition of analysis rather than a secondary constraint. Using the VIIRS Black Marble VNP46A2 product over the Samar–Leyte sub-grid in the Philippines, we quantify how spatial completeness, temporal gaps, and radiance variability shape the availability and interpretability of daily NTL. Observability diagnostics are developed across pixel, settlement, and regional scales, showing that valid observations are intermittent, seasonally structured, and spatially heterogeneous. A valid-pixel threshold (τ) is introduced to regulate observational support, while settlement-based masks derived from GHSL SMOD isolate stable, signal-dominant areas. Exploring these factors jointly reveals how different configurations affect signal continuity and robustness. Alignment with hourly electricity load from the National Grid Corporation of the Philippines (NGCP) is used as an external consistency check. Results show that meaningful correspondence emerges only under constrained conditions defined by sufficient observational support and urban-dominant signal extraction. Optimal configurations vary across neighbouring island grids, but consistently occur at low to mid-range thresholds and within dense settlement classes. These findings highlight a fundamental constraint: in tropical regions, periods of greatest disruption often coincide with the lowest observational availability. By formalising observability and embedding it into the workflow, this study provides a reproducible framework for identifying when daily NTL can be reliably used for disaster monitoring and recovery assessment.

1. Introduction

In recent decades, remotely sensed Nighttime Lights (NTL) have evolved from a coarse socioeconomic proxy into a near–real-time signal of electricity activity, enabled by the daily 500 m VIIRS Black Marble product (Román et al., 2018). The VIIRS Day/Night Band provides globally consistent, atmospherically and BRDF-corrected radiance measurements at daily frequency, representing a substantial advance over earlier composite-based products (Elvidge et al., 2017; Miller et al., 2013). Román et al. (2019) demonstrated that corrected daily NTL can track electricity grid collapse and restoration, establishing a direct link between satellite radiance and power supply. Subsequent studies extended this capability to global scales, using daily NTL to characterise disruption and recovery following tropical cyclones (Mo et al., 2025). Related work has also advanced temporal modelling and change analysis in daily NTL time series, including adaptive neural-network approaches that learn smoothed trajectories from gap-filled records (Chakraborty and Stokes, 2023) and time-series decomposition methods applied to hurricane-related change detection (Zhao et al., 2020).

Despite these advances, the reliability of daily NTL remains uneven. Cloud contamination, sensor limitations, and inconsistent validation—particularly in the Global South—affect both the availability and interpretability of observations (Zheng et al., 2023; Levin, 2025; Zhao et al., 2019). While recent studies have analysed disruption and recovery using daily NTL (Zheng et al., 2025), they typically treat the time series as continuously observed and do not explicitly account for variations in observational support. In this study, *observability* is defined as the degree to which daily radiance values are supported by direct, high-quality satellite observations rather than interpolated or missing data. This distinction is critical because daily NTL is not a uniformly sampled signal. Instead, it is shaped by atmospheric conditions, particularly cloud cover, which can introduce spatially and temporally heterogeneous gaps in the data record.

The Philippines provides an extreme but instructive test case for evaluating these constraints. Located within the western North Pacific tropical cyclone belt, the region experiences persistent cloud cover and frequent storm activity. Samar–Leyte, in particular, was severely impacted by Super Typhoon Haiyan (Yolanda) in November 2013, which caused prolonged and geographically extensive power outages. This event coincides with a period of intense cloud cover, creating a setting in which both electricity disruption and observational limitations occur simultaneously. As a result, the region represents a stringent stress test: if NTL-based inference can be established under these conditions, it is likely to be transferable to less cloud-affected environments.

Figure 1 illustrates the implications of this constraint. On 16 November 2013, during the Haiyan recovery period, only 39% of pixels over Samar–Leyte contain valid observations, with large contiguous areas masked by cloud contamination. This pattern is not isolated but recurs throughout the time series, producing a temporally fragmented record in which each day represents a different level of observational support. Consequently, apparent changes in radiance may reflect not only underlying electricity dynamics but also fluctuations in data availability. This introduces a fundamental ambiguity in

https://doi.org/10.5194/isprs-archives-XLIX-B2-2026-1091-2026

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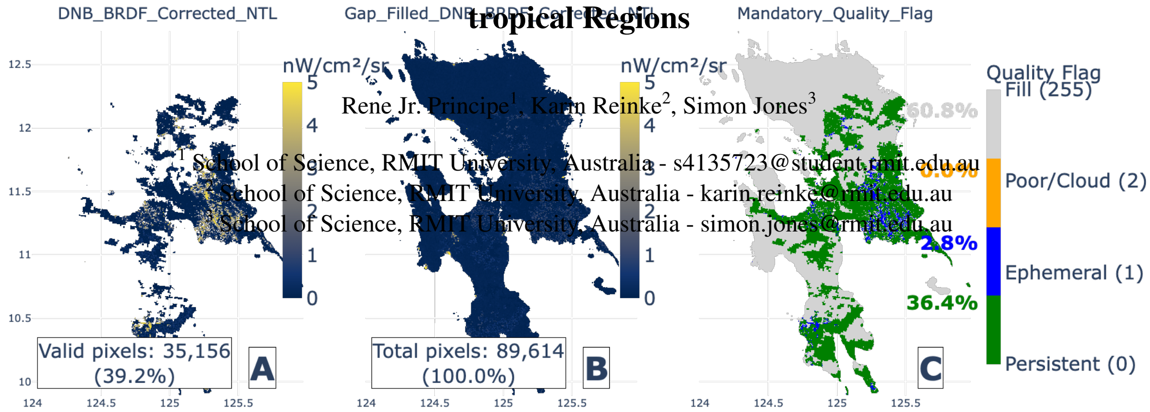

Figure 1. VNP46A2 over Samar–Leyte. (A) DNB-BRDF radiance showing spatially fragmented valid observations after quality filtering. (B) Gap-filled radiance providing full spatial coverage. (C) Mandatory Quality Flag indicating retrieval conditions.

interpreting daily NTL time series that is rarely made explicit, despite being widely acknowledged as a limitation in NTL applications (Skoufias et al., 2021; Small, 2021).

This paradox highlights both the necessity and the challenge of using NTL in cloud-affected environments. On one hand, these regions are among the most critical for monitoring disruption and recovery. On the other, the observational record is inherently intermittent, with gaps that can persist for days or weeks and vary across space depending on settlement structure and atmospheric conditions. While gap-filling approaches improve apparent continuity, they redistribute information across time and can dampen short-term radiance changes, potentially obscuring abrupt disruptions that are central to disaster analysis. Daily NTL is often treated as continuous, but doing so can ignore gaps and inconsistencies in the underlying observations.

This study implements a diagnostic-first workflow that explicitly quantifies observability in VIIRS Black Marble data and evaluates its implications for interpreting electricity dynamics. Using DNB-BRDF as the primary signal of record and gap-filled data for completeness diagnostics, the analysis characterises spatial and temporal completeness, gap structure, and their propagation through spatial aggregation and thresholding choices. These diagnostics are evaluated alongside National Grid Corporation of the Philippines (NGCP) load data to assess whether reliability-qualified NTL signals exhibit temporal structures consistent with independently observed system-level dynamics. By prioritising observational support over model optimisation, the analysis establishes reproducible conditions under which daily NTL can be interpreted with greater confidence. This shifts the focus from extracting signals to first determining when those signals are meaningfully observable.

This study makes three contributions. First, it formalises observability constraints in tropical nighttime lights using explicit spatial and temporal completeness diagnostics. Second, it demonstrates how these constraints interact with spatial aggregation and thresholding choices, revealing non-trivial trade-offs between data availability and signal fidelity. Third, it shows that reliability-qualified NTL signals can recover meaningful system-level dynamics when evaluated under clearly defined observational conditions.

More broadly, this work argues that confronting data reliability is a necessary precursor to applying disaster metrics developed in well-observed, temperate contexts. By establishing a framework that explicitly accounts for observational constraints, the study extends the applicability of daily NTL to cloud-prone regions and provides a foundation for more robust and transferable disaster monitoring approaches.

2. Materials and Methods

2.1 Study Area

The Philippines is selected as a representative tropical, hazard-prone setting where persistent cloud cover and fragmented grid systems constrain the observability of satellite-derived nighttime lights. Within this context, the Samar–Leyte sub-grid is used as the primary diagnostic region due to its severe exposure to Super Typhoon Haiyan (November 2013) and well-documented disruption and recovery patterns. The analysis is extended to neighbouring Visayas sub-grids (Bohol, Cebu, Negros, and Panay), defined according to the spatial units of electricity load reporting by the NGCP, enabling consistent comparison between satellite observations and grid-level demand across regions.

2.2 Data

2.2.1 Nighttime Lights Data

This study uses NASA’s VIIRS Black Marble daily product (VNP46A2, Collection 2 V1; 500 m)[1], which provides global, daily measurements of nocturnal visible and near-infrared radiance from the Day/Night Band (DNB) (Román et al., 2018). The dataset includes both the *DNB_BRDF* band, representing atmospherically and angularly corrected radiance, and the *Gap_Filled* band, a version of DNB-BRDF which interpolates across missing observations. Additional quality layers, including the Mandatory Quality Flag and cloud mask, enable identification of valid observations. Throughout the analysis, the DNB-BRDF band is treated as the primary signal of record, while the gap-filled product is used only for diagnostic purposes to illustrate the effects of interpolation under missing observations. All quantitative analyses and alignment assessments are based exclusively on DNB-BRDF to preserve sensitivity to abrupt changes in radiance.

[1] https://developers.google.com/earth-engine/datasets/catalog/NASA_VIIRS_002_VNP46A2

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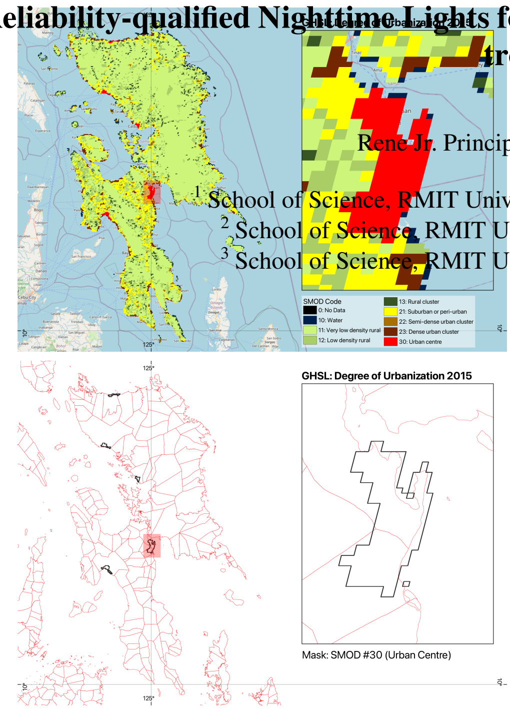

Figure 2. GHSL settlement context used for spatial aggregation. Top: SMOD classification showing degree of urbanisation across Samar–Leyte. Bottom: urban-centre mask (class 30), corresponding to G1, representing the most densely built-up areas used to maximise signal-to-noise in NTL aggregation.

2.2.2 Settlement Data (GHSL)

Settlement context is introduced using the Global Human Settlement Layer Settlement Model (GHSL SMOD v2.0; 2015, 1 km)[2], a globally consistent classification of urban centres, dense clusters, suburban areas, and rural zones. From SMOD, thematic masks are constructed to progressively narrow the spatial footprint from all settlements to dense urban cores, enabling assessment of how observational reliability varies with settlement intensity (Fig. 2). This stratification provides a consistent spatial framework for evaluating aggregation effects and ensuring comparability across regions.

2.2.3 Electricity Load Data (NGCP)

Electricity demand is represented using hourly load data from the National Grid Corporation of the Philippines (NGCP)[3] across five Visayas sub-grids. To align with the VIIRS overpass, the 1 AM observation is selected. The correspondence between NGCP-defined grid regions and the spatial extent of the NTL aggregation enables direct comparison between satellite-derived radiance and electricity demand. The same data sources and processing workflow are applied across all sub-grids to evaluate robustness under varying cloud regimes and settlement structures.

2.3 Observability Diagnostics

Using the DNB-BRDF band as the primary signal of record and the gap-filled band for completeness diagnostics, observability is quantified as the degree to which daily radiance values are supported by direct, high-quality observations rather than interpolated estimates. Three complementary diagnostics are employed. First, *spatial completeness* (SC) is defined as the fraction of valid pixels within a given region on each day. Second, *temporal completeness* (TC) is defined as the fraction of days with valid observations for each pixel over a given period. Third, *gap structure* characterises the persistence of consecutive missing observations, reflecting the duration and clustering of cloud-induced data gaps. Together, these diagnostics characterise the extent and structure of observational intermittency, which in tropical environments is dominated by irregular sampling and extended data gaps.

2.4 Spatial Aggregation and Thresholding

To evaluate how spatial context influences observability and radiance signals, daily radiance is aggregated using eight cumulative masks derived from GHSL SMOD v2.0. These masks range from dense urban centres (G1) to full land cover (G8), enabling systematic comparison across gradients of urbanisation (Fig. 2). Using cumulative masks allows controlled assessment of how progressively including less dense settlement types affects signal stability and interpretability. For each mask, daily aggregates are computed using only pixels that satisfy a minimum valid-pixel fraction. Valid-pixel thresholds (τ) ranging from 10% to 90% are applied to control the trade-off between data quality and temporal coverage. Lower thresholds increase retained days but admit partially observed scenes, while higher thresholds ensure stronger observability at the cost of reduced temporal continuity. To ensure comparability across configurations, time series values are constrained to the 0–95th percentile, followed by a 30-day moving average (applied only to stabilise alignment comparisons under intermittent sampling) and z-score normalisation.

2.5 Alignment with Electricity Load Data

To contextualise the observational diagnostics, aggregated DNB-BRDF radiance is compared with NGCP load data over a common temporal window (2012–2024). Alignment is evaluated using Pearson’s correlation coefficient (r), root mean square error (RMSE), and retained coverage (N), capturing temporal coherence, error magnitude, and data availability. Alignment is treated as an external consistency check rather than a validation target. The aim is to assess whether radiance signals, once filtered for observability, exhibit temporal patterns consistent with independently observed system-level dynamics. In cloud-affected environments, observational intermittency can distort apparent trends independently of underlying activity. Accordingly, alignment metrics are interpreted conditionally: strong agreement indicates that the retained radiance signal is both observable and interpretable, while weak agreement may reflect either true divergence or insufficient observability. To compare configurations across thresholds and spatial masks, a composite score is defined as:

$$S = 0.7 \cdot r - 0.1 \cdot \mathrm{RMSE} + 0.2 \cdot \tilde{N} \qquad (1)$$

where $\tilde{N}$ is the normalised retained coverage. The weights are set heuristically to prioritise temporal coherence while accounting for error magnitude and data availability. These comparisons are interpreted with caution, as factors such as seasonal economic activity or local generator use may influence radiance independently of grid-level electricity supply.

[2] https://developers.google.com/earth-engine/datasets/catalog/JRC_GHSL_P2023A_GHS_SMOD_V2-0
[3] https://www.ngcp.ph/operations#operations

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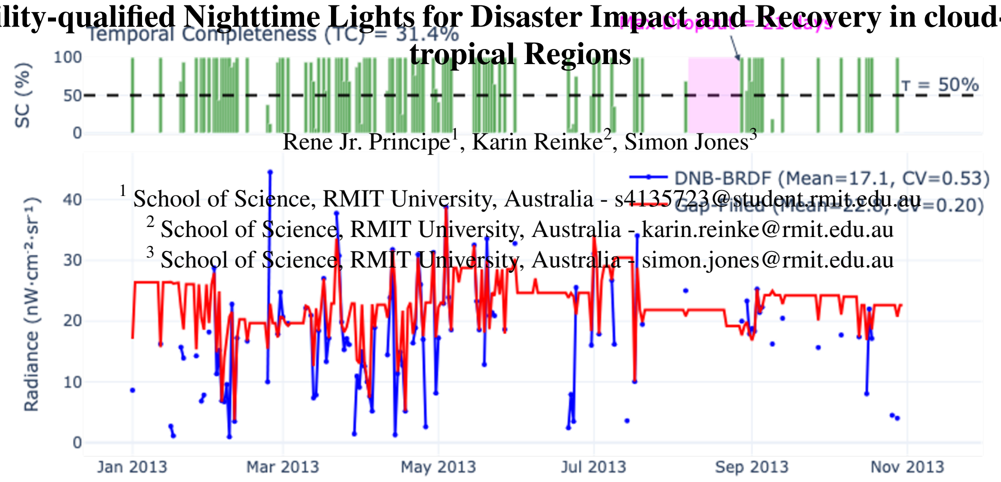

Figure 3. Pixel-level observability diagnostics. The upper panel shows daily SC with dropout periods, while the lower panel compares observed DNB-BRDF and gap-filled radiance under intermittent sampling.

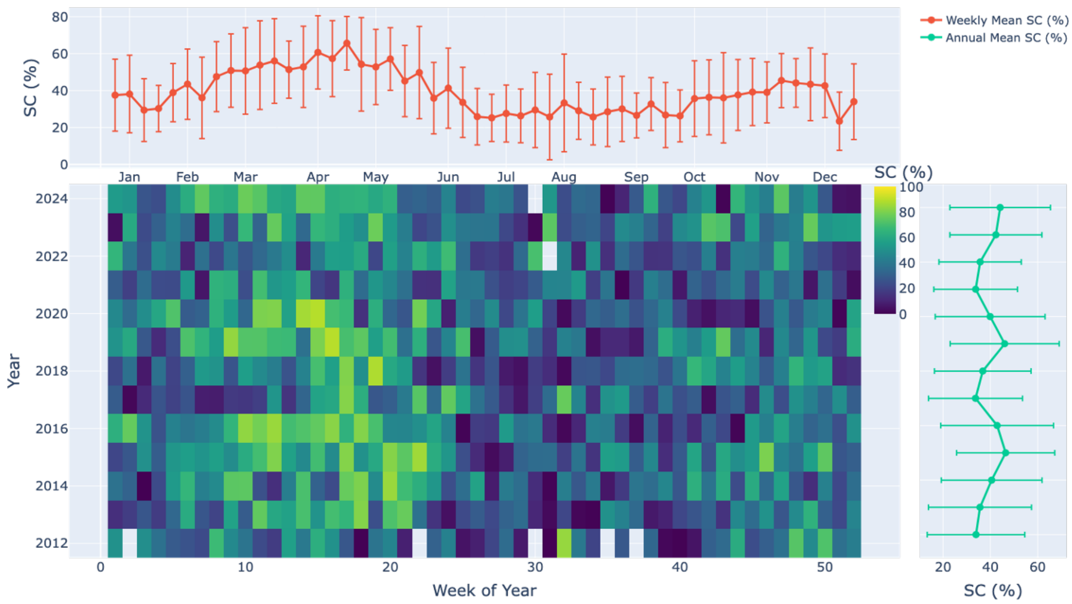

Figure 4. Seasonal and interannual variation in spatial completeness (SC) over Samar–Leyte (2012–2024). The figure includes weekly mean SC with variability ranges, a week-by-year heatmap, and annual summaries.

3. Results and Discussion

3.1 Observability Diagnostics Across Scales

Using the DNB-BRDF band as the fidelity signal and the gap-filled band for completeness diagnostics, the spatial and temporal availability of valid observations across the Samar–Leyte sub-grid was quantified. Across 2012–2024, spatial completeness is typically limited to about 30–40% of pixels per day, reflecting persistent cloud contamination and the highly uneven structure of valid observations already visible in Figure 1. This means that, even before any aggregation or downstream analysis, daily NTL images differ substantially in how much of the landscape is directly observed.

At the pixel scale, this intermittency is illustrated in Fig. 3. The upper panel shows the observation sequence for a representative location (Tacloban City Center), where valid observations occur irregularly rather than as a continuous daily record. The derived temporal completeness (TC = 31.4%) indicates that less than one-third of days contribute direct observations, while the maximum dropout period of 21 consecutive days shows that missingness is temporally clustered. The lower panel shows the corresponding radiance trajectories, where irregular observation support produces a discontinuous and more variable DNB-BRDF signal, while the gap-filled series appears smoother due to interpolation across missing periods.

At broader timescales, the same constraint persists. Figure 4 shows the long-term structure of spatial completeness from 2012 to 2024, where the weekly mean series exhibits a pronounced seasonal cycle, with higher completeness during relatively dry periods and systematically lower completeness during monsoon and cyclone-active months. The heatmap further demonstrates that this pattern recurs consistently across years, indicating that observational availability is governed by persistent climatic regimes rather than random noise. Annual summaries show moderate mean completeness overall, but with substantial intra-annual variability.

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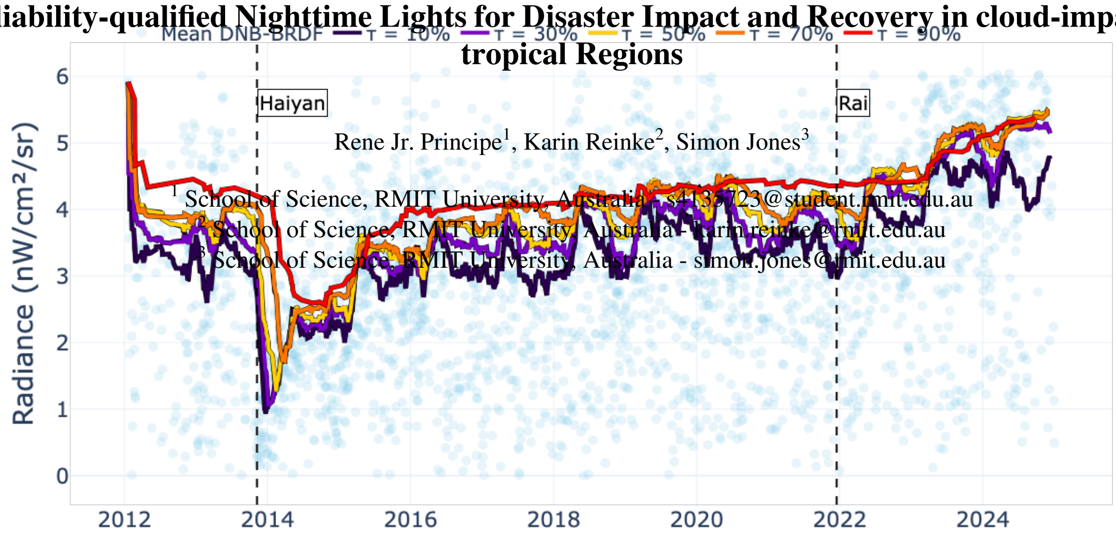

Figure 5. Effect of valid-pixel threshold (τ) on aggregated DNB-BRDF radiance. Dots represent the raw daily mean radiance over Samar–Leyte without completeness filtering, while lines show the corresponding time series after applying different τ thresholds.

These patterns extend the daily spatial snapshot (Fig. 1) and pixel-scale behaviour (Fig. 3). Just as individual pixels exhibit clustered dropout and irregular sampling, the aggregated record inherits this structure at seasonal and interannual scales. As a result, different segments of the time series are supported by fundamentally different levels of observational evidence. Periods of lower completeness are not simply noisier; they are systematically under-observed. Across scales, these diagnostics converge on the same conclusion: daily NTL in Samar–Leyte behaves as an intermittently observed signal rather than a continuous one. Pixel-level dropout and seasonal completeness patterns reflect a common structure of irregular sampling and extended data gaps, defining the limits of interpretability prior to any aggregation or filtering.

3.2 Thresholding and Signal Conditioning

Given the variability in observational support, it becomes necessary to explicitly control how much valid data contributes to each daily aggregate. This is operationalised through a valid-pixel threshold (τ), which defines the minimum fraction of observed pixels required for a day to be retained. As shown in Figure 5, varying τ directly alters the structure of the resulting time series. Lower thresholds retain more days but include partially observed scenes, leading to higher variability and increased sensitivity to incomplete spatial coverage. Higher thresholds restrict the analysis to days with stronger observational support, producing smoother and more stable trajectories, but at the cost of reduced temporal continuity.

Importantly, the effect of τ is not uniform across the time series. During periods of low completeness, stricter thresholds disproportionately remove observations, fragmenting the record and altering the apparent timing and magnitude of radiance changes. Lower thresholds tend to retain more transitions but may include partially observed scenes, introducing noise, while higher thresholds enforce stronger observational support but can delay or attenuate abrupt changes by excluding days with insufficient valid pixels. As a result, the inferred timing and fidelity of disruption and recovery signals are directly shaped by how τ filters the observation record. Rather than a fixed parameter, τ defines a trade-off between observational support and temporal continuity, and must therefore be evaluated across a range of values rather than selected a priori.

Crucially, thresholding does not recover missing observations but constrains the conditions under which aggregation is considered valid. The resulting time series is therefore a filtered representation of the underlying signal, where both retained observations and excluded periods reflect the structure of sampling. In this sense, τ acts as a reliability control, determining which portions of the record can be interpreted with sufficient observational support. This establishes the basis for subsequent analysis: any comparison with external data must be interpreted relative to the observational filtering applied, rather than assuming a uniformly observed signal.

3.3 Alignment with Grid Load and Portability

Building on this reliability-controlled signal, alignment with NGCP load is used to evaluate whether NTL preserves meaningful electricity-related dynamics under intermittent observation, across GHSL-based spatial masks and valid-pixel thresholds. As shown in Fig. 6, the agreement between NTL and load is strongly dependent on spatial aggregation. Urban-focused masks (G1–G3) exhibit clear co-movement with NGCP load, particularly during major disruption and recovery periods. The Haiyan-induced collapse is sharply captured, with DNB-BRDF radiance declining synchronously with the load drop and recovering along a similar trajectory. In contrast, broader masks (G4–G8) show visibly noisier behaviour, with fluctuations that are not reflected in the load series, indicating reduced signal coherence.

This contrast reflects the spatial concentration of stable illumination. Urban cores provide consistent, high-intensity signals that scale with electricity consumption, whereas mixed and rural landscapes introduce low-signal and intermittently lit pixels that dilute the aggregate. As a result, expanding the spatial domain beyond dense settlements systematically reduces alignment strength. These patterns are quantified in Fig. 7, where Pearson’s r is mapped across mask–threshold

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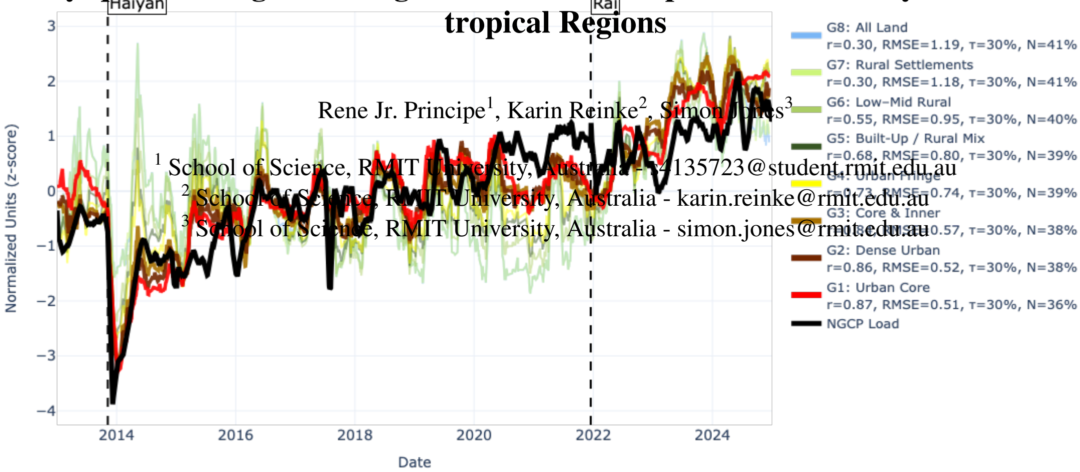

Figure 6. Standardised DNB-BRDF radiance and NGCP load across GHSL-based spatial masks. Multiple mask-based time series are shown alongside the load reference, with event markers indicating major disruptions.

combinations. Strong alignment ($r \approx 0.8$–0.86) is concentrated in urban-dominant masks (G1–G3), particularly under low to mid-range thresholds ($\tau \approx 10$–30). In contrast, broader masks show weaker and less stable correlations ($r < 0.6$), with limited sensitivity to threshold variation. This indicates that including peri-urban and rural areas introduces variability that is not mitigated by stricter observational filtering.

The structure of the heatmap further reveals important edge behaviour. At very low thresholds ($\tau = 10$), alignment is maximised for urban masks due to increased temporal coverage, but this comes at the cost of incorporating partially observed scenes. As τ increases, correlation declines gradually, reflecting the loss of temporal continuity. At higher thresholds ($\tau \geq 60$), alignment deteriorates sharply across all masks, as the retained time series becomes increasingly fragmented and insufficient to capture system-level dynamics. This defines a practical upper bound on τ, beyond which reliability gains are offset by loss of usable signal.

The trade-off between signal fidelity and temporal coverage is further reflected in Table 1. The best-performing configurations (highest composite score S as per Eq. 1) consistently occur under low to mid-range thresholds and for urban-focused masks, with correlations reaching up to $r = 0.86$ (Bohol, G1, $\tau = 20$) and $r = 0.84$ (Samar–Leyte and Panay, G2, $\tau = 10$–20).

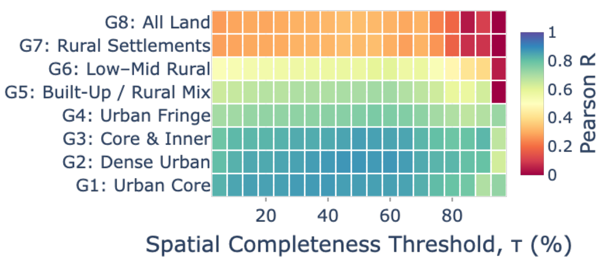

Figure 7. Pearson correlation (r) between aggregated DNB-BRDF radiance and NGCP load across GHSL-based masks (rows) and valid-pixel thresholds τ (columns). Each cell represents the alignment strength for a given mask–threshold combination.

These configurations retain between ∼30–50% of days, indicating that strong alignment is achieved without requiring near-complete temporal coverage. In contrast, stricter thresholds reduce retained observations substantially (e.g., $N \approx 20\%$ in Cebu at $\tau = 60$), limiting their ability to represent continuous system dynamics despite improved observational support. Across sub-grids, no single threshold is universally optimal. Cebu achieves peak performance under stricter thresholds, consistent with more stable observational conditions in its urban core, while Bohol and Negros favour lower thresholds to maintain sufficient temporal coverage under more frequent cloud-induced gaps. Despite this variation, the broader pattern remains consistent: alignment is maximised when both spatial and observational filtering are jointly constrained.

Table 1. Top-performing GHSL masks and valid-pixel thresholds for NTL–NGCP alignment across Visayas sub-grids.

Area	Mask	Threshold	r	RMSE	N (%)
Samar–Leyte	G2 (23–30)	10	0.84	0.57	49.81
Bohol	G1 (30)	20	0.86	0.54	28.71
Cebu	G1 (30)	60	0.78	0.67	21.38
Negros	G1 (30)	10	0.78	0.66	38.69
Panay	G2 (23–30)	20	0.84	0.56	37.30

3.4 Limitations and Implications for Use

Despite the strong alignment observed under reliability-qualified conditions, several limitations must be acknowledged. First, data availability remains fundamentally constrained. Across the study period, only ∼30–50% of days contain valid DNB-BRDF observations, meaning that a substantial portion of the temporal signal is either missing or reconstructed. At face value, this may suggest that daily NTL is too incomplete for reliable analysis. However, the results demonstrate that this is not a dead end: meaningful dynamics can still be recovered when observability is explicitly characterised. Rather than assuming a continuous signal, analysis must be restricted to spatial and temporal regimes where observational support is sufficient, allowing the retained observations to be interpreted with defined conditions of reliability.

Second, the utility of NTL must be understood in the context of limited ground-based alternatives. In archipelagic and hazard-prone regions such as the Philippines, direct assessment

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of power disruption and recovery is often sparse, delayed, or unavailable due to fragmented infrastructure and logistical constraints. In this setting, even a partially observed satellite signal provides valuable system-level context. While the development of operational recovery metrics is beyond the scope of this study, the results indicate that observability-aware indicators can be developed to translate these constrained signals into usable information for monitoring and assessment.

Third, these findings highlight a critical limitation of existing global studies that treat NTL as a uniformly observed signal. Observational constraints are strongly shaped by cloud regimes, which vary systematically with geography and climate. The Philippine case serves as a stress-test environment where these limitations are amplified, but the underlying issue is not region-specific. Any global application of NTL for power outage or recovery analysis must therefore incorporate observability diagnostics as a core component. Extending this framework is feasible using globally available NTL products, but validation remains limited by the availability and consistency of ground-based load data, which are often difficult to obtain and not standardised across regions.

Finally, the preprocessing choices adopted here, including the use of a 30-day moving average, are conditioned by the observed gap structure. Extended dropout periods necessitate temporal smoothing to recover interpretable trends, but this introduces a trade-off between noise reduction and temporal fidelity. The appropriate parameterisation is therefore context-dependent, and should be informed by local dropout statistics rather than applied uniformly.

Taken together, these limitations do not diminish the value of NTL, but redefine the conditions under which it can be meaningfully interpreted. NTL should be treated as an intermittently observed signal whose utility depends on explicit characterisation of observational support and appropriate spatial and temporal filtering. Under these conditions, it can still reproduce broad patterns of disruption and recovery, providing a valuable proxy in data-sparse environments. This reinforces the central premise of this study: that observability must be explicitly characterised and controlled before NTL can be interpreted as a proxy for underlying system dynamics.

4. Summary and Conclusions

This study demonstrates that daily VIIRS nighttime lights can capture electricity disruption and recovery dynamics in cloud-prone tropical regions, but only within explicitly defined conditions of observational reliability. The central contribution is therefore not simply the observed alignment with grid load, but the formalisation of a framework that determines when such alignment is valid. By treating observability as a first-order constraint, the analysis moves from assuming data continuity to explicitly qualifying the limits of interpretation.

Across pixel, settlement, and regional scales, the results show that the NTL record in Samar–Leyte is inherently intermittent, with temporally clustered gaps, spatial heterogeneity, and strong seasonal structure. These constraints directly shape the observed radiance signal, influencing the visibility, timing, and magnitude of disruption and recovery patterns. The introduction of valid-pixel thresholding (τ) and settlement-based masking provides a systematic means of controlling these effects, demonstrating that the most interpretable signals emerge only when analysis is restricted to well-observed and consistently illuminated domains.

Within these constrained regimes, NTL is able to reproduce major system-level dynamics. The Haiyan-induced collapse and subsequent recovery are clearly reflected in the reliability-qualified signal, with strongest agreement observed in dense urban masks and under low to mid-range thresholds. This confirms that, despite substantial data loss, the retained observations can preserve meaningful temporal structure when both observational support and spatial signal quality are jointly enforced.

At the same time, the results emphasise that this capability is conditional. Alignment deteriorates outside these regimes, particularly when spatial aggregation includes low-signal areas or when thresholding either admits insufficiently observed scenes or overly fragments the time series. NTL should therefore not be interpreted as a uniformly reliable proxy, but as a conditionally valid signal whose interpretability depends on explicitly defined filtering and aggregation choices.

These findings have broader implications for the use of NTL in disaster and resilience research. Methods developed in temperate regions, where cloud-induced missingness is less persistent, are not directly transferable to tropical environments. In such settings, the periods of greatest analytical interest often coincide with the lowest observational availability, creating a structural mismatch between data and application. Without explicit treatment of observability, this can lead to misinterpretation of both the severity and timing of disruption.

By introducing a diagnostic-first framework, this study provides a reproducible approach to navigating these constraints using globally available datasets. The integration of completeness metrics, radiance stability analysis, threshold sweeping, and settlement stratification enables the identification of locally valid signal regimes and supports transparent evaluation against independent reference data. While validation remains limited by the availability of consistent load data, the approach itself is transferable and can be extended to other regions with similar observational challenges.

Overall, the results argue for a shift in how NTL is used in practice. Rather than treating the data as continuous and complete, the observation process must be explicitly interrogated and reported. Observability is not ancillary context; it defines the conditions of trust. When these conditions are met, NTL provides a valuable, scalable, and low-cost proxy for monitoring disruption and recovery in data-sparse environments. When they are not, the limitations must be acknowledged to avoid overinterpretation. This reframing establishes a more robust and defensible basis for the use of NTL in disaster monitoring and resilience assessment.

Acknowledgment

The authors acknowledge the support and resources provided by the Department of Mathematical and Geospatial Science, RMIT University, Melbourne, Australia. This research was supported by an RMIT Research Stipend Scholarship and an RMIT International Tuition Fee Scholarship.

Reliability-qualified Nighttime Lights for Disaster Impact and Recovery in cloud-impacted tropical Regions

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