

Reply on CC1

Specific Comments

Comment 1:

The detection efficiency of WWLLN is spatially non-uniform, and is relatively low in regions with sparse station coverage (e.g., the Tibetan Plateau, Xinjiang, and Mongolia). Although the authors mention in Section 2.3 that the mean location accuracy of WWLLN is approximately 10 km, the following issues are insufficiently discussed: How does the intrinsic location error of WWLLN propagate into the final correction results? Does it significantly affect the geolocation accuracy assessment (approximately 15 km)? The manuscript notes that sparse lightning occurrence in Xinjiang and Mongolia leads to fitting difficulties, but makes no attempt to disentangle the two. Given that this distinction has direct implications for the reliability of the correction in these regions, a brief discussion would be warranted.

Response:

Thanks the reviewer for raising this important issue.

1. Propagation of WWLLN location error into the correction results

The intrinsic location uncertainty of WWLLN (about 10 km) is largely random in nature. Our fitting procedure aggregates many matched LMI–WWLLN event pairs within each subregion and 10-minute time bin, and calculates the mean deviation over these samples. The random errors from WWLLN tend to cancel out during this averaging process. Consequently, the fitted correction curves primarily reflect the systematic biases of LMI rather than the random noise of WWLLN. After correction, 74.8% of events fall within 20 km, and most residual errors are around 15 km, which is comparable to WWLLN’s own uncertainty. This indicates that further improvement would require higher-quality reference data (e.g., regional networks). This point will be clarified in the revised manuscript.

2. Distinguishing WWLLN limitations from sparse lightning occurrence

In regions such as Xinjiang and Mongolia, both WWLLN detection efficiency and natural lightning occurrence are low. It is difficult to quantitatively separate the two factors. Instead, we adopt a practical criterion: where the number of matched LMI – WWLLN events is insufficient for robust curve fitting (e.g., below a minimum threshold), we do not apply the empirical correction. In such data-sparse regions, we retain the original physics-based corrections and flag the data accordingly. Thus, regardless of whether the low match count is due to WWLLN inefficiency or true lightning scarcity, the outcome is the same – no empirical correction is applied. A brief discussion of this rationale will be added in the revised manuscript (Section 4), and users will be advised to exercise caution when using data from these regions.

We thank the reviewer again for the careful reading and constructive comments.

Comment 2:

A temporal threshold of 3 seconds is selected for matching LMI events with WWLLN flashes. Since individual lightning flashes typically occur within a fraction of a second, a 3-second window is physically quite broad. Please clarify the rationale for this choice. Specifically, is this intended to account for clock synchronization uncertainties between the satellite platform and the ground-based network, or to capture a statistically sufficient number of regional events?

Response:

Thanks the reviewer for this question. The selection of the 3 s temporal window serves both purposes, but the primary driver is to obtain a statistically sufficient number of matched events.

First, clock synchronization uncertainties between the FY-4A satellite and WWLLN stations can introduce timing errors on the order of a second. A 3 s window provides a safe margin to account for such asynchrony.

Second, and more importantly, both LMI and WWLLN have relatively low detection efficiencies. Using a very narrow temporal window (e.g., <1 s) would result in an insufficient number of matched events for robust curve fitting, especially in regions with moderate lightning activity. As shown in our sensitivity analysis (Fig. 2a), the number of matched events increases rapidly up to ~3 s and then plateaus, indicating that a 3 s window captures most true coincidences without adding excessive false matches. This marginal effect principle has been used in previous studies (e.g., Thompson et al., 2014; Zhu, 2018).

This study does not pursue a strict one-to-one match between individual strokes. Instead, the matching strategy aims to align the overall spatial “footprint” of LMI events and WWLLN flashes. The 3 s window is a practical compromise that balances physical plausibility and statistical robustness, especially given the low detection efficiencies of both systems.

This rationale will be clarified in the revised manuscript (Section 3.1).

References mentioned in this response:

- Thompson, K. B., et al. (2014). A comparison of two ground-based lightning detection networks against the Lightning Imaging Sensor (LIS). *Journal of Atmospheric and Oceanic Technology*, 31(10), 2191–2205. DOI: <https://doi.org/10.1175/JTECH-D-13-00186.1>
- Zhu, J. (2018). Comparison of the satellite-based Lightning Imaging Sensor (LIS) against the

ground-based national lightning monitoring network. *Progress in Geophysics*, 33(2), 541–546. DOI: 10.6038/pg2018AA0631

Comment 3:

The smoothing parameter λ in Equation (1) is a key parameter controlling the trade-off between data fidelity and curve smoothness (line 175). However, the manuscript does not specify the value of λ or the rationale behind its selection (e.g., cross-validation, the L-curve method). Nor does it discuss the sensitivity of the correction results across different subregions to the choice of λ . It is also unclear whether a single uniform value of λ is applied to all 400 subregions or whether it is determined adaptively for each subregion. The authors should either justify this choice in the text or present a sensitivity test in a supplementary appendix.

Response:

Thanks the reviewer for pointing out this omission. In the experiment, a fixed smoothing parameter λ was used, corresponding to a smoothing parameter of 0.5 in the 'SmoothingSpline' method of MATLAB's fit function. λ ranges from 0 to 1, where 0 gives a completely smooth (over-fitted) curve and 1 forces the curve to pass through all data points (no smoothing). $\lambda = 0.5$ provides the best balance between removing high-frequency noise and preserving the diurnal trend of the deviation signal. For consistency and to avoid overfitting, the same λ value was applied uniformly to all 400 subregions. Furthermore, to verify the stability of the fitting and assess sensitivity to λ , we calculated the 95% confidence intervals of the fitted curves for each subregion using bootstrap resampling (500 replicates). The results show that at $\lambda = 0.5$, the confidence bands are narrow (typically <2 km in most regions), and the fitted curves are not highly sensitive to λ variations within the range of 0.4–0.6.

The above explanation and sensitivity test results will be incorporated into the equation description in Section 3.2 and the result discussion in Section 4 of the revised manuscript.

Comment 4:

The assessment of correction performance (Figures 6 and 7) relies exclusively on WWLLN data, which is the same reference used to construct the correction curves. This is, in effect, a circular validation, as the same reference data are used both to derive the correction and to assess its accuracy. We strongly recommend including at least one independent dataset for cross-validation, such as BLNET or ADTD. If access to such data is restricted, this limitation should be stated plainly, along with a candid discussion of how it affects confidence in the reported results.

Response:

We thank the reviewer for this constructive suggestion. We will add a case study in the revised manuscript. The specific content is as follows:

We selected a severe convective weather system that occurred over Beijing from 4 to 5 August 2019. Figure 2 presents a comparison of LMI event locations before and after correction, along with BLNET flashes, WWLLN flashes, and radar composite reflectivity. The time period from 18:00 to 20:00 UTC was chosen because the impact of thermal deformation was most significant during this interval. As shown in the figure, after correction, the LMI events align more closely with the areas of strongest radar reflectivity and show better agreement with both BLNET and WWLLN flash locations, indicating a notable improvement in correction performance. It should be noted that due to differences in detection principles, the detection efficiencies of LMI and WWLLN are relatively low. Consequently, the number of LMI events and WWLLN flashes displayed in the figure is significantly lower than that of BLNET flashes, which has a much higher detection efficiency. Another important point to note is that in Fig. 2b, some WWLLN flashes appear outside the strongest radar reflectivity cores. This is because WWLLN flash locations more promptly reflect the regions of most intense convective activity, whereas the radar reflectivity product has a lower temporal resolution (approximately 5 minutes). In the figure, all lightning strokes occurring between two consecutive radar frames are overlaid on the preceding radar frame, which can create an apparent “misalignment” effect.

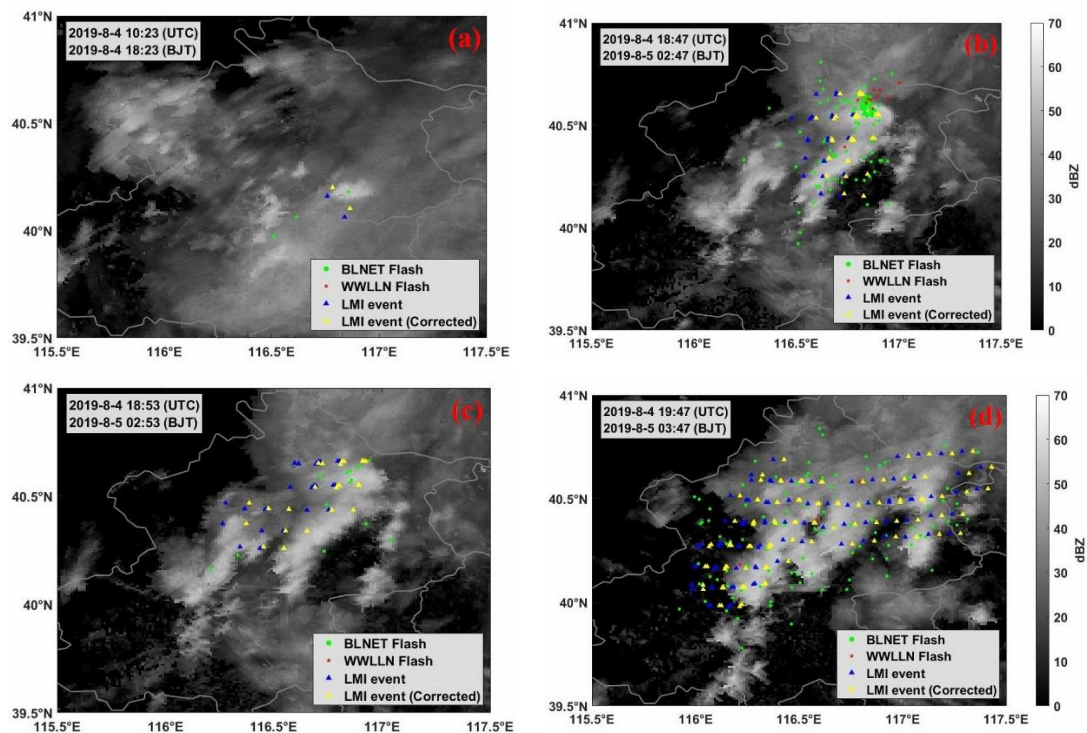


Figure 2: Comparison of LMI correction results before and after with BLNET and WWLLN flash. The red dots represent the matched WWLLN flash data, the green dots indicate the matched BLNET flash data, the yellow dots show the LMI events data after correction, and

the blue dots show the LMI events data before correction. The background indicates radar composite reflectivity.

In addition to the visual comparison, we also conducted a quantitative evaluation of the LMI geolocation for this severe convective system using BLNET as an independent reference. Figure 3 shows the distributions of coordinate deviations between LMI events (before and after correction) and the matched BLNET flashes, based on 20,710 matched pairs. Overall, before correction, LMI events exhibited a systematic southwestward deviation relative to BLNET flashes, WLLN flashes, and the high-radar-reflectivity cores. After correction, the LMI events align more closely with the ground-based lightning location results and generally cover the high-radar-reflectivity areas. Specifically, the median distance error decreases from 20.11 km to 17.63 km, and the longitude error shows a notable improvement, with the median decreasing from 0.1449° to 0.1022° . The overall correction performance is satisfactory, demonstrating that the WLLN-based empirical spline-fitting method effectively reduces systematic geolocation biases in LMI observations, as further validated by independent BLNET and radar data.

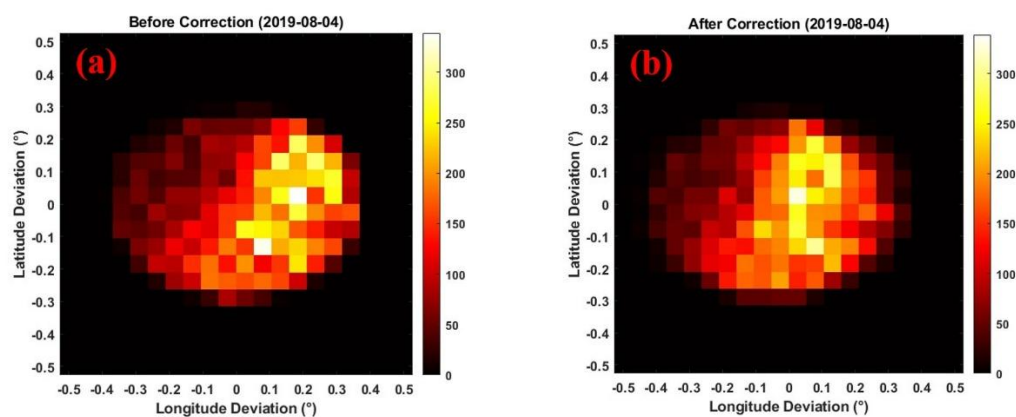


Figure 3: Distributions of coordinate differences between LMI events and BLNET flashes before and after correction.

Comment 5:

The manuscript mentions that additional constraints are applied to downweight time intervals with extremely small standard deviations (lines 191–194) in order to prevent unrealistically large weights. However, neither the specific form of these constraints nor the threshold values are provided. This information is essential for reproducibility and should be included in the main text or in an appendix.

Response:

Thanks the reviewer for raising this reproducibility concern. The specific constraints and thresholds applied to downweight time intervals with extremely small standard deviations are detailed below.

1. Automatic screening (standard deviation threshold)

For each 10-minute interval, if the standard deviation $\sigma_k < 0.02$ or σ_k is NaN, the raw weight ϖ_k^{raw} is set to NaN (i.e., excluded from the fitting). The threshold of 0.02° is chosen because, given the intrinsic uncertainties of LMI and WWLLN, a standard deviation smaller than this is physically implausible and typically results from a very small sample size (e.g., only one matched event).

2. Manual inspection (outlier identification)

After initial fitting for all subregions, the time series of deviations for each subregion are visually inspected. As shown in the example (subregion [1,16]), an obvious outlier appears around UTC 5:00. Statistics reveal that only one matched LMI – WWLLN event exists in this subregion for that specific time bin over the five-year period (2019–2023), leading to an extremely small standard deviation. If left untreated, this outlier would receive a disproportionately large weight and severely distort the fitted curve. Therefore, we manually identify all such obvious outliers across all subregions and set their weights to NaN. All manually flagged intervals are documented in the code annotations (see Appendix).

3. Final weight

After the above automatic and manual steps, the raw weights of the remaining valid intervals are normalized to the range [0.1, 1.0] to obtain the final weight $\tilde{\varpi}_k$. These details will be added to Section 3.2 of the revised manuscript.

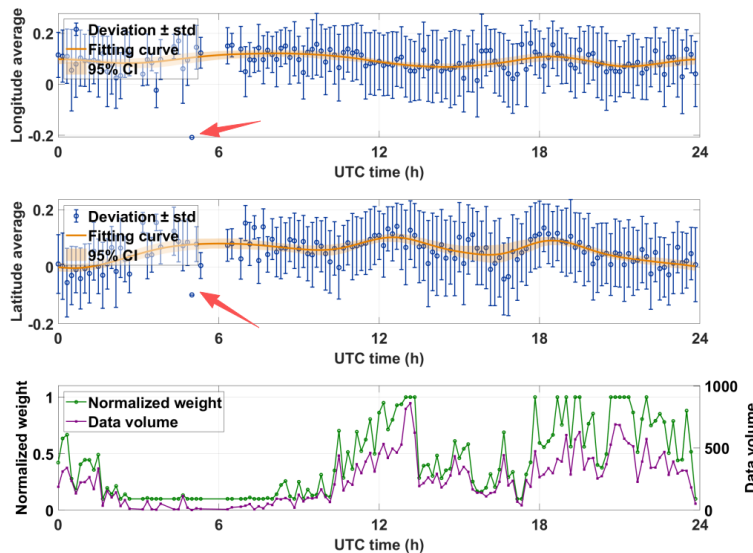


Figure 4 An outlier case in the fitting of subregion [1, 16].

Comment 6:

The color scale in Figure 5 is set to $[-0.3, 0.3]$, with values exceeding the range annotated as

“0.3<” and “-0.3>”. However, no information is provided regarding the proportion of pixels falling outside this range or their geographic distribution. It would be helpful to report this in the caption or the main text.

Response:

We thank the reviewer for pointing out the insufficient description of the color scale in Fig. 5. In the revised manuscript, we will add the following clarification:

Deviations exceeding the $[-0.3^\circ, 0.3^\circ]$ range occur mainly in a few northwestern subregions of the LMI field of view. These subregions inherently exhibit large deviations due to the viewing geometry (large observation angles). In addition, the launch-induced meridional offset of the left-half CCD array further amplifies the deviation in the northwest, making it far larger than in other areas. If the color scale were stretched to the actual maximum, the spatiotemporal variations in the rest of the domain would become barely visible. Therefore, we cap the displayed range at $\pm 0.3^\circ$, with values above 0.3° shown as “0.3<” and values below -0.3° as “-0.3>”. For symmetry, the latitude range is set to the same limits. This explanation will be added in the caption or the main text of Fig. 5. We appreciate the reviewer’s careful reading.

Technical Corrections

Comment 1:

Line 56: The citation “(Peterson and Mach et al. (2022))” contains a formatting error and should be corrected.

Response:

The citation in line 56 has been corrected to the proper format, for example ‘Peterson et al. (2022)’. All references have been reviewed and similar formatting issues have been corrected throughout the manuscript.

Comment 2:

Line 120: The section number “2.3” should be “2.2”.

Response:

The section number has been corrected from 2.3 to 2.2.

Comment 3:

There are two typographical issues worth noting: a spurious colon at the end of line 200, and a Chinese period (“。”) at the end of line 235. Both should be removed. Please also verify whether the captions of Figures 1, 3, and 7 require a terminal period “.” in accordance with journal style.

Response:

Thanks to the reviewer for the careful check. The spurious colon at line 200 and the Chinese period at line 235 have been removed. Periods have been added to the captions of Figures 1, 3, and 7, and other similar issues have been corrected throughout the manuscript.”

Comment 4:

The abstract runs longer than necessary. Tightening the abstract to focus on three elements — the principle of the correction method, the quantified improvement in accuracy, and the key value of the dataset — would improve its impact.

Response (English):

We thank the reviewer for the very pertinent comment. We have shortened the abstract and concentrated it on three main aspects: the scientific problem and methodology, the quantitative improvement in model accuracy, and the value of the dataset. The revised abstract is as follows:

The Lightning Mapping Imager (LMI) aboard FY-4A has accumulated substantial observational data. To address remaining systematic geolocation deviations, we propose a correction method using WWLLN as a reference. The LMI field of view is divided into 400 subregions (20×20 grid). Within each subregion, sensitivity experiments match LMI events with ground-based lightning to quantify systematic deviations, followed by a weighted curve-fitting approach to derive subregional correction curves. The fitted curves are applied to the original Level-2 products to construct a refined correction dataset. Based on over nine million matched LMI–WWLLN pairs (2019–2023), after correction the proportion of events with deviation ≤ 15 km increases from 36.0% to 51.7%, and ≤ 20 km increases from 58.2% to 74.8%. Independent validation using the high-precision BLNET for a Beijing severe convective case on 4 August 2019 shows that the median distance error decreases from 20.11 km to 17.63 km. The coordinate deviations converge substantially, indicating improved geolocation performance. Across most of the LMI field of view, the average error is approximately 15 km (about 1.5 pixels), except in lightning-sparse regions (e.g., Xinjiang, Mongolia) where robust fitting is not feasible. This corrected dataset provides a reliable, long-term, and consistently formatted lightning product, which is expected to significantly enhance the applicability of LMI observations in convective monitoring, model evaluation, and climate studies.

Comment 5:

The Conclusion (Section 6) repeats much of what is already in the abstract. Rather than recapping the methodology, the authors could use this space to look ahead. For instance, a brief discussion of how this dataset might support AI-based lightning analysis or serve as a benchmark for numerical model evaluation would connect naturally with the remarks in the

Introduction (lines 97–98).

Response:

The reviewer's comment is very pertinent. We agree and will rewrite the Conclusions section to avoid repetition with the abstract. Instead of recapping the methodology, here is the revised conclusion:

Spaceborne lightning observations are inevitably affected by solar radiation, satellite platform jitter, and systematic offsets of the detector array, which together introduce periodic and random geolocation deviations. To address these issues for the FY-4A LMI, this study develops an empirical correction framework based on a robust spline-fitting model using WWLLN as a reference for lightning-dense regions. The method quantifies the spatiotemporal patterns of residual deviations and applies fitted correction curves to the original Level-2 products, resulting in a publicly available corrected dataset (<https://doi.org/10.11888/Atmos.tpsc.303312>). Independent validation using the high-precision BLNET over Beijing confirms the effectiveness of the correction. The corrected dataset opens new avenues for advancing lightning research and its applications. It can serve as a benchmark for training artificial intelligence models in lightning nowcasting (e.g., using deep learning to predict convective initiation or lightning jumps) and for identifying lightning-structure relationships from satellite data. The dataset also provides an independent observational constraint for evaluating numerical weather and climate models, particularly the performance of convective parameterizations and lightning parameterization schemes in models such as WRF and GRAPES. Furthermore, it enables long-term climatological analyses of lightning activity over the Northern Hemisphere with improved spatial consistency. Looking forward, the methodology can be extended to FY-4C LMI data, though adjustments will be needed for its different orbital position (133°E) and predominantly oceanic view. Future work will also explore multi-source data fusion, for example combining WWLLN with satellite-borne lightning imagers such as LIS, to further enhance geolocation accuracy, especially over oceans.

Comment 6:

There are multiple instances where a space is missing between a word and a citation bracket (e.g., Lines 34, 37, 43, 48, and 59).

Response:

We thank the reviewer for pointing out these issues. We have corrected the missing spaces at the indicated locations and have carefully checked the entire manuscript. All necessary spaces between words and citation brackets have been inserted where needed. A thorough proofreading has been performed before resubmission.