



Evaluation of the Detection Efficiency of the Meteosat Lightning Imager using Ground-Truth Observations at the Sentech Tower in South Africa

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Abstract—Lightning is a severe atmospheric phenomenon that can cause human casualties, wildfires, infrastructure damages, and aviation disruptions. By timely prediction of lightning occurrences, preventive measures can be advised to counter the adverse effects of lightning. Prediction tasks require high quality data to ensure reliable predictions and avoid false alarms and unnecessary preventive measures. In this work, we analyzed the quality of lightning data collected by EUMETSAT's Meteosat satellite. The assessment is performed by comparing satellite's observations with high-speed camera recordings of lightning activity at the Sentech tower in Johannesburg, South Africa. The tower is chosen because its exact position is known, facilitating accurate matching between the satellite data and ground-based observations. We evaluated the detection efficiency to be 24% for all types of lightning processes, 38% for downward processes, and 12% for upward processes. These values are lower than expected when comparing to the values obtained for Europe (Switzerland and Austria). The reduced performance is attributed to the Sentech tower's position on the edge of the sensor's field of view, resulting in lower quality data and lower detection efficiency.

Index Terms—EUMETSAT, Meteosat, lightning, Geostationary, Lightning imager

I. INTRODUCTION

Lightning is an atmospheric phenomenon that involves sudden exchange of large amounts of electrical charge between clouds and/or ground. This process releases considerable

energy in the form of electromagnetic waves, visible light, sound, and heat, causing severe damage and even casualties to humans, human-made structures, and infrastructure (e.g., [1]–[6]). To mitigate these adverse effects, preventive measures can be implemented. However, to be both effective and not-disruptive, such measures should be deployed well in advance. Therefore, a reliable predictive model is required to address the inherent uncertainty associated with atmospheric phenomena, particularly lightning discharges (e.g., [7]–[12]). Developing such predictive models requires high-quality, dependable data to ensure accurate forecasts [13]. In this work, we investigate these critical aspects of the system, namely data quality and reliability. Lightning data collection methods can be classified into two categories: 1- ground-based measurements, and 2- satellite-based observations. In the ground-based approach, one or a network of sensors are used to detect and locate lightning events. In the satellite-based approach, momentary optical changes in the sensor's field of view are interpreted, after proper filtering, as lightning events. In this work, we use conventional and well established data from ground-based systems as the reference (ground truth) to evaluate the performance of satellite-based detection systems.

In our previous work, [14], we used data provided by European Cooperation for Lightning Detection (EUCLID)

as reference to evaluate the relative detection efficiency of Meteosat's Third Generation Lightning Imager (MTG-LI). For the period of July 2024 to January 2025, we estimated relative detection efficiencies of 70% and 68% for flashes to the Säntis and Geisberg towers, respectively. During the same period, we obtained relative detection efficiencies of 53% and 63% in Switzerland for lightning strokes and flashes, respectively. Comparable results were obtained in Austria, with relative detection efficiencies of 50% for strokes and 62% for flashes.

As indicated in [14], improved satellite lightning imager performance was observed for tower flashes for the Säntis and Geisberg towers (in Switzerland and Austria). Accordingly, in this work, we apply a similar methodology to data from the Sentech Tower (latitude: -26.192478842157, longitude: 28.006780866144823) in Johannesburg, South Africa, to estimate the MTG-LI's detection efficiency in this region. In contrast to [14], where the relative detection efficiency was estimated with respect to EUCLID, the present study uses ground truth data from high-speed camera recordings around the Sentech Tower.

The rest of the paper is organized as follows: In Section II, we first describe the data used in this study in more detail and then elaborate on the algorithm for evaluating the detection efficiency. In Section III, we present the evaluated detection efficiency of the MTG-LI considering the high-speed camera measurements as ground truth, and we report the performance for different event types and scenarios. Finally, in Section IV, we summarize the analysis and present the conclusions.

II. MATERIALS AND METHODS

In this section, we first present the datasets used in this study, namely the high-speed camera recordings of the Sentech Tower and the satellite-based MTG-LI observations. We then describe the matching algorithms and the methodology employed to evaluate the detection efficiency.

A. Data

1) High-speed camera data:

As mentioned above, in this study, the camera lightning data recorded at the Sentech tower in Johannesburg, South Africa is used as the ground truth for evaluating MTG-LI detection efficiency. The Sentech tower is a 237-m tall concrete television tower located in the Brixton suburb of Johannesburg. The tower is instrumented to measure lightning events that strike the tower. The measurement setup provides highly reliable data. In addition, the tower is equipped with high-speed camera continuously monitoring the tower and its vicinity. When lightning occurs, the measurement system detects electromagnetic field changes and triggers the camera to record the event. The camera operate in a pre-trigger mode, allowing data from a predefined interval before the trigger to be stored as well. These recordings are then used to separate and label each lightning process involved in the discharge.

In this work, we analyzed 54 distinct lightning discharges to the Sentech tower that occurred between October 2024 and March 2025. Individual components of these 54 flashes

(e.g., first return strokes, subsequent strokes, ICC pulses) were identified. More precisely, we investigated 211 processes that comprised these 54 flashes.

2) Satellite-based Lightning Location System's data:

The satellite-based lightning location system used in this study is the Lightning Imager on board the Meteosat Third Generation satellite (MTG-LI). The satellite is in Geostationary orbit at a longitude of 3.4°W. The Lightning Imager consists of 4 optical cameras, each with a resolution of 1000×1170 -pixels, observing different regions covering Europe, Africa, and parts of the Middle East and South America with varying resolution (see Fig. 1). Data are recorded with a time resolution of 1 millisecond.

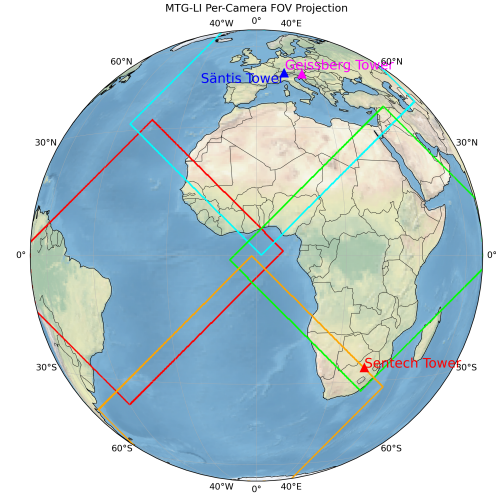


Fig. 1. MTG-LI's per camera field of view over Europe, Africa, and middle east. Also, Sentech (red), Säntis (blue), and Geisberg (magenta) towers.

The MTG-LI processing chain involves several stages. First, each Lightning Imager (LI) camera captures the total radiance for every pixel. In the next stage, transient signals are filtered (Level 1b), retaining only those that exceed a threshold above the system's noise as potential lightning events. Various additional filters are applied at this stage to reduce false positives. The final step, known as false-event rejection (Level 2), involves a secondary filtering algorithm from EUMETSAT to further refine the data and remove any false events. The dataset used in this study consists of Level 2 data.

The LI Level 2 datasets are organized into three hierarchical groups: LI events, LI groups, and LI flashes. LI events refer to transient optical signals that have passed the Level 2 filtering process. LI groups are clusters of neighboring LI events detected within the same time frame (1 millisecond), while LI flashes consist of collections of LI groups. Two groups are considered part of the same flash if they occur within 16.5 kilometers and 330 milliseconds of each other.

Fig. 2 provides an illustration of the pixel grid. In the left panel, the red pixel represents the centroid of a Level 2 event and the green pixels outline the event windows, and potential events that can form a group together with the red pixel. In the middle panel, the red pixels, which correspond to green

pixels in the left panel whose intensity is above a predefined threshold, form an LI group. The right panel shows the spatial and temporal correlation of detected groups that form a flash.

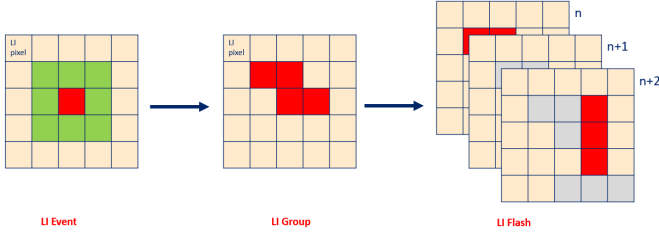


Fig. 2. Events, groups flashes in LI Level 2 dataset [15].

The LI data used in this study cover the mentioned 54 flashes detected at the Sentech tower. The LI data are corrected for Parallax effect and time offset according to EUMETSAT guidelines [14], [16].

B. Methodology

In this section, the steps used for the detection efficiency calculation are explained. This analysis is based on the methodology presented in [14], [17], [18].

1) Detection Efficiency:

The first step is the proper definition of the detection efficiency. For each type of lightning process p , let GT_P denote the set of processes detected by the high-speed camera (ground truth), and let LI_P be the set of processes (groups) detected by MTG-LI. The relative Detection Efficiency (DE) of MTG-LI with respect to the ground truth data is then defined as:

$$DE = \frac{n(LI_P \cap GT_P)}{n(GT_P)} \quad (1)$$

where $n(\bullet)$ denotes the number of distinct elements in the set (Cardinality). In this analysis, we assume that the number of false alarms is negligible and the denominator is only affected by detected processes and missed processes, but not false alarms.

2) Cross Matching:

The next step is to correlate the satellite data and ground truth data to find the matching occurrences of events with different types of processes. The matching procedure is briefly presented as follows. The methodology is thoroughly explained in [14], [17], [18]. It is worth noting that the LI events mentioned in the previous section are only pixels that compose individual groups whose real-world counterpart are lightning processes, e.g., strokes, ICC pulses and leaders. In this study, the LI groups and lightning processes in the ground truth data are matched together.

The matching is performed in both space and time, using spatial and temporal margins of 20 km and 10 ms, respectively. For each process detected by then high-speed camera, the algorithm searches for an MTG-LI group that satisfies both

criteria. These thresholds are adopted from previous studies that combined and matched different lightning datasets [14], [17]–[19]. The pseudocode of the method is presented in Algorithm 1.

Algorithm 1 Matching MTG-LI Groups With Ground-Based processes for DE Computation

Require: Set of MTG-LI groups G ; Set of ground truth processes P ; Temporal window τ ; Spatial threshold δ
Ensure: Number of matched processes M

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1: Sort  $G$  in ascending order of occurrence time
2:  $M \leftarrow 0$ 

3: for all  $p \in P$  do
4:    $t_p \leftarrow \text{time}(p)$ 
    $\triangleright$  Locate time-compatible groups via binary search
5:    $\ell \leftarrow \text{SearchLeft}(G, t_p - \tau)$ 
6:    $r \leftarrow \text{SearchRight}(G, t_p + \tau)$ 
7:   if  $\ell < r$  then
8:     Candidates  $\leftarrow G[\ell : r]$ 
9:     for all  $g \in \text{Candidates}$  do
10:      if  $\text{dist}(g, p) \leq \delta$  then
11:         $M \leftarrow M + 1$ 
12:        break  $\triangleright$  First spatial match is sufficient
13:      end if
14:    end for
15:  end if
16: end for
return  $M$   $\triangleright DE = |M|/|P|$ 

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The number of matched detections is then used to calculate the detection efficiency, as described above.

TABLE I
DETECTION EFFICIENCY OF MTG-LI FOR DOWNWARD LIGHTNING WITH RESPECT TO SENTECH LIGHTNING VIDEO OBSERVATIONS

	Type of process		
	All pulses	1st Return Strokes	Subsequent Strokes
Detected by high-speed camera	99	38	61
Detected by MTG-LI and high-speed camera	38	18	20
Relative Detected Efficiency	38%	47%	33%

III. RESULTS

By considering the high-speed camera data as ground truth, the detection efficiency of MTG-LI is obtained using Algorithm 1. The results are presented in Table I and Table II for downward and upward lightning, respectively. For each case, we also separately evaluate the detection efficiency to different processes, namely, first and subsequent return strokes

TABLE II
DETECTION EFFICIENCY OF MTG-LI FOR UPWARD LIGHTNING WITH
RESPECT TO SENTECH LIGHTNING VIDEO OBSERVATIONS

	Type of process			
	<i>All pulses</i>	<i>ICC pulses</i>	<i>Upward Leaders</i>	<i>Subsequent Return Strokes</i>
Detected by high-speed camera	107	91	12	4
Detected by MTG-LI and high-speed camera	13	10	3	0
Relative Detected Efficiency	12%	11%	25%	0%

for downward flashes, and the upward leader, ICC pulses, and subsequent return strokes for upward flashes. In the examined period, the MTG-LI detected 51 out of 214 processes, corresponding to an overall detection efficiency of 24%. This value is lower compared to the detection efficiency obtained for Switzerland (53%) and Austria (50%) in our previous study [14]. One possible reason becomes clear when examining Fig. 1. This figure shows the field of view of the four distinct cameras on board the MTG. We observe that Switzerland and Austria are located in the center of the cameras' field of view while the Sentechn tower is located near the edge of the field of view of two of the cameras. The sensor's spatial resolution is higher in the center of each field of view and worsens on the way to the edges [15], which can negatively impact the detection efficiency. Furthermore, different levels of glare across the camera lens and off-axis aberrations on the edges may further reduce image quality of the image could be lower, resulting in the lower detection efficiency observed at the Sentechn tower.

Among the ground truth processes, 99 of them correspond to downward processes and MTG-LI detected 38 of them (DE of 38%). A higher detection efficiency is also observed for first return strokes (47%) compared to subsequent return strokes (33%) in downward lightning. This is presumably due to the fact that first return strokes are characterized by higher amplitudes. For upward flashes, the high-speed camera detected 107 processes, of which only 13 were detected by MTG-LI (DE of 12%). This contrasts with our previous observation for Switzerland and Austria, specifically for the S antis and the Gaisberg towers, where the detection efficiency was higher for upward flashes. One possible reason for this discrepancy is again the position of the Sentechn tower on the edge of the camera's field of view, which leads to lower detection efficiency. However, it remains unclear whether, and to what extent, this can affect the detection of upward flashes more than downward flashes.

IV. CONCLUSIONS

In this work, the detection efficiency of the MTG-LI sensor is evaluated by comparing and matching its detections with high-speed camera observations from the Sentechn tower, Jo-

hannesburg, South Africa. The overall detection efficiency of all lightning events is found to be about 24%. When separated by flash type, the detection efficiencies are 38% for downward flashes and 12% for upward flashes. These values are lower than those obtained in our previous work in Switzerland and Austria. This discrepancy is attributable, at least in part, to the location of the Sentechn tower on the edge of the sensor's field of view.

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