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# GLD360: Performance Updates and Flash Climatology

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***Abstract*—While the Geostationary Lightning Mapper (GLM) onboard GOES-East provides robust storm and flash-level detection over much of the western hemisphere, many lightning protection applications still require the higher resolution and additional lightning parameters provided by ground-based lightning locating systems (LLSs). Of these, so-called precision networks, with sensor baselines less than approximately 250 km, provide the highest quality data. However, in more remote regions where it's difficult to maintain the infrastructure for a high-density network, the options for lightning data are restricted to satellite observations, or data from a global-scale LLS.**

**Recognizing the need for higher-quality lightning data in more remote areas, Vaisala has released a series of upgrades to the global LLS called GLD360 over the past several years. These updates have been focused on a variety of performance metrics, including location accuracy, flash and stroke detection efficiency, peak current accuracy, and cloud versus cloud-to-ground (CG) classification. Additionally, there is an ongoing effort to provide a quantitative estimate of ground-flash density, both for asset planning, and to combine with satellite data to provide a global perspective on cloud to CG flash ratios.**

**In this paper, we present the latest improvements to these GLD360 performance metrics, drawing from comparisons from local precision networks and GLM data. Additionally, we report on 5-year global and regional flash density observations. The high yield and 5+ historical data collection provide a unique dataset for large-scale lightning density observations.**

**Keywords—Lightning locating systems; global lightning detection; lightning climatology**

## I. INTRODUCTION

The GLD360 dataset is generated by a global total lightning locating system (LLS). The network geolocates lightning events using both Time of Arrival (TOA) and Magnetic Direction Finding (MDF) using sensors sensitive to the Very Low Frequency (VLF; ~< 50 kHz) range. Maximizing sensitivity in the VLF range enables detection of radio atmospherics (sferics) at distances on the order of 5-10 thousand kilometers, depending on the source amplitude, using the efficient guiding at these frequencies of the Earth-ionosphere waveguide (EIW).

While the EIW enables detection at great distances, it also represents a variable transmission medium, presenting a challenge to reliably measuring a consistent arrival time, and producing a range-normalized signal strength (RNSS) to estimate peak current. The GLD360 network uses an empirical propagation-correction approach for both measurements. The arrival time correction applies a correction term that is specific to the waveform feature detected (ground wave versus subsequent ionospheric hops). The amplitude correction uses a boot-strapping approach, whereby sensor amplitude observations are used to estimate attenuation rates under a variety of propagation conditions, including time of day, geomagnetic latitude, and propagation direction.

While the method to estimate these attenuation profiles is beyond the scope of this paper, Figure 1 shows the result of the propagation correction applied to amplitudes at varying distances. The left panel shows signal amplitudes, normalized by peak current magnitude, over a variety of propagation paths. The right panel shows the resulting normalized signal strengths after propagation correction. The several-dB remaining error is a source of error in the peak current magnitude measurement.

Similar correction schemes are applied to the arrival time estimates to reduce the arrival time uncertainty, improving the location accuracy of the network. In this paper, we provide a brief validation of the peak current magnitude and location accuracy using the U.S. National Lightning Detection Network (NLDN) as a reference, and the flash Detection Efficiency (DE) using GLM flash data as a reference. We then conclude with global and regional flash density plots from raw GLD360 flash observations.

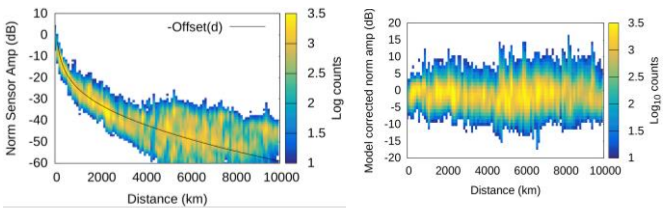


**Figure 1**: (left) Normalized sensor magnitude with distance, with an averaged offset assuming spreading in a spherical earth with an average attenuation of 2 dB / Mm. (right) RNSS versus distance.

## II. Validation Results

We evaluate the peak current magnitude and location error using data from the NLDN as a reference, and provide an upper bound on the flash DE using data from GLM [1]. The NLDN comparison draws from data over the continental U.S. (CONUS) from 2018-Aug-20 – Oct-17th. GLM validation is over the entire field of view of the GLM aboard GOES-East, from 2018-Feb-1 – 2019-Apr 1. The location accuracy and peak current magnitude validation (NLDN and GLD360) draws from matched CG return strokes and cloud pulses, using a matching window of 30 km and 90 microseconds. The relative flash DE measurement (GLM and GLD360) counts a GLM reference flash as “matched” if there is a corresponding GLD360 flash within 200 milliseconds and 20 km of the GLM flash.

Figure 2a shows the peak current magnitude error against NLDN events, with ~20% error for matched CG strokes. The larger disagreement with effective peak current magnitudes in matched IC pulses is likely due to a combination of two factors. First, GLD360 sensors operate in a smaller frequency band compared to the VLF/LF sensors that comprise NLDN. Thus, they truncate part of the observed impulse, affecting the observed magnitude. Second, it’s possible that reflections off the anisotropic plasma in the ionosphere lead to more efficient detection of some horizontal channels compared to a network that only measures the direct ground wave.

Similarly, the location offset with respect to NLDN solutions is larger for IC pulses compared to CG return strokes, as seen in Figure 2b. While the median offset for CG return strokes is < 2 km, the median IC pulse offset is ~3 km. The primary driver for this difference is likely signal-to-noise ratio (SNR) considerations. Since CG return strokes emit stronger radio emissions in the VLF/LF range than IC pulses, the SNR is larger at each sensor, and more sensors contribute to the solution. A secondary consideration is that IC pulses are less regular, making it more difficult to disambiguate the ground wave from subsequent ionospheric reflections.

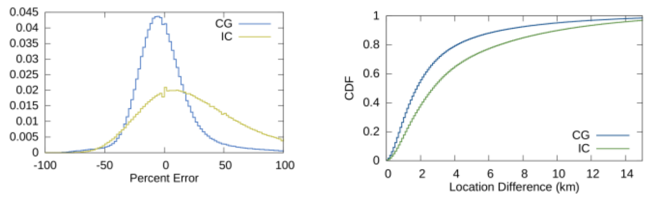


**Figure 2**: (Left) Distribution of percent error in the peak current magnitude estimate. Blue curve shows the peak current magnitude error of matched CG peak current magnitudes; yellow shows the error for IC pulses. (Right) Cumulative Distribution Function (CDF) of location offset from matched NLDN CG return strokes (blue) and IC pulses (green) in the same time range.

While NLDN can provide a valuable reference to estimate the upper bound of the CG flash DE, and provide an incomplete reference for the cloud flash DE, it only evaluates these metrics over CONUS. The GLM instrument on Goes-East provides a much more robust reference for total lightning (TL) DE estimates over the entire field of view (FOV). Figure 3 compares the total flash counts from GLD360 against GLM over the evaluation time, and shows a relative TL DE map using GLM as a reference. As explained in [2], the conditional DE does not translate to a total flash DE, since the reference (GLM) does not represent an absolute reference. Nevertheless, this view provides an estimate of regional variation of GLD360’s DE over the field of view.

Over most of the land masses, the total flash counts reported by GLD360 and GLM are within ~20%, underscoring the fact that GLD360 is indeed a TL network. GLD360 reports over 2x as many flashes as GLM in the northwest quadrant of CONUS, which is at the edge of GLM's FOV. The relative DE is between 40-80% over most of the land masses and adjacent oceanic regions, and between 60-80% over most of the interior of South America. The regions with very low DE around the perimeter of the FOV, and the spatially sharp features in the Atlantic and parts of the eastern Pacific, are likely dominated by false events from GLM due to sunlight intrusion and other artifacts of the instrument. The low DE in the Southern Pacific reflects the lower GLD360 sensor density in that region.

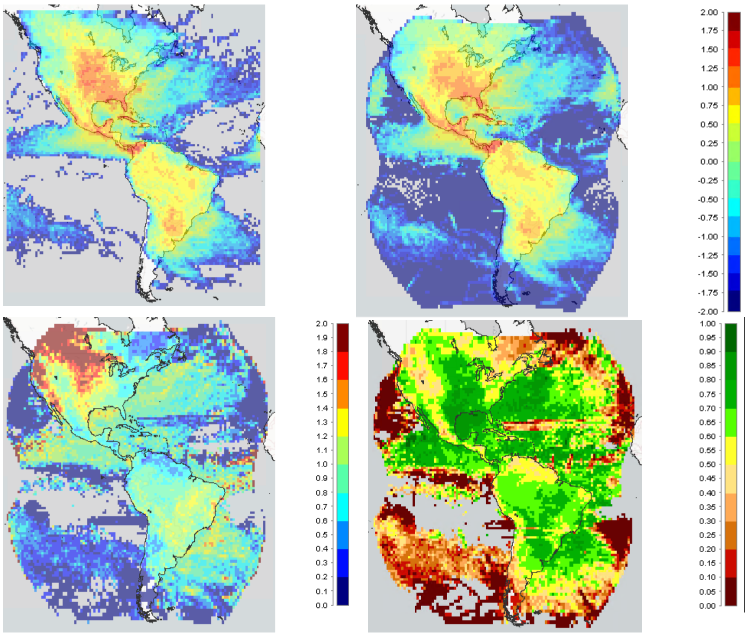


**Figure 3**: (Upper left) GLD360 Flash density, in units fl / km^2. (Upper right) GLM Flash Density, in fl / km^2. (Lower left) Ratio of GLD360 flash counts to GLM flash counts. (Lower right) relative flash DE of GLD360 with GLM as a reference.

## III. GLD360 Flash Climatology

The relative uniformity of the flash DE against GLM data, particularly over the land masses, provides confidence in GLD360's coverage over much of the western hemisphere. Figure 4 expands this view to show GLD360 flash density over most of the globe, using data from 2014-2018 inclusive. This global climatology provides qualitative agreement with previously published global climatologies, including from satellite instruments.

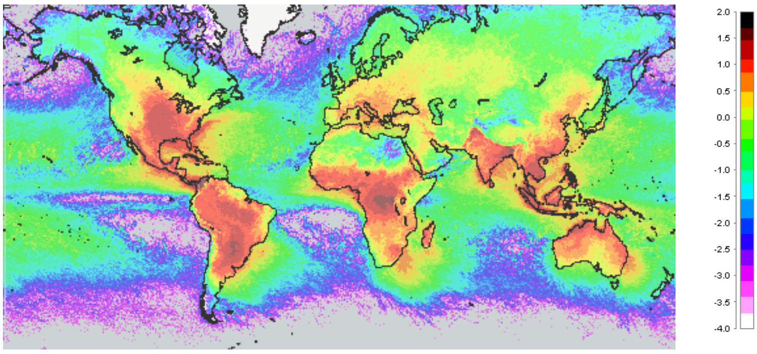

**Figure 4**: Log (base 10) of the raw 5-year (2014-2018 inclusive) GLD360 flash density, without any corrections applied. Resolution of 0.25 degrees (fl / km^2 / year).

Figure 5 zooms into the 5-year flash climatology over South America, and adjusts the color scale to highlight the regional differences throughout the continent.

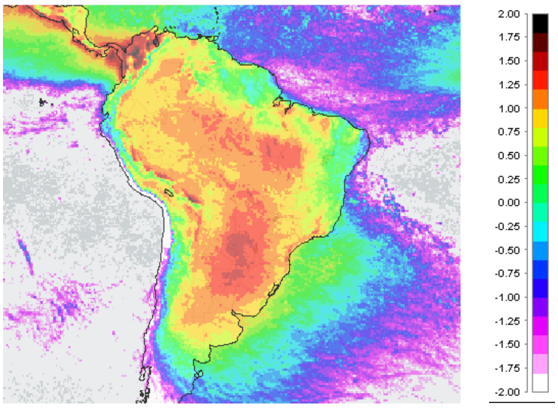

**Figure 5**: : Zoom into South America from the flash density plot in Figure 4, with a different color scale to highlight regional differences in flash density.

Figure 6 shows the peak local time (LT), with a 2-hour resolution, of GLD360 strokes on a 0.25 degree grid over the 5-year time span. Over much of Central America, the Amazon, the western region over South America, and SE Brazil, the peak time for lightning activity is in the late afternoon hours (14-18 LT), resulting from diurnal heating effects. The distribution is skewed to nocturnal lightning over much of the oceanic regions and southern part of the continent. Additionally, there are pockets of nocturnal lightning in regions with abnormal lightning patterns driven by local topology.

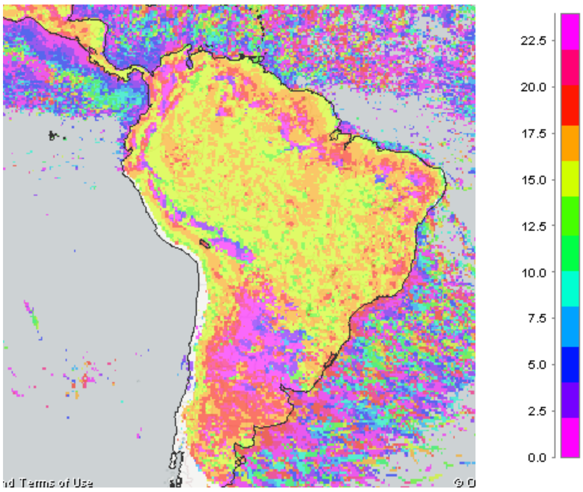

**Figure 6**: Peak local time (LT) of GLD360 strokes over the 5-year period 2014-2018 on a 0.25 degree grid. Grid cells with fewer than 100 events are omitted.

## REFERENCES


[1] Goodman, S.J. et al. (2013), The GOES-R Geostationary Lightning Mapper, Atmos. Res., 125-126, 34-49.

[2] Bitzer, P.M. and J.C. Burchfield (2016), Bayesian techniques to analyze and merge lightning locating system data, Geophys. Res. Lett., 43, doi:10.1002/2016GL0719