EXTREME WEATHER

New WMO Certified Megaflash Lightning Extremes for Flash Distance and Duration Recorded from Space

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Initial global extremes in lightning duration and horizontal distance were established in 2017 (Lang et al. 2016) by an international panel of atmospheric lightning scientists and engineers assembled by the WMO. The subsequent launch of NOAA's latest *GOES-16* and *GOES-17* with their Geostationary Lightning Mappers (GLMs) enabled extreme lightning to be monitored continuously over the Western Hemisphere up to 55° latitude for the first time. As a result, the former lightning extremes were more than doubled in 2019 to 709 km for distance and 16.730 s for duration (Peterson et al. 2020). Continued detection and analysis of lightning "megaflashes" (American Meteorological Society 2021) has now revealed two flashes that even exceed those 2019 records. As part of the ongoing work of the WMO in detection and documentation of global weather extremes (e.g., El Fadli et al. 2013; Merlone et al. 2019), an international WMO evaluation committee was created to critically adjudicate these two GLM megaflash cases as new records for extreme lightning.

Megaflashes do not occur in ordinary thunderstorms. They require expansive electrified clouds that discharge at sufficiently low rates to facilitate single horizontal flashes spanning extraordinary distances. The overhanging anvils and raining stratiform regions in mesoscale convective systems (MCSs) meet these criteria. However, few MCSs produce lightning at extreme scales, and such storms have only been observed in the Great Plains of North America and the La Plata basin in South America (Peterson 2021). This is largely due to the availability of observations although the Lightning Mapping Imager (LMI) on the *Fengyun-4A* satellite can partially observe northeastern India (Fig. 1 from Cao et al. 2021). Future platforms like the Meteosat Third Generation (MTG) Lightning Imager will allow us to observe extreme lightning in more regions across the globe.

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Both hotspot regions were represented in the new extreme lightning candidate flashes submitted to the current WMO evaluation committee. The geographic locations and extents of these flashes (red lines) are mapped in Fig. 1. The longest-duration candidate flash was reported by GLM to have developed continuously over a 17.102 s period along the Argentina–Uruguay border starting at 0648:58.822 UTC 18 June 2020. The longest-distance candidate flash was observed to extend over a 768-km (477-mi) distance between Texas and Mississippi starting at 1432:39.016 UTC 29 April 2020.

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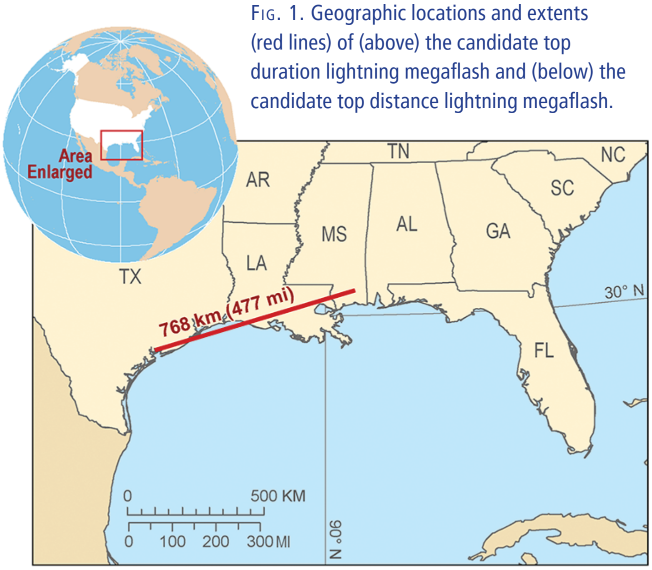

Fig. 1. Geographic locations and extents (red lines) of (above) the candidate top duration lightning megaflash and (below) the candidate top distance lightning megaflash.

GOES-16 measurements of the top duration candidate are displayed in Fig. 2. The horizontal structure of the flash (white line segments) and maximum spatial extent (gold X symbols) are overlaid on top of GLM Flash Extent Density (FED) imagery (color contours) showing spatial variations in flash rate across the storm and Advanced Baseline Imager (ABI) visible–infrared-composite cloud imagery. GLM reported that the megaflash developed laterally throughout the low-flash-rate trailing stratiform region of an MCS. Its measured 17.102-s duration would be more than 1/3 of a second longer than the previous flash duration record.

Similar *GOES-16* observations are shown for the top distance candidate in Fig. 3. This megaflash was produced by an MCS that originated over the Great Plains and moved southward before migrating offshore over the Gulf of Mexico. The megaflash occurred after the storm had moved offshore and it extended throughout the trailing stratiform region stretching along the Gulf Coast between Texas and Mississippi. Its 768-km (477-mi) extent mapped by GLM would be 59 km (37 mi) greater than the previous flash distance record.

These two flashes were analyzed independently by members of the WMO evaluation committee using available coincident data. A slightly longer-duration of 17.2 s was proposed for the top duration case. This difference was determined to be within the expected error for the analyses, and the lower GLM-reported duration of 17.102 s was ultimately selected as the reported value. The top distance case happened to occur completely within the domains of the GLM instruments on both *GOES-16* and *-17*, allowing each GLM to provide an independent measurement of flash size. Even though the *GOES-17* GLM viewed the flash near the edge of its field of view where pixels are larger and triggering thresholds are particularly high, it still reported the same flash extent as the *GOES-16* GLM to within 1 km. As with duration, the slightly smaller distance (768 km from *GOES-17*) was accepted as the reported value.

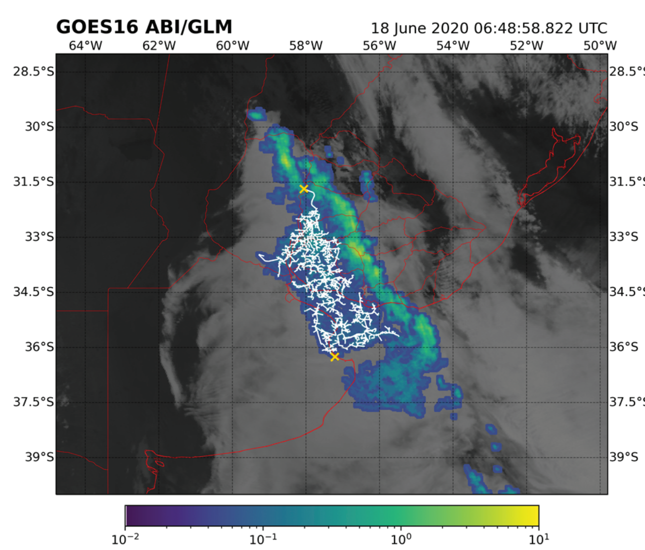

Fig. 2. *GOES-16* GLM Flash Extent Density (color contours) flash rate imagery and ABI composite visible/infrared imagery of the thunderstorm that produced a megaflash that GLM recorded as having a 17.102 s duration. The horizontal structure (white line segments) and maximum extent (gold X symbols) of this megaflash are overlaid.

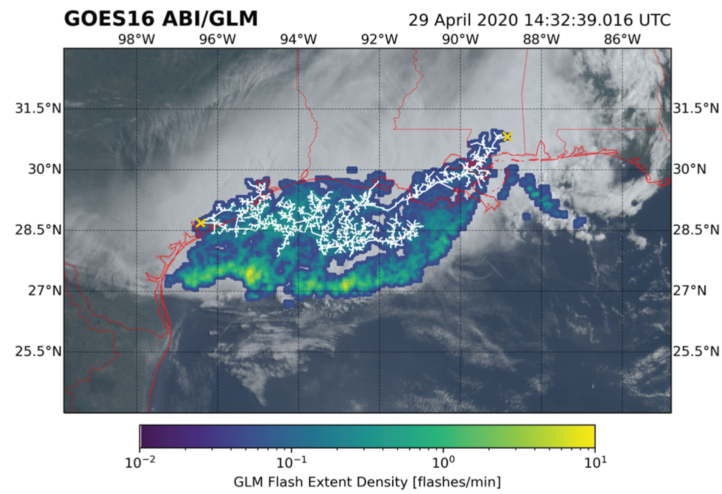

Fig. 3. *GOES-16* imagery as in Fig. 2 showing the candidate top distance megaflash and its parent thunderstorm.

Stratiform clouds become electrified via a combination of charged hydrometeors being advected from the thunderstorm core and in situ processes from collisions between local hydrometeors. In either case, the precipitation structure of the surrounding thunderstorm is an important control on the horizontal development of megaflashes.

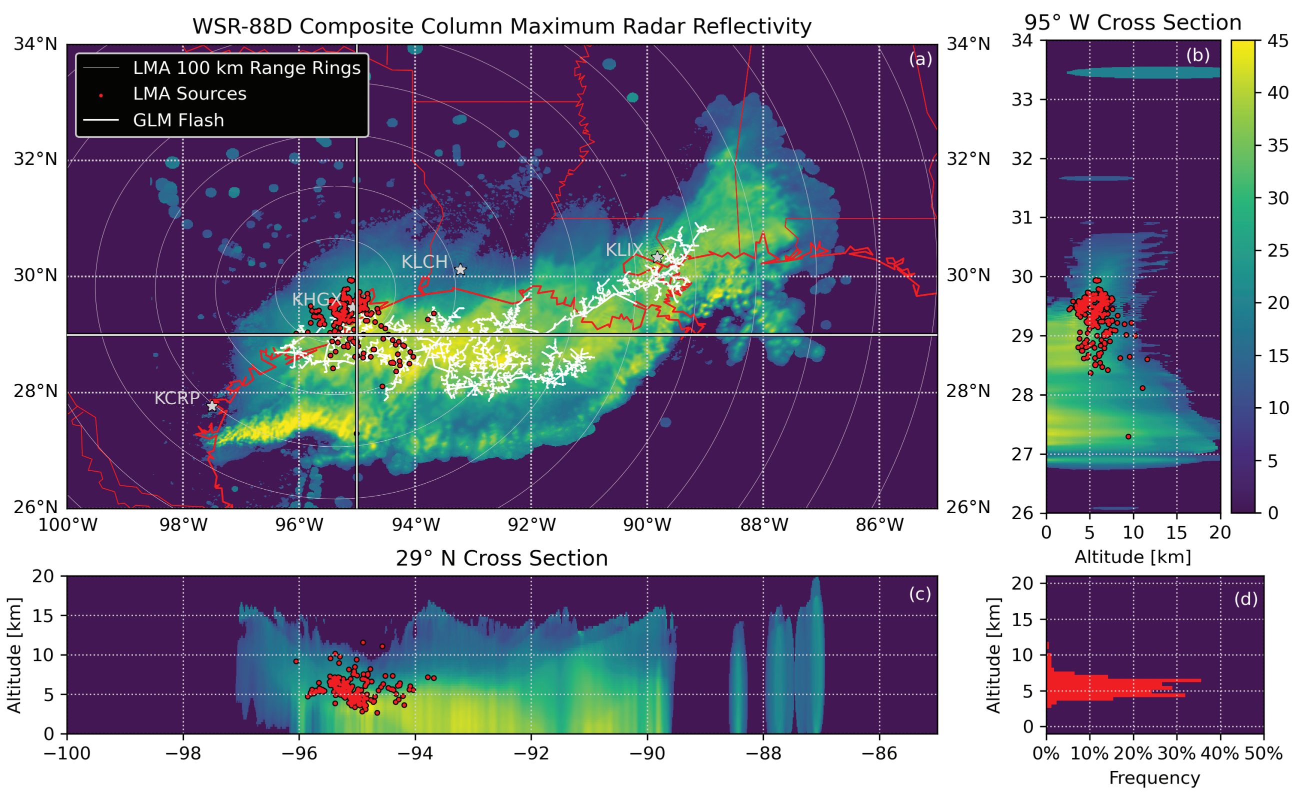

Fig. 4. GLM (white) and HLMA (red) observations of the top distance candidate megaflash overlaid on top of composite NEXRAD radar imagery. (a) Map of flash structure and WSR-88D maximum column reflectivity. (b) Latitude–altitude cross section along the 95°W meridian with all LMA sources overlaid. (c) Longitude–altitude cross section along the 29°N parallel. (d) Histogram of LMA source altitudes.

The 768-km flash was also partially mapped from the ground by a Lightning Mapping Array centered in Houston, Texas (HLMA). Figure 4 overlays the HLMA sources (red dots) and GLM flash structure (white lines) on top of composite WSR-88D imagery constructed using the Py-ART package (Helmus and Collis 2016) and four NEXRAD sites (gray stars). While most of the flash occurred >200 km from the center of the array, and thus was not mapped, the ground-based network partially detected the northward propagation of the flash and characterized its vertical structure (Fig. 4). LMA sources were clustered at relatively low altitudes centered around 6 km MSL, which is commonly observed with MCS stratiform region lightning (e.g., Carey et al. 2005; Lang and Rutledge 2008).

Stratiform clouds become electrified via a combination of charged hydrometeors being advected from the thunderstorm core and in situ processes from collisions between local hydrometeors (Schurr and Rutledge 2000; Stolzenburg et al. 1994). In either case, the precipitation structure of the surrounding thunderstorm is an important control on the horizontal development of megaflashes. Indeed, the shape of the top distance megaflash case bears a striking resemblance to the 30-dBZ WSR-88D maximum echo region behind the convective line in Fig. 4a, with LMA source altitudes clustered along the upper boundary of the enhanced echo region in Figs. 4b,c. What appears to make this flash exceptional—even compared to other megaflashes in the same MCS thunderstorm—is its unique ability to expand laterally throughout a large fraction of the horizontally extensive stratified charge layer at ~6-km altitude.

Another possible charging mechanism which could have amplified the charge layer noted at ~4–6 km is the melting charging mechanism (Stolzenburg and Marshall 2008; Silveira 2016; Drake 1968). Given the reflectivity cross sections (Fig. 4), it is possible that the charge layer is near the melting layer.

These comparisons also demonstrate the advantage that GLM has for documenting extreme flashes that surpass the traditional range of an LMA. However, GLM might not resolve every branch in a given flash. This can happen, for example, when the optical emissions are too dim to trigger GLM. In these cases, merging GLM and LMA data can provide a more complete picture of the horizontal extent of the flash. While LMA sources can be observed beyond the boundaries of the GLM flash in Fig. 4a, we found that none of them would have increased the overall size of the candidate flash.

It should be noted that the sizes reported by GLM are only a minimum estimate for the true extent and duration of these flashes and the actual flashes may exceed these accepted values. Also, as with all WMO evaluations of extremes (temperature, pressure, wind, etc.), the proposed lightning extremes are identified based on only those events with available quality data that are brought to the WMO's attention by the meteorological community. Environmental extremes are living measurements of the capabilities of nature, as well as markers for scientific progress in being able to make such assessments. It is likely that greater extremes still exist, and that we will be able to observe them as more data are collected and lightning detection technology improves.

The committee unanimously recommended acceptance of these two GLM-identified extremes as new global records employing uncertainty estimates as established in previous lightning extremes analyses (Peterson et al. 2020). Consequently, the longest WMO-recognized lightning flash is the single stratiform flash that covered a horizontal distance of 768 ± 8 km (467.2 ± 5 mi) across parts of the southern United States on 29 April 2020. The greatest WMO-recognized duration for a single lightning flash is 17.102 ± 0.002 s from the flash that developed continuously through the stratiform region of a thunderstorm over Uruguay and northern Argentina on 18 June 2020.

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