A New WMO-Certified Single Megaflash Lightning Record Distance: 829 km (515 mi) occurring on 22 October 2017

Michael J. Peterson[1], Rachel Albrecht[2], Sven-Erik Enno[3], Ronald L. Holle[4], Timothy Lang[5], Timothy Logan[6], Walter A. Lyons[7], Joan Montanya[8], Shriram Sharma[9], Yoav Yair[10], Jessica Losego[1], Randall S. Cerveny[11]*

1. Georgia Tech Research Institute, Atlanta, Georgia USA
2. Universidade de São Paulo, Sao Paulo, Brazil
3. EUMETSAT, Darmstadt, Germany
4. Holle Meteorology & Photography, Oro Valley, Arizona USA
5. NASA Marshall Space Flight Center, Huntsville, Alabama USA
6. Texas A&M University, Houston USA
7. FMA Research, Fort Collins, Colorado USA
8. Polytechnic University of Catalonia, Barcelona Spain
9. Tribhuvan University, Kathmandu Nepal
10. Reichman University, Herzliya Israel
11. Arizona State University, Tempe, Arizona USA

*Corresponding Author: cerveny@asu.edu

Capsule Comment: The World Meteorological Organization has recognized a new world record lightning discharge distance of 829 km ± 8 km (515 ± 5 mi) that extended from eastern Texas to near Kansas City MO USA within a 22 October 2017 thunderstorm complex.

Lightning is viewed as a localized hazard to the general public, with safety guidance implying being close enough to the thunderstorm to hear or see lightning (Cooper, 2012). Lightning "megaflashes" (Lyons et al. 2019) challenge this view as single continuous long horizontal flashes that extend for hundreds of kilometers through the clouds, initiating up to hundreds of Cloud-to-Ground (CG) strokes along their paths. Moreover, megaflashes occur in regions of organized storm systems that might seem inactive with 30 minutes or longer passing between flashes (Peterson and Stano 2021). They are also known to produce noteworthy effects – including potentially damaging high peak current CG strokes with continuing current, and dazzling sprites above the cloud-top.

Documenting extreme cases of megaflashes – where nearly the entire electrified stratiform region in storms spanning multiple states is discharged all at once – is important for lightning physics to understand the limits of what lightning in expansive charge reservoirs is capable of, and for lightning safety by revealing the maximum extent of lightning hazards from the most impactful individual flashes on Earth. Each new extreme event identified provides insights into the context, locations, and environments conducive to expansive flashes that are necessary to ultimately answer the question of why certain organized convective systems produce megaflashes while other similar systems produce none. A new record megaflash has been identified that was initiated by the convective line of a thunderstorm over land that was previously analyzed for its large flashes (Lyons et al. 2019) but in a later, more mature, state. Flashes at this extreme scale always existed, and are now becoming identifiable as our detection capabilities and data processing methods improve.

Just as the early investigations of sprites led us to a deeper understanding of the unique characteristics of positive lightning CGs and their complex continuing currents, investigating the megaflash is providing new insights into poorly understood mesoscale electrical charge reservoirs in MCS trailing stratiform regions. Furthermore, it illustrates the threat of the newly recognized “bolt from the gray,” analogous to the “bolt from the blue” from distant cells, but one that can travel many hundreds of kilometers from the main charge generating region.

Beginning in 2017, the World Meteorological Organization (WMO) has evaluated single lightning flash extremes with regard to their geometric length and temporal duration. In 2017, the first WMO-recognized ‘longest flash’ record was determined to be a single lightning discharge over Oklahoma that extended a distance of 321 km in 2007 (Lang et al. 2017). It was evaluated using data collected by ground-based Lightning Mapping Arrays (LMAs). Shortly thereafter, a seminal paper introducing the concept of megaflashes (single continuous flashes >100 km in horizontal length typically with durations of 5 s or greater) detailed the phenomenon using the Geostationary Lightning Mapper (GLM) sensor onboard the GOES-16/17/18/19 platforms (Lyons et al. 2019). The authors evaluated a quasi-linear convective system (QLCS) that moved through the central United States on 21-22 October 2017 and focused on one of its many megaflash lightning discharges that extended at least 500 km in horizontal length.

Since that time, numerous compilations of megaflash distances using the GLM sensor have been undertaken (e.g., Peterson et al. 2020, Peterson et al. 2023) expanding our understanding of megaflashes while also increasing their documented extent. Most recently, in 2023, a WMO evaluation committee recognized a megaflash lightning discharge of 768 km ± 8 km (477 mi ± 5 mi) that occurred across the southern United States and the Gulf of Mexico on 29 April 2020 (Peterson et al 2023).

In 2024, the entire GLM data record was reprocessed with new computational methods whose improved efficiency allowed difficult portions of the data record to be examined. This reprocessing inspired a reevaluation of the 2017 megaflash-producing QLCS discussed in Lyons et al. (2019) after it identified a hitherto-overlooked discharge in the early-morning hours of 22 October potentially longer than the current 768 km record. Preliminary analysis indicated that the detected megaflash extended for a distance of 829 km (515 mi) as depicted in Fig. 1. This is approximately equivalent to the geographical distance from Dallas TX to Kansas City MO (or, for Europe, from Paris to Milan). Consequently, a new WMO extremes evaluation committee was formed to adjudicate this new candidate event.

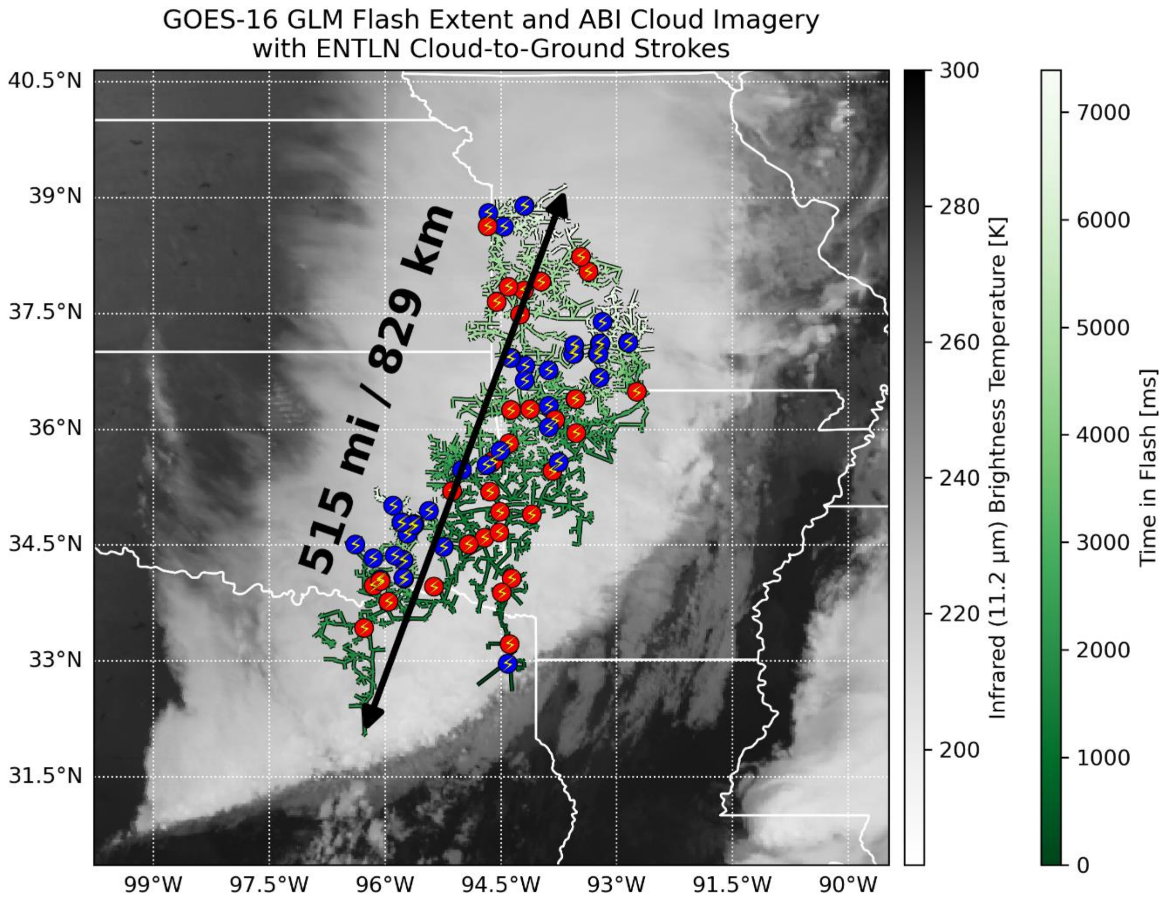

Fig. 1. Composite satellite imagery mapping the candidate megaflash. GOES-16 satellite GLM flash structure is depicted as line segments colored by time overlaid on Advanced Baseline Imager (ABI) 11.2 um infrared brightness temperature imagery showing the Mesoscale Convective System (MCS). The 116 CG strokes detected by the Earth Networks Total Lighting Network (ENTLN: Zhu et al., 2017) are indicated with lightning symbols colored by polarity (blue: 83 negative, red: 33 positive). The maximum extent (515 mi, 829 km) is indicated with a black arrow.

Extensive imagery and data files were reviewed for the 21-22 October 2017 QLCS. Synoptically, the QLCS developed from isolated cellular convection initiated ahead of a sharp cold front extending from Minnesota into northern Texas. After 0000 UTC 22 October 2017, as the QLCS approached Oklahoma City, the continuous line developed a rapidly expanding leading-line trailing stratiform (LLTS) region configuration with an expansive embedded secondary precipitation maximum visible behind the convective line on radar (Fig. 2). The trailing stratiform region reached its maximum areal coverage and reflectivity intensity between 0400–0900 UTC, after which it decayed slowly through the dawn hours over Missouri and Arkansas.

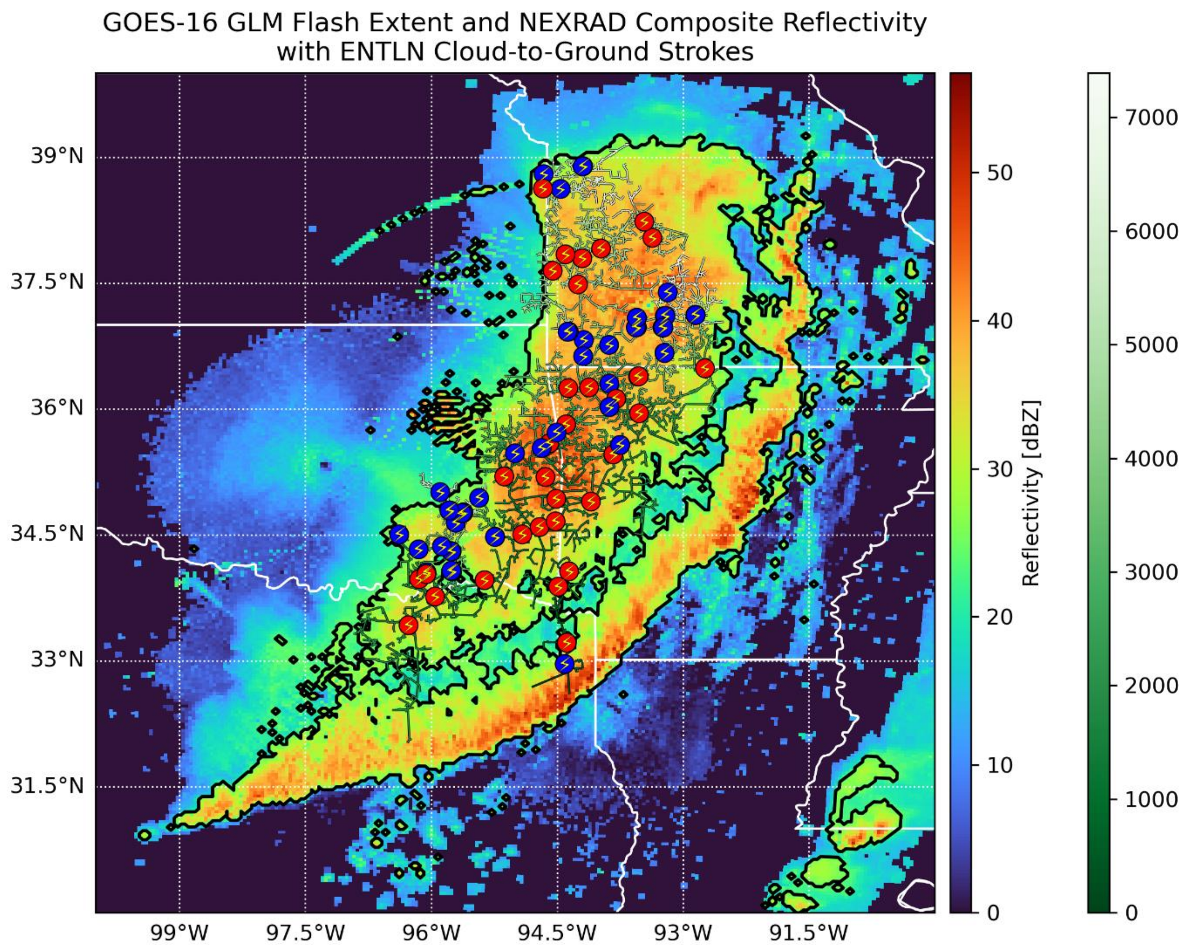

Fig. 2. Lightning flash imagery as in Figure 1 overlaid on top of multi-radar composite NEXRAD radar reflectivity imagery (Heiss et al., 1990; Helmus and Collis, 2016). The megaflash propagated from the convective line to fill nearly the entire 25 dBZ reflectivity region (bounded by the solid line contour) within the stratiform region. With reflectivity tracking the

distribution of hydrometeors that are potentially charged, the flash extent is close to the maximum expected flash extent from this storm.

The present-day reanalysis focused on an exceptionally long megaflash within this QLCS initiated at 08:56:45.834 UTC on 22 October 2017. The WMO committee considered the limitations inherent in GLM data. The two most relevant are cloud blocking and over-clustering. As an optical sensor, GLM has difficulty detecting emissions originating at low altitudes where scattering in the intervening cloud layers decreases the signal intensity at the cloud top (Thomas et al. 2000, Peterson 2021). Cloud blocking causes notable temporal gaps and/or spatial holes in GLM flashes otherwise observable by LMAs unaffected by optically thick clouds. Over-clustering can occur when multiple distinct flashes occur close to one another in space and time. If these nearby flashes satisfy the GLM clustering model, they will be merged into a single flash. Over-clustering has the potential to degrade GLM's ability to measure flash extent.

One question raised by the committee was how megaflashes can propagate for such long distances. The concern was voiced that the ambient electric field strengths may not be large enough to drive the discharge for such a long span. Committee members noted that the length of the leading line CG lightning activity is only one diagnostic for a system to create exceedingly-long megaflashes. Investigations of sprite-generating CG flashes have shown the parent megaflash often originates near the top of the leading line convection and then propagates rearward and downward in altitude into the trailing stratiform (Lang et al. 2010). As part of this investigation, another candidate thunderstorm over the United States was examined (i.e., 31 October 2024) but the megaflashes produced in that storm only reached the 300-km range. The evaluation committee noted while the 2024 thunderstorm had appropriately similar dimensions along the 1100 km leading line, the secondary-precipitation maxima (and likely the charge pools) in the trailing stratiform were weaker and less organzied. Thus, the MCS's structure behind the leading line plays a key role (Lang et al. 2004). By analogy, a megaflash can be thought of as a series of incremental sparks similar to the step leaders evident in CG flashes. The unique horizontal charge structures that become established in trailing stratiform regions, very unlike those in cellular convection, have been discussed at length in the literature (Lang, Rutledge and Weins 2004, van der Velde et al. 2014).

Following the methodology of past world record distance evaluations, the horizontal extent of the newly identified 2017 megaflash was measured according to the energy-weighted centroid positions of the most distant groups (e.g., Peterson et al. 2020, Peterson et al. 2023). Events were only used in the standard GLM clustering model to delineate flashes according to spatiotemporal proximity (events within 330 ms and 16.5 km of each other form the same flash). Clustering model choice is important for high flash rate intense convection but does not have a large effect on low flash rate scenarios (Mach, 2020) as we would encounter in stratiform clouds. The committee considered how the representation of the flash changes with a clustering model based on group centroids (as used with EUMETSAT's Lightning Imager instrument) rather than event centroids (as used with GLM). Group-based clustering caused parts of the flash to become disjointed where group centroids failed to meet the clustering distance threshold and would be assigned to different flashes despite representing contiguous illumination at the event level. This was most prominent in the early optical sources in the convective line but also occurred in certain areas of the stratiform portion of the flash. A notable cause of flash splitting with group-based clustering is when particularly fast leaders do not occur near the temporal boundaries of an integration frame. Thus, all their optical outputs over a large area are deposited in a single frame. This resulted in a single highly linear group represented by a single centroid point rather than a sequence of smaller groups that trace the growing branch across frames. When the growth of the branch over that single frame exceeds the distance clustering threshold, the flash will be artificially split into two flashes.

Using a conservative 'exclusion' of any potential extraneous flash components, the total duration of this 2017 flash would be 7.391 seconds. This is well short of the current WMO-recognized world record for longest duration megaflash which is 17.102 ± 0.002 seconds for a flash event over Argentina and Uruguay in June 2020. Differences in leader propagation speeds and the structure of the branching channels (Van der Velde et al., 2014) allow larger flashes to have shorter durations.

After detailed study of the imagery and data files of the 22 October 2017 QLCS, the committee unanimously recommended to the WMO Rapporteur of Extremes that the 829 km ± 8 km (515 ± 5 mi) extent measured by GLM represents a new WMO-recognized lightning flash distance extreme. Fundamentally, the committee stated, "This case is prototypical on many accounts. A discharge propagating from front-to-rear in a LLTS MCS was frequently noted in past studies of megaflashes associated with major sprite events above trailing stratiform regions (and therefore diagnostic of high peak current / large charge moment change +CG events)." Of note is that such megaflashes often occur in regions far-removed from centers of active lightning, and sometimes much later than 30 minutes after the last local thunder was heard. Megaflash-generated CGs in trailing stratiform regions may represent a poorly understood safety hazard. In summary, with regard to the measured horizontal distance traversed, the new WMO-recognized Lightning Megaflash distance extreme is the 829 km ± 8 km (510 ± 5 mi) as determined by GLM occurring on 08:56:45.834 UTC 22 October 2017. Geographically, the flash extended from eastern Texas to near Kansas City Missouri USA.

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