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The Added Value of Geostationary Lighting Mapper Data for Ground-Based Lightning Applications

Michael J. Peterson
Earth System Science Interdisciplinary Center
University of Maryland
College Park, MD, USA
mpeterso@umd.edu

Scott D. Rudlosky
NOAA/NEDIS/STAR
College Park, MD, USA
scott.rudlosky@noaa.gov

***Abstract*—Ground-based radio frequency networks and orbital lightning imagers provide different perspectives on the same lightning discharge. Thus, there is value in integrating such measurements to construct a more comprehensive picture of lightning. Two example applications are presented that integrate Washington DC Lightning Mapping Array (DCLMA) Radio Frequency (RF) measurements with Geostationary Lighting Mapper (GLM) optical measurements to map lightning flashes over the Washington, DC metro area and identify venues that are under a direct lightning hazard. These applications exemplify how data fusion between LMA systems and GLM leverage the strengths of each observation type while hedging against their respective limitations.**

Keywords—lightning; data fusion; GLM; LMA; applications

I. Introduction

Orbital lightning imagers and ground-based radio frequency lightning locating systems provide complementary views of lightning. Radio Frequency (RF) systems see through the thunderclouds to pinpoint precise locations of lightning discharges. Long-range networks excel at locating return strokes in cloud-to-ground lightning flashes while regional Lightning Mapping Arrays (LMAs: Rison et al., 1999) map 3-D lightning channels over a limited range. Orbital lightning imagers such as the Geostationary Lightning Mapper (GLM: Goodman et al., 2013) on the Geostationary Operational Environmental Satellite (GOES)-16 and the Lightning Imaging Sensor (LIS) on the International Space Station (ISS/LIS: Blakeslee et al., 2014) measure the optical energy produced by lightning that leaves the top of the cloud. Lightning imagers have high detection efficiencies (70% - 90% for LIS: Cecil et al., 2014) over broad geographical domains. In addition to providing detection on global scales, they are also capable of resolving lateral flash development. This helps identify flashes that propagate from one cloud region to another (Peterson et al., 2017a).

Researchers at the University of Maryland have developed several applications that use Washington DC Lightning Mapping Array (DCLMA) and GLM data – separately – to provide non-operational situational awareness of local thunderstorms. In this study, we explore the value added by integrating the VHF and optical perspectives of the same flashes to provide a comprehensive view of regional lightning.

II. Data Sources

A. Washington DC Lightning Mapping Array (DCLMA)

The DCLMA is a 9-station network of GPS-synchronized VHF-band radio receivers spread across the DC-Maryland-Virginia (DMV) metro area. A map of DCLMA stations is shown in Figure 1 as a ring around the capital. DCLMA VHF source data from 2009 until the present are available for public download via the DCLMA website at the following link: https://lightning.nsstc.nasa.gov/lma/dclma/. Reported in these files are the time, latitude, longitude, and altitude of VHF atmospehric radio emissions (sferics) produced by lightning along with the estimated current and a mask specifying which DCLMA stations participated in the solution.

The DC urban environment limits the detection capabilities of the DCLMA. Frequent VHF emissions from sources other than lightning provide a high level of background noise that makes it difficult to detect weak or distant lightning signals. Under relatively quiet conditions, the DCLMA can detect thunderstorms passing through Pennsylvania, but consistent coverage is only practical in the immediate viscinity of the DMV metro area.

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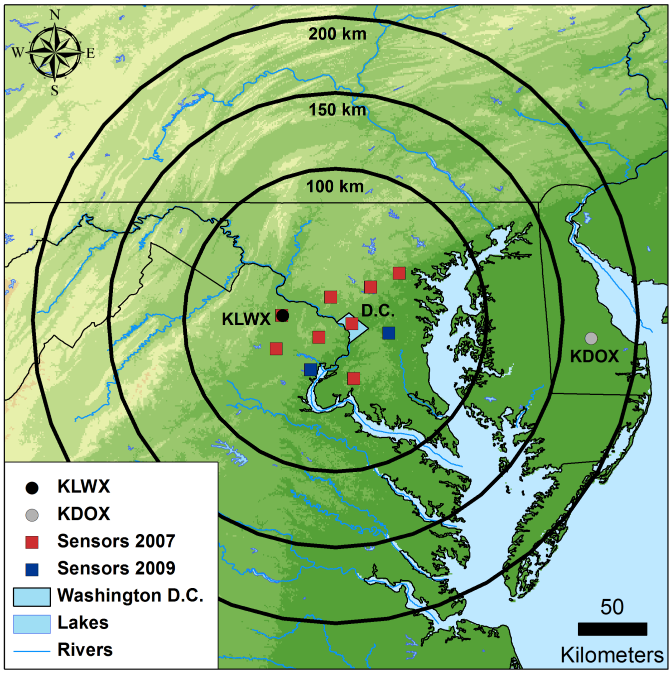

Fig. 1. The locations of DCLMA stations.

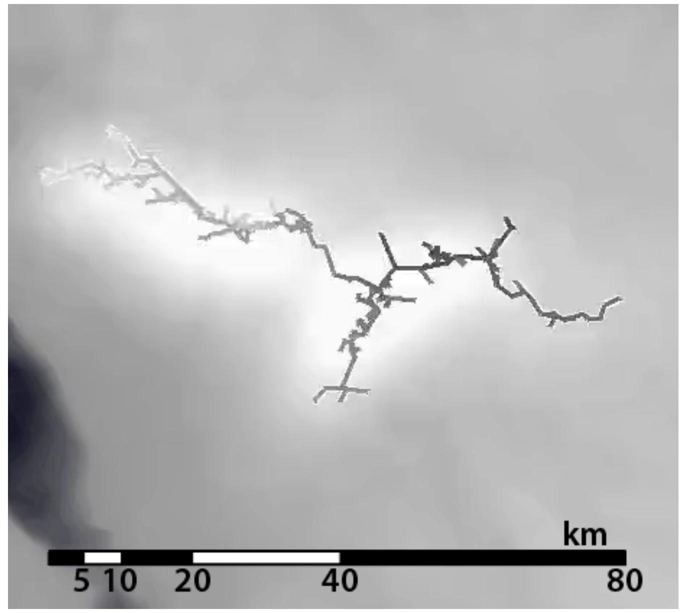

Fig. 2. An expansive lightning flash mapped from orbit. The greyscale cloud top temperature is "brightened" according to the optical energy at each point in the flash, while the evolution of the flash is traced in time from the beginning of the flash (dark grey) to the end (light grey).

B. *Geostationary Lightning Mapper (GLM)*

The GLM on GOES-16 is a staring imager that records the 7774 Å oxygen emission line at approximately 500 frames per second to identify optical lightning signals. The spatial and temporal distributions of optical energy are reported over the course of each flash, making it possible to examine how they change from one 2-ms frame to the next.

These frame-by-frame measurements trace the lateral development of optical flashes and allow us to identify flashes that propagate from one cloud region to another. One such flash is shown in Figure 2. The flash began at the darkest point along its eastern flank and propagated to the west, south, and east with time along more than three identifiable branches.

Lightning imagers such as GLM and LIS can provide a 2D map of flash extent. One important caveat, however, is that optical measurements are sensitive to radiative transfer (i.e., scattering) in the cloud. Scattering adds uncertainty to the locations of intense lightning signals and may prevent detection of low-altitude emission sources entirely if a sufficient optical depth of cloud exists between the source and the sensor (Thomas et al., 2000). Maps of optical flashes can thus disagree with 2D composites of 3D LMA maps where sources along the lightning channel are missed. This is particularly an issue for flashes embedded in convective clouds that typically lack notable lateral motions. Lateral development of the scale in Figure 2 is most common with anvil and stratiform flashes.

III. Lightning Applications

The DCLMA and GLM detect total lightning activity (Cloud-to-Ground and Inter-Cloud discharges) and provide maps of flash extent that are useful for identifying areas in the DMV that are under a direct lightning threat. These measurements are partciularly valuable for documenting cases of long stratfirom flahses and bolts from the blue that pose a risk dozens to hundreds of kilometers from the convective core of the thunderstorm (Lang et al., 2017; Peterson et al., 2017b).

We have developed two lightning applications for the DCLMA to provide non-operational situational awareness of lightning hazards across the DMV. These applications and how they could benefit from integrating GLM measurements are outlined below.

A. *Augmented and Virtual Reality Lightning*

It is essential to seek shelter at the first sign of lightning nearby. We see Augmented and Virtual Reality (AVR) as a tool for contextualizing the lightning threat and allowing users to experience nature's fury from the safety of the indoors. We developed a DCLMA VR application that overlays LMA sources on 360 imagery from around Washington DC in real time. When the application detects a thunderstorm, it uses the incoming DCLMA measurements to aproximate the view of total lightning that would be seen from 8 pre-seleced locations across the DMV. These include:

- The Washington Monument, Washington, DC
- Greenbelt Park, Greenbelt, MD
- Ft. McHenry, Baltimore, MD
- Maryland Statehouse, Annapolis, MD
- The pier at Chesapeake Beach, MD
- Mt Vernon, VA
- Dulles Airport, Sterling, VA
- The confluence at Harpers Ferry, WV

Once the thunderstorm has left the DCLMA domain, these images are collected into 360 spherical videos and uploaded to

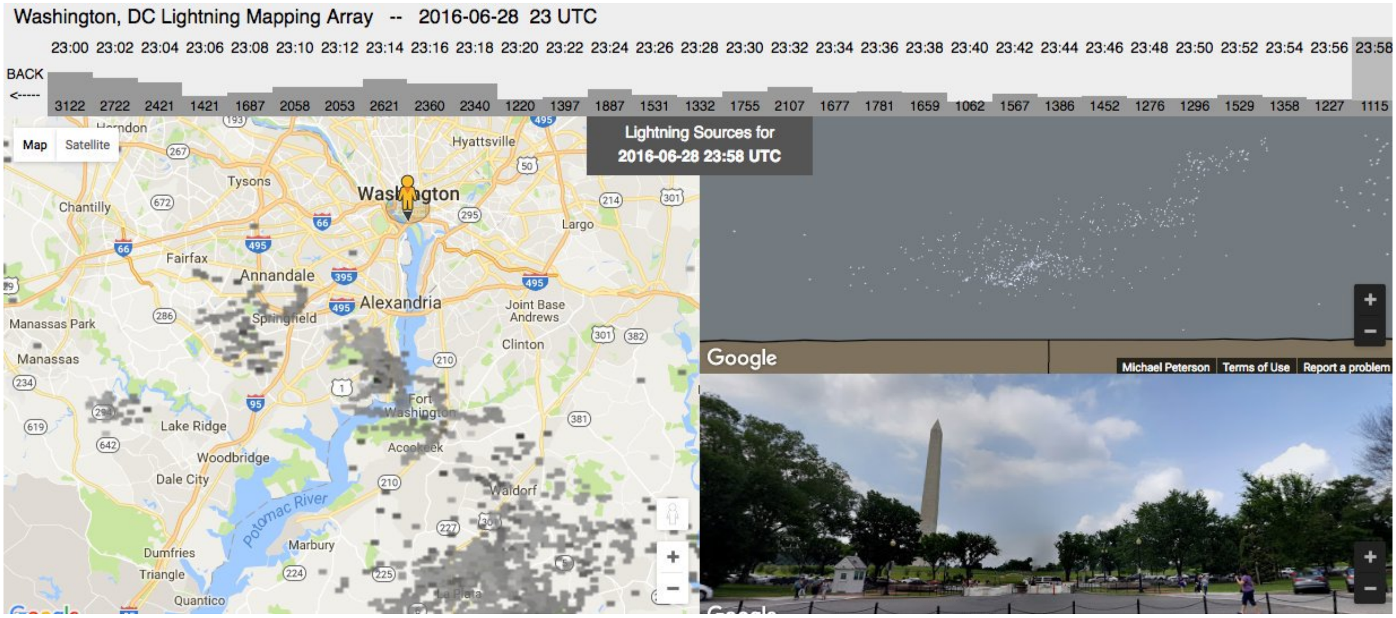

Fig. 3. A prototype of our interactive AVR DCLMA application that calcualtes the locations of lightning sources around an observer at an arbitrary location

YouTube. We also maintain a VR catalog of every thunderstorm measured by the DCLMA since 2009 at the following link: https://www.youtube.com/channel/UCO-WQWf04TmxeJmDcXoYLlg.

For the case of observers not near the pre-selected locations listed above, we are working to extend the VR application into an AR implementation that computes the locations of sources around an observer at an aribtrary location in real time. Google SteeetView or the camera on GPS-enabled smartphones provide background imagery and DCLMA sources are overlaid. AR is the logical next step for this application, though the methods are still in the prototype stage at the time of writing. A screenshot from the current version is shown in Figure 3. When finished, it will allow users to see the lightning around them wherever they happen to be, or to drag a marker to place themselves upstream and view the approaching thunderstorm before it hits.

B. *Interactive 3D Lightning Web Application*

While the AVR application focuses on users on the ground, the interactive 3D lightning web application (http://dclma_demo.wxarchive.com) provides a bird's-eye-view of DC thunderstorms. DCLMA data are used to create KML that plots the 3D structure of lightning flashes across the DMV. The applicationn is powered by Cesium.js whose 3D engine allows users to pan, zoom, and even tilt the camera to look at DCLMA flashes from all angles.

The application is configured to draw from many imagery providers to customize the base layer to show satellite imagery, black marble imagery, and even 3D terrain tiles. Combining the DCLMA data with these base layers shows the venues under a lightning threat in fine detail – for example, airports, sporting arenas, and tourist attractions. This web application is our newest project and not yet avilable in real time, however.

C. *The Added Value of GLM Data*

The areas where GLM adds value to these DCLMA applications are best shown with the interactive 3D lightning web application. Figure 4 shows a screenshot of of the DCLMA appliation with 2D GLM flashes added as a base layer at ground level (yellow) below the 3D dclma flashes (blue: negaitve, red: positive). The GLM flash extents are drawn using the same technique that was used for the flash in Figure 2. White rings are drawn at 100 km and 200 km from the network center of the DCLMA at the bottom edge of the image.

The DCLMA and GLM both show lightning activity over Bethesda and Silver Spring, MD with lateral development to the west into Virgina. The most striking difference between the 3D DCLMA flash extent map and the 2D GLM flash extent map, however, is that GLM detects lightning activity to the north beyond the 100 km ring that is completely missed by the DCLMA. It is posisble that the DCLMA recorded these sources at its norhternmost stations, but we require 6+ stations registering the same source for it to be plotted.

This demonstration shows two possible uses for GLM data in the AVR and 3D interactive lightning appliations. The first is to provide an independent verification that DCLMA signals are valid lightning sferics. When the DCLMA and GLM agree on the lateral extent of lightning, then we can have an increased conficence in the measurements and our flash clustering. The second is to fill data voids, especially at the edge of the network.

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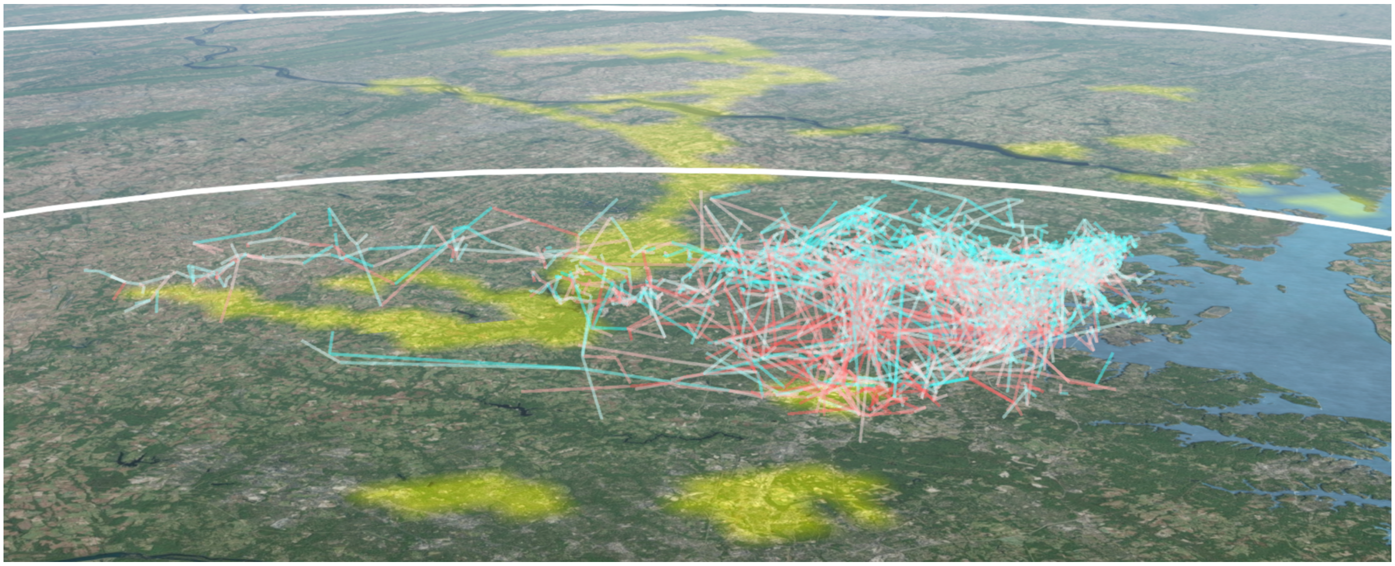

Fig. 4. A screenshot from the DCLMA 3D lightning web application from June 19th, 2017 20:05 – 20:10 UTC with GLM flash extents (yellow) added. Positive (red) and negative (blue) LMA sources are clustered into flashes. Range rings of 100 km (lower) and 200 km (higher) from the network center are overlaid.

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