Basic Description of Lightning Detection Technologies

Rapidly-updating lightning observations provide valuable insights into thunderstorm evolution. Intra-cloud (IC) lightning better indicates thunderstorm intensity since it relates more closely to updraft evolution than cloud-to-ground (CG) lightning. The growing number of lightning detection networks and variety of users increases the importance of understanding network detection capabilities. This document describes the basics of lightning detection technologies to help orient users of lightning observations.

Lightning generates electromagnetic pulses that propagate as radio waves in all directions. CG lightning generally exhibits strong current in long vertical channels, emitting most efficiently in the low-frequency (LF) to very-low frequency (VLF) range. IC lightning channels typically are more horizontal with weaker current, emitting most efficiently in the high-frequency (HF) to very-high frequency (VHF) range. Ground-based lightning detection networks geolocate lightning using the signal arrival angle and/or arrival times at multiple sensors. Algorithms differentiate between IC pulses and CG strokes based on height estimates and/or waveform shape. IC pulses and CG return strokes are combined into IC and CG flashes using space and time criteria. A typical CG flash contains many IC pulses and at least one return stroke.

Strong VLF signals propagate long distances (1000's of km) within the earth-ionosphere waveguide, so long-range networks such as the GLD360 (3-30 kHz) and WWLLN (3-30 kHz) can detect high-current pulses and return strokes globally with fewer than 100 sensors. Alternatively, Lightning Mapping Arrays (LMAs; 8-12 sensors; 50-200 MHz) detect VHF emissions associated with electrical breakdown during lightning channel formation and re-illumination, providing detailed 3-D mapping of IC lightning channels and the IC components of CG flashes. LMAs observe 10's to 1000's of geolocated emission sources per lightning flash, but are spatially limited by the line-of-site propagation of VHF radio waves. The ENTLN employs a blended technique (1 Hz to 12 MHz) to provide a degree of global CG lightning detection with better performance (i.e., CG+IC detection) in regions with greater sensor density. Since higher frequency signals attenuate more quickly than lower frequency signals, radiometric IC lightning observations are inherently limited by the distance IC signals propagate. Thus, regardless of the technology, IC lightning observations are limited in regions lacking sensors (e.g., the deep ocean). The NLDN operates in the LF range (1-350 kHz) and detects nearly all CG lightning. A recent upgrade has improved the NLDN IC flash detection efficiency to a vendor-reported 50-60%.

Although the ENTLN has many more sensors than the NLDN (~700 vs. ~120), its sensors are concentrated near population centers while the NLDN sensors are more evenly spaced. Sensor spacing influences network performance and sensitivity, impacting the IC detection efficiency and the number of IC components observed per flash. The number of ENTLN pulses/strokes per flash may vary from 2-3 in some western states to 5-10 in the Mid-Atlantic. These networks do not report the full spatial extent of lightning flashes due to the separation distances between their sensors.

Non-uniformity of ground-based observations coupled with continual network modifications helped to motivate the planned GOES-R GLM. Unlike the ground-based networks, the GLM will detect optical lightning signals from clouds, providing nearly uniform observations over land and ocean within 8x8 km grid cells (i.e., not point-based observations). Similar to lightning mapping arrays, the GLM will be able to report the full spatial extent of flashes. Planning is underway to optimize the fusion of the satellite- and ground-based lightning observations to provide the most useful tools to forecasters.

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Networks: World-Wide Lightning Location Network (WWLLN), Global Lightning Dataset 360 (GLD360), Earth Networks Total Lightning Network (ENTLN), National Lightning Detection Network (NLDN)