VAISALA / WHITE PAPER

Benefits of Very High Frequency Total Lightning Mapping over Very Low or Low Frequency Cloud Lightning Detection for Meteorological Applications

Over a decade of lightning research conducted at universities, meteorological services/institutes, and Vaisala have shown that all areas where cloud lightning is overhead are at risk for cloud-to-ground (CG) lightning. The only effective way to capture the full CG lightning threat is with VHF (very high frequency) total lightning mapping provided by Vaisala TLS200/LS8000 technology.

As a thunderstorm approaches a fixed asset (90% of the time) where people are located, VHF cloud lightning mapping provides 10s of minutes of lead time before the first cloud-to-ground strokes reach this asset. At times when a thunderstorm develops directly over the fixed asset (~10% of the time), the cloud flash detection efficiency exceeding 90% maximizes lead time during thunderstorm growth because cloud flashes usually precede CG lightning.

Most critically, VHF cloud lightning mapping vastly improves CG lightning warnings by eliminating false alarms. For severe weather nowcasting, lightning data provide more frequent updates than radar to decision makers. Rapidly increasing cloud flash rates indicate a strengthening storm updraft capable of producing large hail. Rapidly decreasing cloud flash rates indicate a weakening storm updraft as rainfall and strong winds reach the ground.

Meteorological agencies and universities around the world have shown how VHF total lightning mapping has improved protection and nowcasting.

Combining VHF and LF Enables High Detection Efficiency and Stroke Location Accuracy

The Vaisala Thunderstorm Information System combines highly accurate lightning sensing, lightning location and parameters, and real-time and historical application software. The platform integrates two effective lightning detection technologies: VHF interferometry and very low frequency(VLF)/low frequency (LF) combined magnetic direction finding and time-of-arrival. VHF interferometry technology enables highly accurate detection and mapping of cloud lightning, while VLF/LF combined magnetic direction finding and time-of-arrival technology offers the highest detection efficiency and most accurate location for CG lightning strokes. By combining these two technologies, more than 90 percent of all lightning can be detected.

Limitations of Cloud Lightning Detection With VLF/LF Technology

Cloud-to-ground lightning emits the highest amplitude pulses in the LF (low frequency) to VLF (very low frequency) range due to a large amount of current traveling over long distances. In contrast, cloud lightning results in short-range discharges with weaker current, producing small VLF/LF pulses near the origination of the cloud flash but larger VHF pulses throughout all of the branches of the cloud flash. Since the overall electrification and lightning discharge process involves many electrical events, single origination points detected in the VLF/LF range are not at all representative of the true spatial extent of the lightning threat.

Figure 1 shows a typical example of cloud flash detection at VHF and VLF/LF frequencies. The blue dots show VHF cloud lightning mapping and the red dots show VLF/LF cloud lightning detection. The VLF/LF cloud flash representation is missing >90% of the branching areas shown at VHF. In addition, since the VLF/LF cloud pulses are small in amplitude, VLF/LF cloud lightning detection networks typically only detect <~50% of all cloud lightning flashes with large detection efficiency fluctuations that are extremely sensitive to sensor baselines. In contrast, the larger VHF pulses allow >90% cloud flash detection efficiency for VHF lightning detection networks with little-to-no fluctuations in detection efficiency.

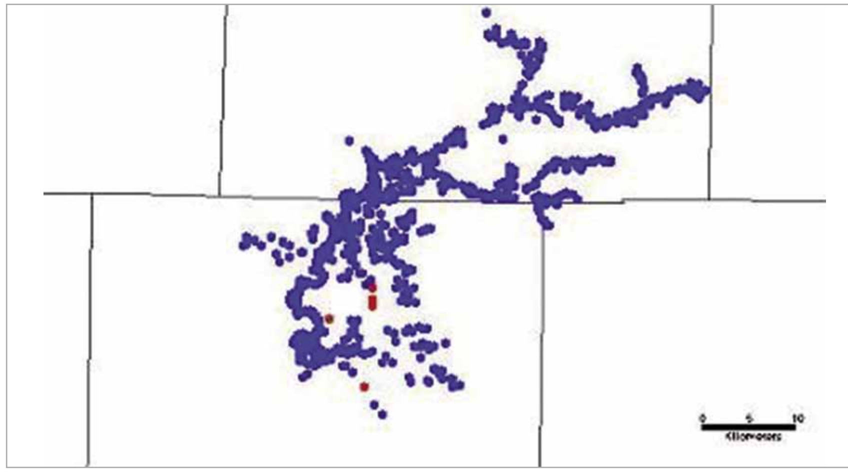

Figure 1. *Cloud lightning flash detected in the Dallas-Fort Worth area of Texas, USA. The blue dots show VHF cloud lightning mapping and the red dots show VLF/LF cloud lightning detection. The total length of this cloud flash as shown by VHF cloud lightning mapping is ~50 km.*

Lightning Mapping Enables Improved Storm Detection and Protection

Every area where cloud lightning is overhead is at risk for cloud-to-ground (CG) lightning, so the only effective way to capture the full CG lightning threat is with VHF total lightning mapping technology (such as Vaisala's TLS200/LS8000). Mapping provides a much more comprehensive picture of the lightning threat through all phases of thunderstorm activity, from growth and development through to maturity and decay. This feature includes a clear picture of the full electrification of the thunderstorm cloud, including the potentially dangerous anvil and stratiform areas later in the storm life cycle. Anvil and stratiform cloud flashes routinely travel distances of 25 to 100+ km as only observed using VHF detection technology **(Fig. 2)**. At each storm stage, detailed lightning mapping provides a clearer picture of the storm life cycle and potential lightning risks to ground-based activities. Simply detecting the cloud-flash origination point using VLF/LF technology is not enough.

Consider the most frequent situation of a thunderstorm approaching a fixed asset (occurs ~90% of the time) where people are located. VHF cloud lightning mapping provides 10s of minutes of lead time before the first cloud-to-ground strokes approach the fixed asset. During the 2007/2008 North American Monsoon seasons, Vaisala analyzed the arrival times of (1) VHF total lightning mapping, (2) VLF/LF cloud lightning detection, and (3) CG lightning for 29 thunderstorms directly affecting Tucson International Airport. VHF cloud lightning mapping data arrived at the airport with a mean (median) lead time of 25 (19) minutes before the first CG stroke arrived at the airport. VLF/LF cloud lightning data provided no lead time with a mean (median) lead time of 2.1 (0) minutes late. The VHF cloud lightning lead time was provided by anvil and stratiform mapping. By comparison, the cloud flash origination points detected at VLF/LF are located in the same convective core areas as the CG strokes and therefore provide little-to-no advanced warning.

At times, there also may be a situation where a thunderstorm develops directly over the fixed asset. For this infrequent situation (occurs ~10% of the time), better than 90% cloud flash detection efficiency at VHF maximizes the lead time during the growth phase of a thunderstorm because cloud flashes

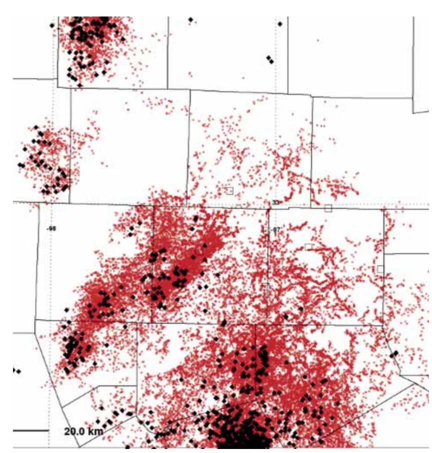

Figure 2 *Map of VHF total lightning mapping in red and VLF/LF cloud pulses in black in north Texas for a 15-minute period. Note the large area of anvil lightning reaching northward from the center of the storm on the south side of the map.*

usually precede CG lightning strokes. VLF/LF cloud lightning detection networks only detect <~50% of all cloud lightning flashes, at best, and therefore miss cloud flashes that could maximize lead time before the first CG stroke in a thunderstorm.

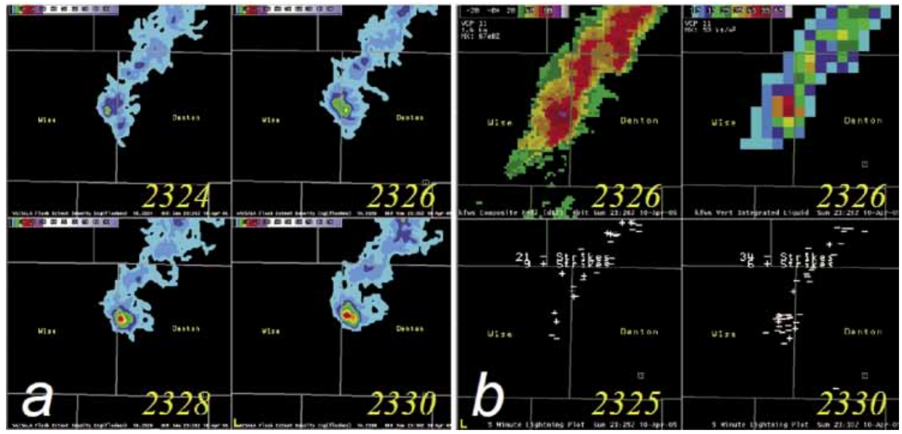

Figure 3 AWIPS D2D imagery from 10 April 2005. (a) Four panel image of VHF total lightning density between 2324 UTC (upper left) and 2330 UTC (lower right) shows increase in values from 5 flashes km-2 min-1 to 15 flashes km-2 min-1 near the Wise-Denton County line in north Texas, USA. (b) KFWS Composite reflectivity at 2326 UTC (upper left); KFWS Vertically Integrated Liquid (VIL) product at 2326 UTC (upper right); Vaisala National Lightning Detection Network (NLDN) 5 minute CG strokes ending at 2325 UTC (lower left); and NLDN 5 minute strokes ending at 2330 UTC (lower right). (Courtesy of the Dallas-Fort Worth National Weather Service Forecast Office)

Continuous Monitoring of Storm Activity Using VHF Total Lightning Mapping

VHF total lightning mapping improves thunderstorm nowcasting. It enables monitoring of rapid changes in updraft intensity and new updraft development as well as any rapid changes in thunderstorm organization. Stable, high cloud flash detection efficiency (>90%) is critical for this type of application. It ensures that the cloud flash rate changes are due to actual storm intensity changes. Variable, lower cloud flash detection efficiency (<~50%) leaves the user questioning whether these cloud flash rate changes are due to actual storm intensity changes or highly variable cloud flash detection efficiency.

VHF total lightning mapping allows continuous monitoring of thunderstorm growth and dissipation. Forecasters can use the valuable dataset provided by continuous total lightning mapping to monitor thunderstorm activity at much shorter timescales than the five to ten minute intervals typically possible through radar volume scan updates. Total lightning rates and areas of coverage help forecasters to identify updraft intensification and new updraft development in a storm **(Fig. 3).**

Improved Location and Timing of Severe Weather Events

Lightning data provide updates to decision makers at much more regular intervals than radar reflectivity data – every two minutes or less compared to approximately every 5 to 15 minutes. Studies have also proven that mapped cloud lightning data can provide a better indication of the severity of a storm than CG lightning information, especially when combined with high-quality radar information.

The high detection efficiency (over 90%) of cloud lightning enabled at VHF frequencies provides earlier warning of the locations and times of severe weather events that can follow rapid changes in lightning rates and spreading in areal coverage as the storm matures. A rapid increase in cloud lightning rates indicates that the storm updraft has strengthened and is capable of producing large hail **(Fig. 4).** A rapid decrease in cloud lightning rates indicates that the storm updraft strength has weakened as rainfall and strong winds reach the ground **(Fig. 4).** As it spreads, the downdraft presents a significant danger to power lines, aircraft, and other surface assets. As discussed earlier in this paper, the user can only trust that these rapid changes in cloud flash rate are due to storm intensity changes when using stable, high cloud flash detection efficiency (>90%) provided by VHF lightning detection networks.

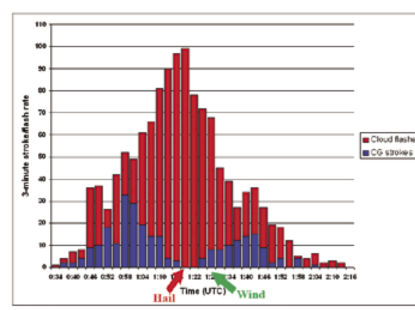

Figure 4*.* *Cloud-to-ground lightning stroke and VHF cloud flash rate time series for a severe thunderstorm in the Tucson, AZ, USA area on 11 August 2007. Cloud-to-ground stroke rates shown by blue bars and VHF cloud flash rates shown by red bars. The top of the red bars indicates the overall total (cloud plus CG) lightning flash/stroke rate. Actual VHF cloud flash rates are calculated by subtracting the cloud-to-ground stroke rates (top of the blue bars) from the total lightning flash/stroke rates (top of red bars). All lightning flash/stroke rates were calculated using 3-minute time intervals.*

Numerical Weather Prediction With Lightning Data Assimilation

Assimilation of lightning data into numerical weather prediction (NWP) models has also enabled the production of more accurate forecasts. Notable examples include the Rapid Update Cycle model used by the National Weather Service and aviation community.

Lightning data information is typically converted to radar reflectivity, rainfall, or moisture for assimilation into NWP models. Several studies have reported robust relationships between lightning density and other storm properties such as reflectivity or rainfall. The lightning data help to provide better estimation of these fields, which in turn results in improved analyses and short-term forecasts. The lack of spatial cloud lightning mapping at VLF/LF and variable, lower cloud flash detection efficiency will likely result in poorer analyses and short-term forecasts. The fundamental requirements for successful lightning data assimilation are the extensive and accurate spatial coverage, timing of the onset of convection, and high detection efficiency.

VHF cloud lightning mapping provides a more accurate representation of current lightning activity, including full areal extent. As shown in Figs. 1 and 2, the VLF/LF cloud lightning detection methods often miss >90% of the areal coverage of active convection. The cloud clusters typically cover large areas up to thousands of square kilometers and assimilating lightning data to the correct locations is essential for an accurate analysis and forecast. In contrast, VLF/LF cloud lightning data assimilation can result in incomplete and biased information in the NWP models.

The timing of the onset of a thunderstorm is especially important in short-term (1-6 h) forecasts. As shown in section 4, the VHF data can provide 10s of minutes of lead time before the first CG strokes develop. In the early stages of thunderstorm development, the timing, location and intensity of the updrafts and subsequently the latent heat release play an important role in the storm evolution. With VHF lightning data assimilation, it is possible to capture the initial stages of the storm development resulting in more accurate short-term forecasts.

Several studies have shown that the intracloud (IC) to cloud-to-ground (CG) ratio (Z) is very large in developing severe storms. While a typical value of Z in low-latitude tropical regions is estimated to be in the order of 5-10, some studies have confirmed values of 20-70 during the severe stages of the storm. This emphasizes the importance of cloud flash detection when the data are assimilated into NWP models. On the other hand, a VLF/LF system may miss a low-lightning rate storm altogether, whereas a VHF system can still provide useful information of enhanced moisture and convection for NWP models.

Conclusions

Over a decade of lightning research conducted at universities, meteorological services/institutes, and Vaisala have shown that all areas where cloud lightning is overhead are at risk for CG lightning. VHF cloud lightning mapping networks (such as Vaisala's TLS200/LS8000 networks) clearly provide superior information for understanding all areas at risk for cloud-to-ground lightning. VHF lightning detection networks map all branches in cloud lightning flashes and detect >90% of all cloud lightning flashes. VLF/LF cloud lightning detection networks only detect <~50% of all cloud lightning flashes and miss over 90% of the spatial area covered by cloud lightning flashes.

Cloud lightning mapping and stable, >90% cloud flash detection efficiency provided by VHF lightning detection networks (such as Vaisala's TLS200/LS8000) improve thunderstorm nowcasting for both severe and non-severe thunderstorms by providing data users can trust for diagnosing storm intensity. By comparison, variable, low cloud flash detection efficiency (<~50%) and the lack of cloud lightning mapping can degrade thunderstorm nowcasting for both severe and non-severe thunderstorms by providing the user with incomplete, misleading information.

Finally, VHF total lightning mapping data provides a complete picture of the current lightning state of the atmosphere, which is fundamental for successful lightning data assimilation. This leads to improved initial conditions for numerical weather prediction models and improved short-term forecasts. Poorer initial conditions due to variable, lower cloud flash detection efficiency and lack of cloud lightning mapping at VLF/LF are likely to result in less accurate analyses and poorer short-term forecasts.

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