Creating Proxy Radar Reflectivity Maps from Total Lightning Data

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Abstract

Utilizing total lightning data which includes both intra-cloud (IC) and cloud-to-ground (CG) flashes from the Earth Networks Total Lightning Network (ENTLN), a lightning cell tracker was developed and used in severe weather alerts. This study relates the total lightning flash rates from the lightning flash cells to the maximum radar reflectivity derived from the National Weather Service (NWS) NEXRAD system. The study is based on the radar and lightning data from thunderstorms within CONUS covering dates from March 2011 to November 2011. Comparing the total lightning flash rate and the radar reflectivity (dBZ) of each flash cell through the evolution of the cells, this study shows clear relationships between the two factors. The quantitative relations are derived statistically for different climate zones in different seasons, and statistical models are used to create the radar dBZ maps, known as "PulseRad[SM]", from the total lightning data. The dBZ value in PulseRad can be used to enhance the predication of severe thunderstorms, and as a cost-effective radar alternative in areas that lack of radar coverage.

Introduction

Lightning flash rates have been the subject of many studies with respect to many storm characteristics such as radar reflectivity, storm cell height, vertically integrated liquid (VIL) and precipitation for several decades. Severe thunderstorms which may generate lightning, high winds, hail and tornadoes have certain characteristics in associated lightning flashes such as high IC flash rates in the storm formation stage. Severe storms may have either exceptionally low negative CG flash rates, or have exceptionally high positive CG flash rates; the greater volume of strong updrafts during a severe thunderstorm results in more charging overall, leading to greater numbers of ICs and positive CGs (Lang and et al., 2000 and 2002). Past studies have shown that the CG flash rate has no correlation with tornadogenesis and that using CG lightning flash patterns exclusively to detect tornado formation is not practical (Perez et al., 1997). One study [MacGorman et al., 2007] used a SCIT cell isolation algorithm and showed that the negative CG lightning flash rates have correlation with such radar-derived cell parameters as maximum vertically integrated liquid (VIL) and cell height, but there is no correlation with the maximum radar reflectivity. Another study [PESSI et al., 2007] used a low resolution 0.5°x0.5° grid cell to study the relationships among CG lightning, precipitation and hydrometeor characteristics over the Northern Pacific Ocean. This study showed a logarithmic increase in convective rainfall rate and radar reflectivity with increasing hourly lightning rates. The different conclusions from the above two studies may indicate that CG lightning rate may correlate with radar reflectivity statistically in low resolution but does not correlate in high resolution such as a SCIT storm cell level. This is consistent with the findings that CG lightning rates have no correlation with the severity of the storms.

The Earth Networks Total Lightning Network (ENTLN) is a total lightning detection network—its wideband sensors detect both IC and CG flash signals. The deployment of this high density sensor network and the improvement in the detection efficiency on the server-side, especially in IC flash detection, made it practical to track and predict severe weather in real time. Studies have shown that severe weather often occurs minutes after the total lightning rate reaches the peak and tracking the rise of the total lightning flash rate provides increased severe weather prediction lead time [Liu et al., 2011]. By using the ENTLN total lightning data, a real-time lightning cell tracking system and subsequent Dangerous Thunderstorm Alert system have been developed. By investigating the relationships between the total lightning flash rate and the radar reflectivity inside the lightning cells, the goal of this study is to find the statistical models that can be used to create the proxy radar map from the total lightning data for convective storms.

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Earth Networks Total Lightning Network (ENTLN) and Lightning Cell Tracking

An Earth Networks Lightning Sensor (ENLS) can acquire detailed signals emitted from both IC and CG flashes and continuously sends information to a central server. An ENLS is comprised of an antenna, a global positioning system (GPS) receiver, a GPS-based timing circuit, a digital signal processor (DSP), and onboard storage and internet communication equipment. The ENLS is unique compared to other existing sensor technologies. The sensor is a wideband system with a detection frequency ranging from 1HZ to 12MHZ. The wide frequency range enables the sensor to not only detect CG strokes, but to also detect IC pulses. The sensor records whole waveforms for each flash and sends the waveform back in compressed data packets to the central server. Instead of using only the peak pulses, the whole waveforms are used in locating the flashes and differentiating between IC and CG strokes. The rich signal information enhances the detection efficiency and location accuracy of the system. Sophisticated digital signal processing technologies are employed on the server-side to ensure high-quality detection and to eliminate false locations. The precise arrival times are calculated by correlating the waveforms from all the sensors that detected the strokes of a flash. The waveform arrival time and signal amplitude can be used to determine the peak current of the stroke and its exact location including latitude, longitude and altitude. Strokes are then clustered into a flash if they are within 700 milliseconds and 10 kilometers. A flash that contains at least one return stroke is classified as a CG flash, otherwise it is classified as an IC flash. In the lightning cell tracking and PulseRad generation, only flashes are used. Significant effort has been extended in improving IC detection efficiency both in sensor deployment as well as server-side optimization. Detection efficiency is improving with continual increased sensor deployment and through server-side algorithm improvement.

A lightning cell is a cluster of flashes with a boundary as a polygon determined by the flash density value for a given period. The polygon is calculated every minute within a six-minute data window. The cell track and direction can be determined by correlating the cell polygons over a period of time. By counting the flashes in the cell, it is possible to estimate the lightning flash rate (flashes/min). The cell speed and area are also calculated.

The flash data is streamed from a lightning manager service to the cell tracker as soon as a flash is located. The cell tracker keeps the flashes in a moving time window of six minutes. Two gridding processes are executed every minute, using a snapshot of the flash data in that time window. The first gridding is on a coarse grid to quickly locate areas of interest and the second gridding is operated on a much finer grid using density functions to find the closed contours. To simplify the calculation, a convex polygon, which is the cell polygon at the time, is generated from each of the closed contours. In most cases, the cell polygon is similar to the previous minute polygon, so the correlation between the two polygons is straightforward. But in the case of a sharp rise in the flash rate, or a cell split or merger, the correlation of subsequent cells is not obvious. Special care is taken to link the cell polygons and produce a reasonable path of the moving cells. When a storm cell regroups after weakening a continuous cell path may be maintained based on the trajectory of the cell and the time-distance of the two polygons. With the lightning cells maintained during the life of the storms, the comparison of the lightning flash rate and radar reflectivity for the areas inside the cells can be done.

Lightning Flash Rate and Maximum Radar Reflectivity

When plotting the lightning flash data on top of the radar reflectivity map, one can see that most of the lightning activities occur in the areas with high dBZ values (>30dBZ) (Figure 1). The lightning flash rate for a location is calculated by counting the number of flashes within an 8km radius area from the last 6 minutes.

To study the relationship between lightning flash rate and radar reflectivity, the composite radar maps, which have the maximum dBZ reflectivity from any of the reflectivity angles of the NEXRAD weather radar, are used. For each composite radar dBZ reflectivity map with a certain scan interval, the lightning cell map is generated by using the lightning cell tracker program. The median lightning flash rate in each lightning cell (polygon) and the median radar reflectivity value in the corresponding polygon are recorded as a sample (Figure 2). Since all the samples are collected from the lightning cell polygons, this ensures that only the convective storms are considered in the study. From the samples, the statistic variables, such as mean and modal can be calculated. The statistics clearly indicate a logarithmic increase in maximum radar reflectivity with increasing total lightning flash rates. The relationships vary in different climate regions and seasons.

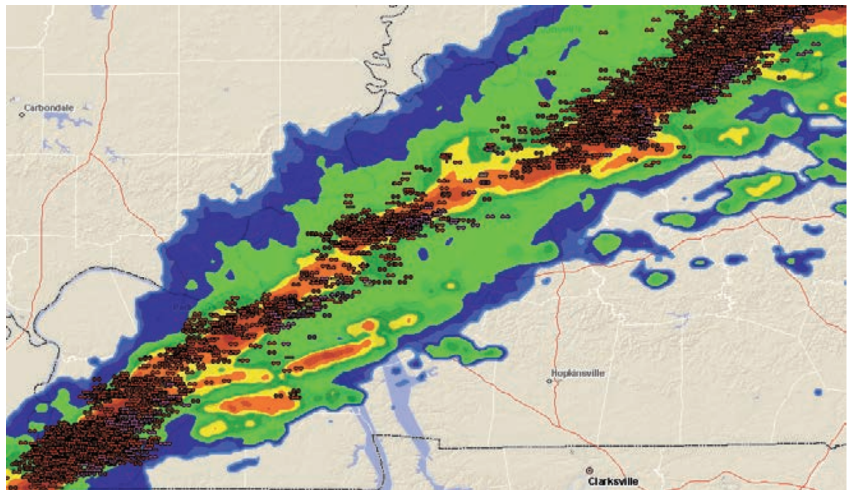
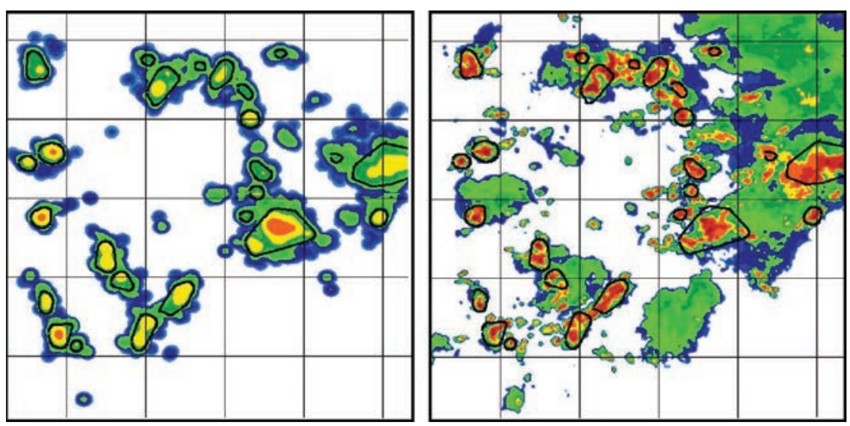


Figure 1 Lightning activities corresponding to high dBZ values



(a) Lightning Cells

(b) Corresponding Radar Cells

Figure 2 Comparing lightning rate with radar dBZ value in the lightning flash cells

PulseRad: Proxy Radar from Total Lightning

To quantantize the relationships between the lightning flash rates and the dBZ values of the composite radars, three climate regions were chosen in CONUS. The three regions include mid-latitude east (above 32 and east -102), subtropical (below 32 and east -102) and mid-latitude west (above 32 and west -102). The seasons are divided into a warm season extending from June to September, and a cold season pertaining to the remainder of the year. Applying the statistic model to each climate region for the different seasons, the lightning flash rates can be converted to the relative dBZ values, which in turn can be used to create the simulated radar map, i.e. PulseRad (Figure 3). Early studies have shown that a high lightning rate or sudden jump of the total lightning rate is usually the precursor for severe storms. Thus the high dBZ values or sudden increase of dBZ values in PulseRad can be used as an indicator for intensifying storms.

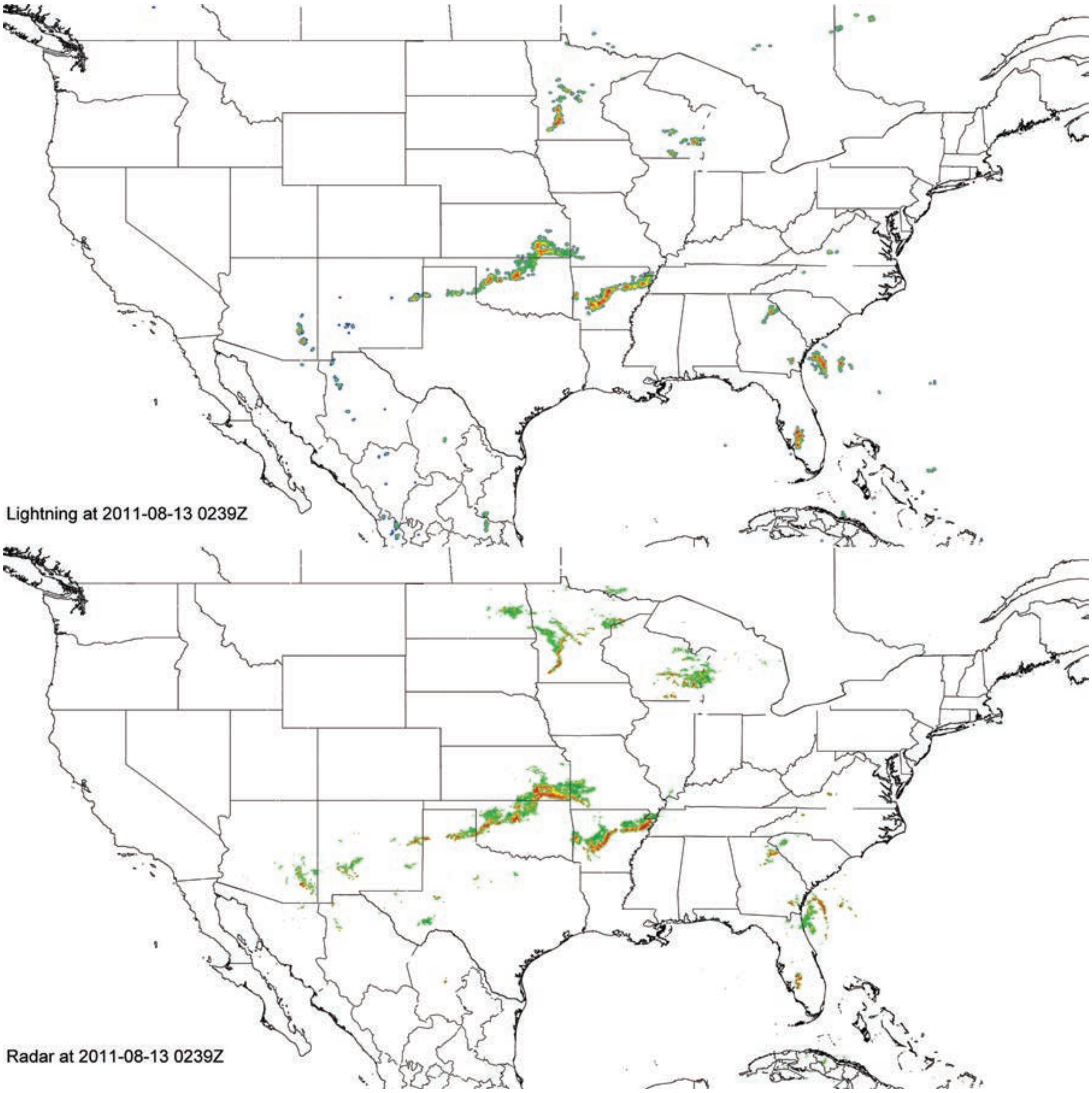


Figure 3 PulseRad (top) and Doppler Radar (bottom) Comparison

Like regular Doppler radar maps, PulseRad can also be used in precipitation estimation (Figure 4). By combining historical PulseRad data, it is possible to issue drought or flood warnings in areas during convective storm seasons. Lightning in areas with the same climates have similar characteristics, thus statistic models from one region can be applied to other regions with the same climate. As long as the total lightning data is available, PulseRad can be created for any region with a known climate.

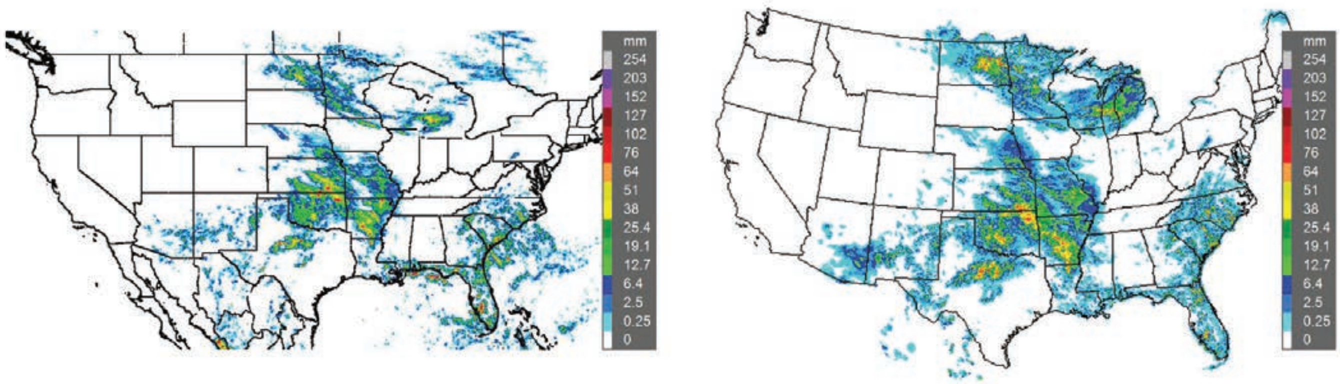


Figure 4 24-hour precipitation estimate for 8/13/2011, from PulseRad (left) and NWS (right, Courtesy of NWS Advanced Hydrologic Prediction Service, http://water.weather.gov/precip/index.php)

Conclusions

This study shows that the logarithmic scale of the total lightning rate (dBR) correlates well with the maximum radar reflectivity (dBZ) in convective storms. The relationships between dBR and dBZ vary for different climate regions and different seasons. By converting the dBR to dBZ, a proxy radar map (PulseRad) can be created from total lightning data. PulseRad can be used as a radar alternative for weather nowcasting in areas that lack of radar coverage, and it can also be employed to enhance the lead-time and accuracy of severe weather warnings. By applying the same formula as the Doppler radar, PulseRad can be used for precipitation estimations, and drought or flooding predictions.

References

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