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Lightning Characteristics and Relationship to Preliminary Local Storm Reports

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ABSTRACT

The Storm Prediction Center (SPC) has traditionally utilized cloud-to-ground (CG) lightning for a variety of purposes but recently intra-cloud (IC) flash data as part of total (CG + IC) lightning has been made available. To further explore characteristics of considering both CG and IC flashes in an operational setting, a systematic evaluation and comparison of the Vaiasala's National Lightning Detection Network (NLDN) and Earth Networks Total Lightning Network (ENTLN) data sets for all of 2014 was performed to provide some initial statistical characteristics. In addition, the relationship of lightning flashes to preliminary severe and winter-weather Local Storm Reports (LSRs) was explored on an hourly, high-resolution grid covering the contiguous United States. Results showed that thunderstorms became more numerous in April with a marked increase in IC lightning flashes during the summer compared to the steadier rise of CG activity. Aggregate annual counts from the ENTLN and NLDN show similar CG flash patterns, but NLDN CG detections were 1.22 times more numerous than ENTLN detections. Furthermore, tallies of IC flashes were often more extensive and numerous than CG flashes across the contiguous United States and ultimately contributed a substantial portion [~0.89] to total lightning.

On a national scale, hourly cumulative CG (total) lightning flashes reached their greatest count for the year at 2200 UTC (2300 UTC) with the lowest sum for the hour ending at 1600 UTC (1500 UTC). Not surprisingly, locations in Florida and along the Gulf Coast exhibited the highest frequency of thunderstorms with a secondary max more evident with the IC flash dataset in the Missouri Valley. Finally, the time/space matching of LSRs and lightning was accomplished through a direct grid-point to grid-point comparison and application of a spatial neighborhood approach, with the latter exhibiting a higher number of matches. More precisely, severe (winter) weather type LSRs consistently (rarely) coincided with lightning, as greater (less) than 97% (1%) of grid-points met the matching criteria. The greatest concentration of severe LSRs without lightning occurred near the Mid-Atlantic States. On the other hand, principal locations for winter LSRs with lightning stretched from the Central and Southern Plains northeastward towards the Great Lakes, with a secondary maximum over the Rocky Mountains.

1. Introduction and Background

By definition, all thunderstorms (regardless of severity) require the presence of lightning, which in itself can be life threatening and produce property damage. While relatively rare, winter thunderstorms can similarly occur where lightning is coincident with freezing rain, sleet, or snow (i.e., thundersnow), and evidence has shown a tendency for heavier amounts of frozen precipitation to be located in close proximity to these types of events (e.g., Crowe et al. 2006). In light of that relationship, winter thunderstorms are capable of disrupting transportation, electricity, and other public services.

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The NWS Storm Prediction Center (SPC) is primarily responsible for forecasting the risk of tornadoes and severe thunderstorms as well as the probability of lightning across the contiguous United States. A severe thunderstorm is defined by the National Weather Service (NWS) to contain wind gusts ≥ 50 kt, hail ≥ 1" in diameter, and/or produce a tornado. Most notably, this has been accomplished through scheduled products (e.g., convective outlooks) as well as those that are issued on an as-needed basis (e.g., tornado and severe thunderstorm watches). In addition, the mission of the SPC has expanded to include other hazardous mesoscale weather phenomena since the organization moved from Kansas City to Norman in the late-1990s. For this purpose, separate outlooks are produced for the prospect of favorable fire weather conditions (e.g., dry thunderstorms) and mesoscale discussions are also issued for high-impact winter precipitation events that are expected over the next six hours.

Observational data play a crucial role at the SPC given the short-term nature for many of the products issued. Besides being essential for the purpose of verifying forecasts, observations provide situational awareness as forecasters monitor current conditions. In fact, the ability to combine data from various observational networks can help to validate the occurrence of significant weather events, as well as provide more detailed information about developing convective storms. Typical national composite overlays include standard surface observations in conjunction with radar and/or satellite image products. More recently, post-processing of decoded Local Storm Reports (LSRs) and total (cloud-to-ground [CG] and intra-cloud [IC]) lightning data has facilitated a more comprehensive analysis of storm characteristics in near real-time.

The relationship between preliminary LSRs and total lightning flash data was explored using time-matched, high-resolution gridded data during 2014 for the contiguous United States. The purpose of the current work is to provide some initial statistical characteristics of the lightning data when stratified by geographic region, time of year, time of day, and type of flash (IC or CG). Details on the location and frequency of active lightning grid-points relative to severe and winter type LSRs are also examined.

2. Data

a. Lightning Data at SPC

The availability of total lightning within the operational weather community has been a relatively new phenomenon, and until recently, most lightning applications have used CG data sets. Bothwell (2014) documented the use of CG flashes from lightning detection networks at SPC over the last 30 years to monitor on-going convective systems and created frequency climatologies from these data. For evaluation purposes at the SPC, the Short-Range Ensemble Forecast (SREF) calibrated thunder probabilities have also relied upon a threshold of one or more CG lightning flashes as ground truth (Bright et al. 2005). Traditionally, access to real-time data at SPC has been provided by Vaisala's National Lightning Detection Network (NLDN). From the same vendor, an annual quality-control (QC) version of the CG flash data was also obtained the following year for climatological assessments and other research objectives.

There are several motives behind the current shift to examine both CG and IC flashes on a routine basis. In terms of actual flash counts, the CG portion is small when compared with IC. Furthermore, and more importantly, IC flashes often precede CG flashes in identifying convective initiation (MacGorman and Rust 1998), and there is ongoing research on how these data aid in the diagnosis of convection related to severe weather (or possibly hazardous winter weather). As noted by Bothwell (2014), this was addressed by late 2012 as SPC acquired total lightning data from another vendor, namely the Earth Networks Total Lightning Network (ENTLN). For the current work, characteristics from the QC-CG NLDN data for 2014 will be compared to the CG and IC flash counts from the ENTLN.

b. Local Storm Reports

LSRs are issued by the NWS Weather Forecast Offices (WFOs) to provide preliminary and timely information about previous or ongoing hazardous weather events. SPC has been decoding tornado, hail, and thunderstorm wind gusts and wind damage LSRs associated with severe thunderstorms in an automated manner for about 20 years. A new LSR decoder was developed recently to include winter weather-related reports from the NWS. Winter weather event types that are used in these preliminary LSRs include snow, heavy snow, blizzard, freezing rain, ice storm, and sleet. Of these six, snow, heavy snow, freezing rain and sleet require an event magnitude to be entered, as either estimated or measured (NOAA 2015). All LSR types for severe thunderstorm and winter events are examined in this study for 2014 except for those associated with blizzard and ice storm, as they comprise a very small proportion of the winter sample size. This finding agrees with the 2010-2012 analysis period used in Sullivan et al. (2014), in which only about 1 percent of the total winter reports came from these two categories combined.

3. Methodology

a.) Assembling the Datasets

For all of 2014, hourly lightning accumulation bins were created for flash counts from the QC-CG NLDN as well as for CG, IC, and total lightning flashes from ENTLN. An analogous procedure was performed for total severe LSRs and total winter LSRs. The observations were then placed on nearest 0.04° × 0.04° lat-lon grid-points in GEMPAK (GEneral Meteorological PAcKage; desJardins et al. 1991) format. In order to properly match against storm reports, a mask was also applied to eliminate oceanic lightning flashes by restricting the analysis domain to the continental United States. For each grid-point, separate tallies were then created to represent each of the hours (00-23 UTC) and a final annual total. To round out the analysis, domain-wide total counts were obtained in each grouping. Data issues with the ENTLN CG and IC lightning counts for 1 July and 2 July resulted in the sample size being reduced to 8712 hours (363 days).

b.) Matching LSRs with Lightning

For an effective comparison, hourly binary (1/0) event grids for both LSRs and each of the lightning datasets were constructed by specifying thresholds. For the former, an observed severe/winter object was recorded if ≥ 1 report occurred within the hour. Similarly, the latter dataset used a threshold of ≥ 1 lightning flash to indicate the presence of a thunderstorm. Using these new event grids, a direct grid-point-to-grid-point comparison between the two sets of observations could then result in four possible outcomes (Table 1; Wilks 2006). Of the four possibilities shown in Table 1, only those grid-points where LSRs occur with lightning or without lightning were examined further to obtain percentages of all LSRs matched with CG or IC flashes.

Table 1. 2x2 contingency table matching binary event grids for both LSRs and Lightning.

LSR with Lightning	Lightning with NO LSR
LSR with NO Lightning	Neither Lightning nor LSR

Matching grid-point to grid-point is challenging on a high-resolution grid given the fact that lightning activity might be in close proximity to the observed severe weather (e.g., tornado) even if not precisely co-located. In order to account for this possible offset, one standard approach relies on setting a radius of influence (ROI) to incorporate a spatial "neighborhood" around each grid-point. In setting an appropriate ROI, a 40-km value was used here to be consistent with SPC Convective Outlooks. For the current investigation, a neighborhood maximum was applied to each of the hourly lightning flash counts from the NLDN and ENTLN datasets. From these new gridded fields, corresponding binary events were produced by requiring ≥ 1 flash within 40-km of each 4-km grid box over the one-hour period and paired against LSRs. This resulted in a set of neighborhood tallies and related percentage values that were compiled for all of 2014.

4. Results: Lightning Dataset Comparisons

a.) Annual Trend Characteristics

Some basic characteristics and comparisons of the various lightning datasets in 2014 will be discussed in the next few sections. Figure 1 shows the running tally of hourly flashes throughout the year from the QC-CG NLDN in comparison to the CG, IC, and combined total lightning flashes from ENTLN. As expected, thunderstorms were relatively suppressed in the first couple months when generally more cool and stable environments prevailed across the contiguous United States. However, the regular presence of both CG and IC lightning first becomes noticeable by the beginning of April with convection increasing in frequency through the summer (Fig. 1). Finally, the lightning activity across the country began to diminish by the middle of October.

While there were day-to-day variations, the number of IC flashes was typically much greater when compared to CG flashes. In fact, a very large proportion (~0.89) of the total lightning by the end of 2014 came from the IC contribution (Fig. 1). Consistent with this outcome, it is interesting to note the marked increase in the slope of the accumulations came during the summer months during which there were a total of about 90 to 100 million lightning flashes. In terms of CG lightning, the annual tally rises more steadily to a total of roughly 20 million flashes (Fig. 1). In spite of the general similarities between the two vendors, NLDN detections of CG flashes were about 1.22 times higher than those from ENTLN.

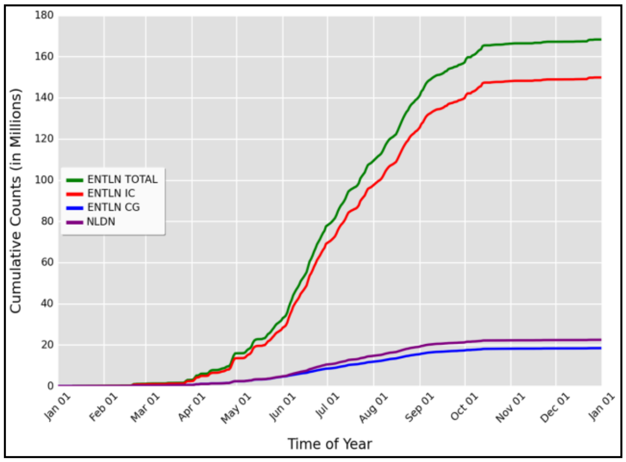

Figure 1: Running annual tally of hourly lightning flashes in 2014 from QC-CG NLDN. For comparison, total lightning counts from ENTLN as well as the corresponding CG and IC flash components are provided.

b.) Diurnal Trend Characteristics

To identify diurnal trends, lightning flash tallies from the datasets were obtained for each hour in a day by summing every day in 2014. Figure 2 shows the cumulative hourly count of total lightning from ENTLN alongside the corresponding percent contribution to the annual result established in Fig. 1. This diagnosis revealed a typical pattern of thunderstorm coverage maximizing with solar heating in the late afternoon time period. After the relative minimum of about 1% for the hour ending at 1500 UTC, Fig. 2 showed a substantial increase in total lightning between 1700-1900 UTC with more than half of all flashes occurring over the next seven hours. During this active time frame, the peak amplitude surpassed 15 million flashes for the hour ending at 2300 UTC and approximately represented a 9% share of the full diurnal cycle (Fig. 2).

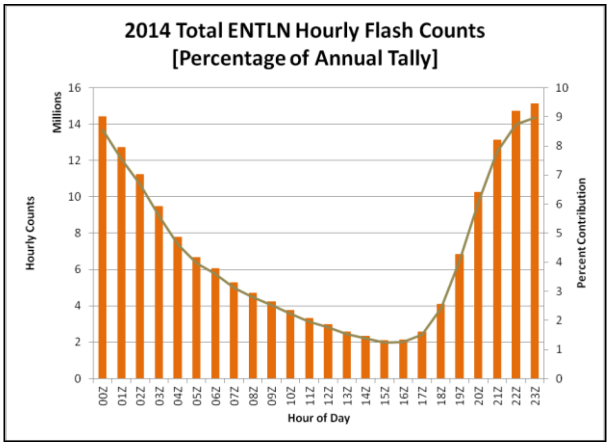

Figure 2: 2014 Total ENTLN hourly flash counts (in millions) and percentages of annual tally.

A brief examination of separating the ENTLN dataset into CG and IC components for every hour is also pursued. Figure 3 suggested the IC (CG) portion to be consistently large (small) with a range between 85 to 91% (9 to 15%). More precisely, the relative number of IC flashes exceeded the overall annual result (~0.89 in Fig. 1) for half the day extending from 1800-0600 UTC On the other hand, a comparison of Fig. 2 against Fig. 3 demonstrated the lowest frequency of total lighting during the morning coinciding with the maxima (minima) in CG (IC) ratios.

A diurnal comparison of CG lightning from the NDLN and ENTLN is shown in Fig. 4. On a national scale for 2014, both networks reached their greatest flash tally for the year at 2200 UTC with the lowest sum for the hour ending at 1600 UTC. This timing pattern closely agrees with that of Holle (2014) who examined average CG flash densities across the contiguous United States in two hour bins over the course of eight years (2005-2012). However, the smaller amplitudes here for NLDN compared to his work (compare Fig. 4 to Fig. 2 in Holle 2014) are at least partly the result of neglecting favorable convective areas offshore in the Atlantic Ocean and Gulf of Mexico that Holle (2014) included in his analysis. While the CG flash relationship between the datasets varied hour to hour, the cumulative NDLN to ENTLN ratios established that NLDN often had many more CG flashes with nearly 1.4 times more detections by 0100 UTC (Fig. 4).

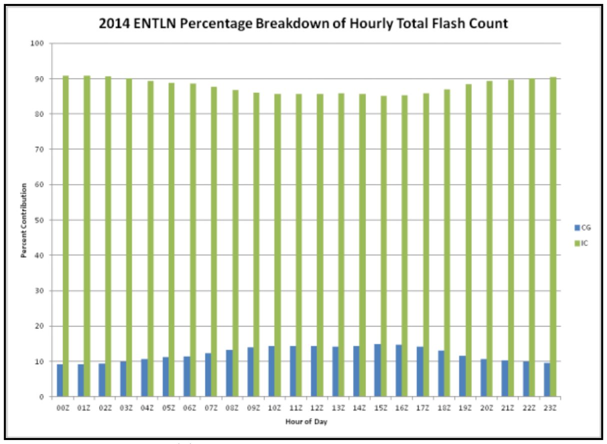

Figure 3: 2014 ENTLN percentage breakdown of hourly total flash counts into CG and IC portions.

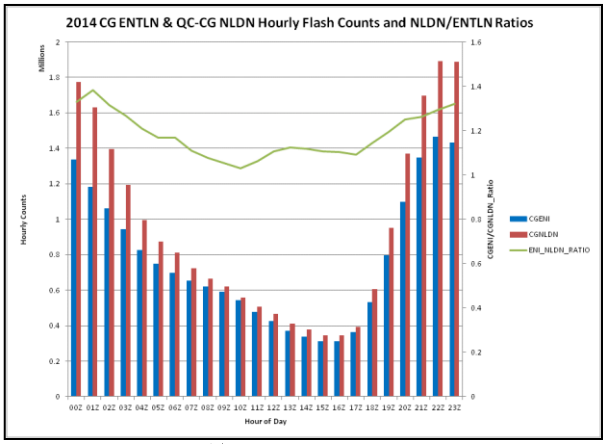

Figure 4: 2014 CG ENTLN and QC-CG NDLN hourly flash counts (in millions) into NLDN/ENTLN Ratios.

c.) Spatial Pattern Characteristics

The information considered thus far was accumulated across the entire analysis domain with no specifics about geographic variability. To examine spatial characteristics, plots were constructed to explore variations in lightning characteristics for different regions of the country. Figures 5 and 6 present analyses of high-resolution, aggregate CG flash counts for all of 2014 from the NLDN and ENTLN, respectively. For the year, the highest frequency of thunderstorms was located in Florida and along the Gulf Coast.

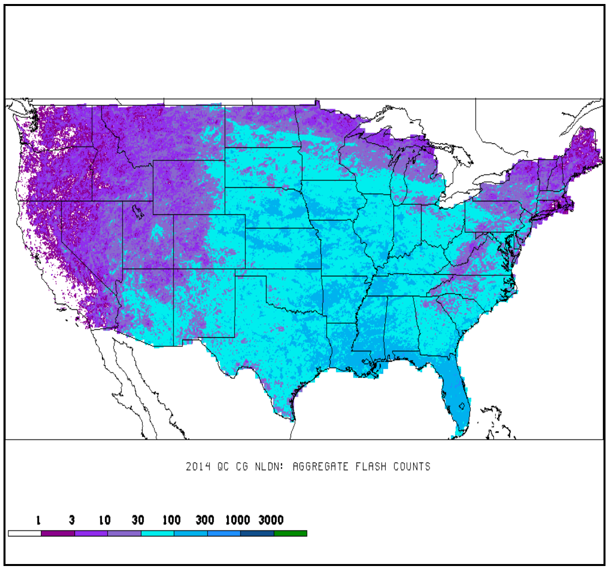

Figure 5: 2014 QC-CG NLDN aggregate flash counts for the high-resolution grid covering the contiguous United States.

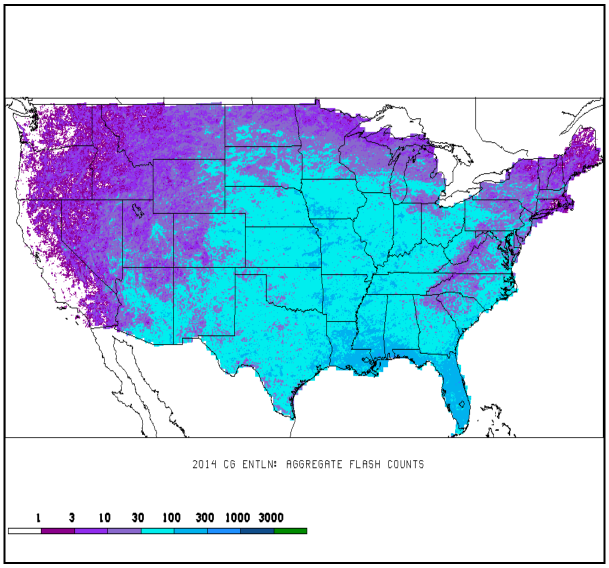

Figure 6: Same as in Fig. 5 except for 2014 CG ENTLN aggregate flash counts.

A broader and less dense, secondary maxima in CG flashes also extended northwestward into the Missouri Valley, this being especially evident in the NLDN analysis (Fig. 5) compared to the ENTLN analysis (Fig. 6). The higher number of detections in Fig. 5 is also supported and made more distinct by the difference plot in Fig. 7. This perspective shows that many more data points across the country, especially east of the Rockies, have higher CG flash counts from the NLDN compared to the ENTLN. Finally, the lowest concentration of lightning activity for 2014 was confined along the West Coast and to a lesser degree in the northern Plains and northern New England. Most of the characteristics emphasized in Figs. 5 and 6 are also consistent with the literature, as found in Orville and Huffines (2001) and Holle (2014).

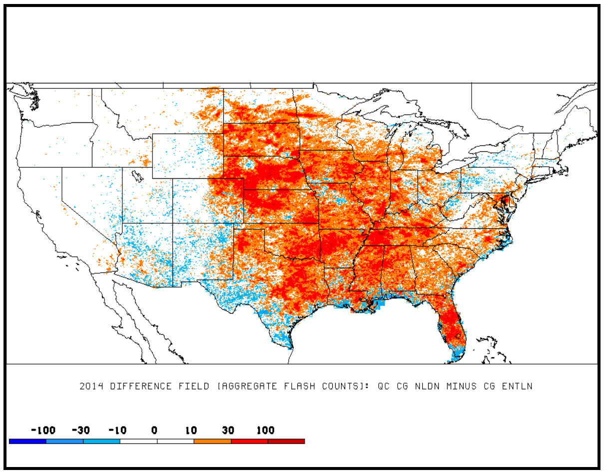

Figure 7: 2014 difference field of aggregate flash counts (QC-CG NLDN – CG ENTLN).

To complement the CG flash map in Fig. 6, yearly counts of IC flashes for each grid-point from the ENTLN are provided in Fig. 8. A comparison of the two highlights the much more extensive, higher number of IC compared to CG flashes. Many locations in the Southeast and Central United States exhibited more than 1000 IC flashes whereas CG flashes only numbered around a few hundred. For completeness, a combined analysis of total lightning from the two ENTLN datasets was also created (Fig. 9). A contrast of Figs. 6 and 8 with Fig. 9 reveals that purely CG activity provides a rough illustration of thunderstorm coverage, but by incorporating IC, a more robust and accurate depiction on the frequency of all deep convection is obtained.

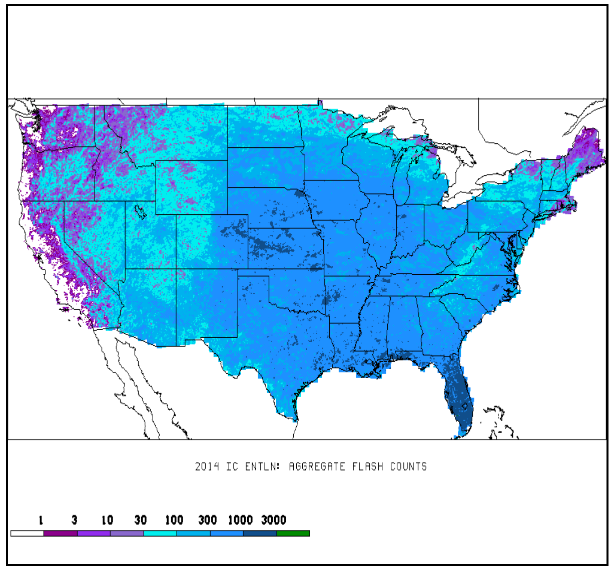

Figure 8: 2014 IC ENTLN aggregate flash counts for the high-resolution grid covering the contiguous United States.

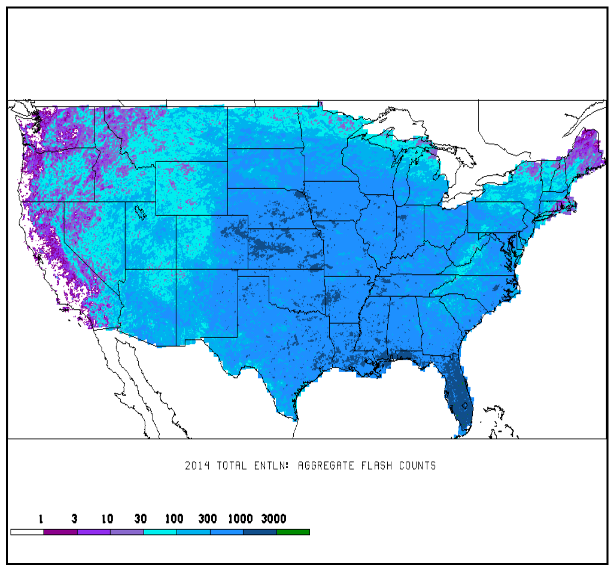

Figure 9: Same as in Fig. 8 except for 2014 Total (CG+IC) ENTLN aggregate flash counts.

5. Results: Matching LSRs with Lightning

a.) Annual Domain Wide Percentages

A method to determine the occurrence of lightning with LSRs was obtained by requiring both datasets to have at least one or more observations for each grid-point. In addition to the traditional matching of grid-point to grid-point, a neighborhood technique was also accomplished by applying a 40-km ROI maximum value to the lightning flash datasets before setting the threshold.

From both approaches, LSR events with or without lightning were accumulated for hourly time steps.

For the first set of comprehensive results from all of 2014, domain-wide percentages of all severe LSRs with lightning flashes are given in Table 2. The percentage of severe LSRs with ENLTN CG flashes was lowest (i.e., ~56% at the grid-point in Table 2) presumably due to the fewer number of lightning detections compared to NLDN. By taking into account the IC flash portion in the ENTLN, a higher fraction of severe reports was associated with IC flashes. For all lightning datasets, though, application of a neighborhood concept resulted in more matches with the LSRs, in which both sets of observations might be slightly displaced from one another but still considered to be in proximity. Results from this method showed that severe LSRs consistently coincided with CG and IC flashes (97% to 98% in Table 2). Eventually, the highest correspondence overall (and highest percentage computed for Table 2) was found by combining the effects of CG and IC together (total lightning) from ENTLN.

Table 2. Domain wide percentages [%] of all severe LSRs with lightning flashes are presented for all of 2014. In the evaluation, results are separated into NLDN or ENTLN datasets and whether the matching approach was just grid-point to grid-point or a 40-km ROI (neighborhood) was applied to the lightning flashes. The sample size was 21,194 grid-points with one or more LSRs.

Lightning Dataset	QC-CG NLDN	CG ENTLN	IC ENTLN	TOTAL ENTLN
Grid-point	65.868	56.389	83.675	84.467
Neighborhood	97.462	97.211	97.933	98.014

For the association of winter-type weather LSRs with lightning, domain-wide percentages in Table 3 for 2014 show a very low percentage of winter LSRs associated with lightning, regardless of whether the NLDN or ENTLN was utilized in the matching scheme. Again, the highest percentages were obtained by combining occurrences of both CG and IC flashes and specifying a neighborhood area around each grid-point. Nevertheless, winter LSRs very rarely were located near thunderstorms as less than 1% of all grid-points were matched to any type of lightning (Table 3). A comparison of Table 3 to Table 2 reveals the distinction in the percentages is even more pronounced since the sample size of grid-points of winter LSRs (64,332) was more than three times greater than that of severe LSRs (21,194).

Table 3. Same as in Table 2 except for domain wide percentages [%] of all winter LSRs with lightning flashes in 2014. The sample size was 64,332 grid-points with one or more LSRs.

Lightning Dataset	QC-CG NLDN	CG ENTLN	IC ENTLN	TOTAL ENTLN
Grid-point	0.04	0.03	0.05	0.06
Neighborhood	0.555	0.622	0.639	0.759

b.) *Locations of Severe LSRs without Lightning*

Identification of preferred areas in the contiguous United States that experience severe LSRs without neighboring lightning was explored next. Since the annual frequency was only 2-3% (i.e. Table 2), counts of one or more objects in a 40-km ROI were needed to successfully emphasize event concentrations that might not show up well on a high-resolution grid. From this effort, Figs. 10 and 11 show the resultant spatial plots using either the QC-CG NLDN or total lightning from ENTLN, respectively. Higher density coverage occurred near larger-sized cities, mostly east of the Rocky Mountains and particularly in the mid-Atlantic states. Figure 10 showed that clustering of five or more severe LSR events without lightning was often common in such locations when using the NLDN. In contrast, using IC flashes through total lightning as Fig. 11 indicated a reduction in LSRs without lightning across the domain.

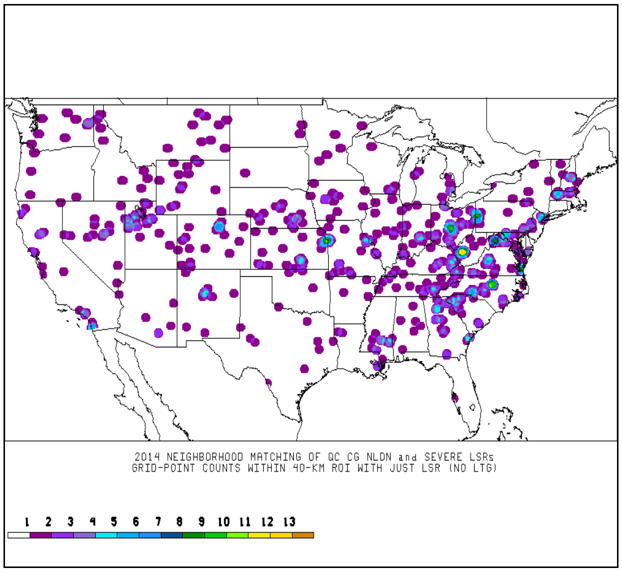

Figure 10: Neighborhood matching of QC-CG NLDN and severe LSRs. Grid-point counts of 1 or more reports without lightning within 40-km ROI.

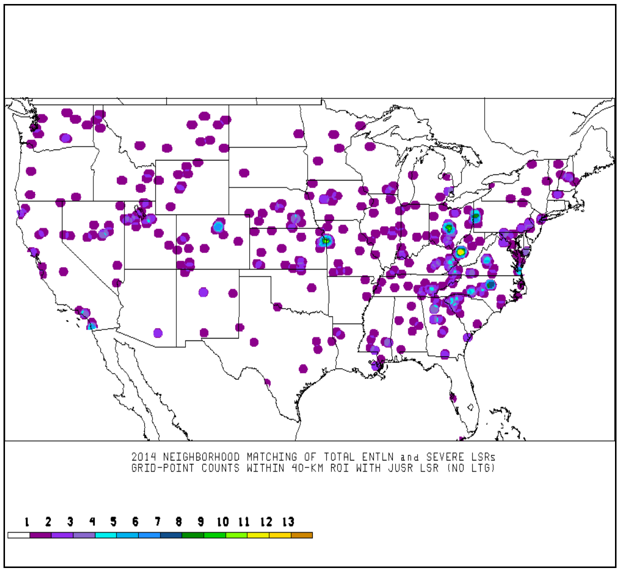

Figure 11: Same as in Fig. 10 except for neighborhood matching of total (CG+IC) ENTLN and severe LSRs.

c.) Locations of Winter LSRs with Lightning

A similar process was used to determine geographical regions which exhibit winter LSRs *with* lightning in the vicinity. Again, the QC-CG NLDN or total lightning from ENTLN were utilized to create the analyses in Figs. 12 and 13, respectively. Both perspectives revealed winter LSRs with nearby lightning occurred primarily in an axis from the Southern Plains northeastward toward the southern Great Lakes, with a secondary maximum scattered over the Rocky Mountains. Again, comparison of Fig. 12 with Fig. 13 suggested further evidence that matching of reports against convection should not be limited to just CG flashes. In fact, more winter LSRs were found with total lightning from the ENTLN as event concentrations increased noticeably in many populated areas (e.g., compare results near Detroit and Pittsburgh in Fig. 12 versus Fig. 13).

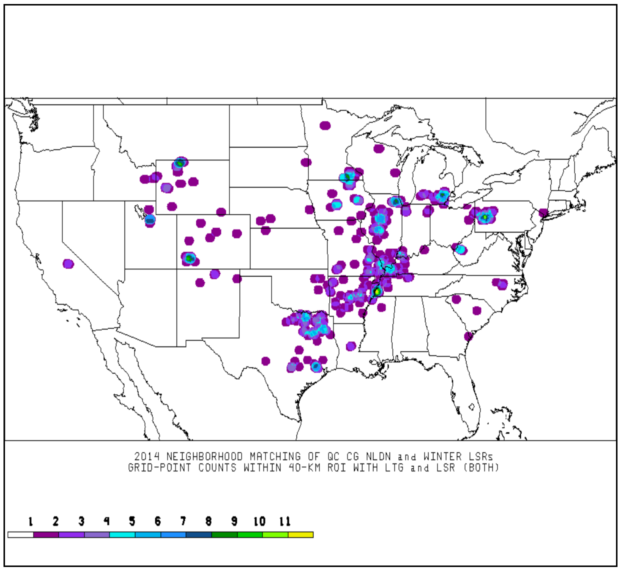

Figure 12: Neighborhood matching of QC-CG NLDN and winter LSRs. Grid-point counts of 1 or more reports with lightning within 40-km ROI.

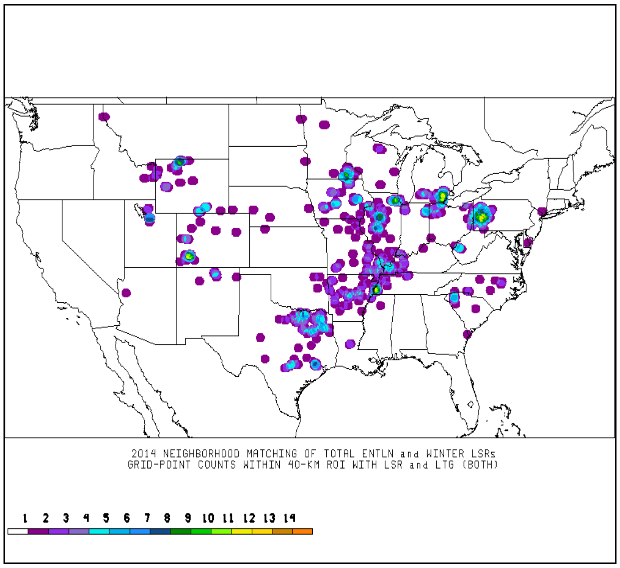

Figure 13: Same as in Fig. 12 except for neighborhood matching of total (CG+IC) ENTLN and winter LSRs.

6. Summary and Conclusions

SPC has traditionally utilized CG lightning for a variety of purposes to identify, track, and verify the presence of thunderstorms. Recently, the inclusion of IC flash data through total lightning has been made available to the forecasters at the SPC. Characteristics of how total lightning aids in the diagnosis of convection related to severe weather (or possibly hazardous winter weather) are an ongoing area of research. To address this issue, a systematic evaluation and comparison of annual lightning properties from two different detection networks was performed in the current work. Ultimately, this will contribute to a growing awareness of the advantages of incorporating IC flashes and total lightning instead of just relying on CG flashes in an operational environment.

For all of 2014, archived QC-CG flashes from the NLDN were utilized and evaluated against the CG, IC, and combined total (CG+IC) lightning from the ENTLN. In addition to understanding basic characteristics of these datasets, different types of observations were examined to gain extra detail on convective storms. For this study, the correspondence of lightning flashes and preliminary LSRs (both total severe types and total winter-weather types) were examined on an hourly, high-resolution grid covering the contiguous United States. In addition to directly matching grid-point to grid-point, a spatial neighborhood approach was used to account for lightning activity that might be in close proximity to storm reports even if not precisely co-located. This was accomplished at each grid-point by setting a 40-km ROI maximum value to each of the hourly lightning flashes. Of the four possible outcomes, only those grid-points where LSRs occur with lightning or without lightning were examined further to obtain percentages of all LSRs matched with CG or IC flashes.

The following conclusions highlight some initial statistical characteristics of the lightning data when stratified by geographic region, time of year, time of day, and type of flash (IC or CG). After thunderstorms were somewhat suppressed early in 2014, the regular presence of lightning first becomes noticeable by the beginning of April. As deep convection grew in frequency through the summer, there was a marked increase in the accumulation of IC lightning flashes compared to the slower increase of CG activity. Finally, the persistent activity throughout the country began to diminish by the middle of October. Aggregate annual counts from the ENTLN and NLDN show overall similarity in CG flash patterns but NLDN detections were 1.22 times more common than ENTLN flashes. Furthermore, tallies of IC were often much more extensive and numerous than CG across the contiguous United States as the exceptionally large IC proportion [~0.89] for the entire domain dominated the contributions to total lightning. Not surprisingly, locations in Florida and along the Gulf Coast exhibited the highest frequency of thunderstorms with a secondary maximum more evident with the IC flash dataset extending into the Missouri Valley.

The diurnal trend analysis revealed a typical pattern of thunderstorm occurrence maximizing with solar heating in the late afternoon. On a national scale, hourly cumulative CG flashes from both lightning detection networks reached their greatest count for the year during the 2200 UTC hour with the lowest sum for the hour ending at 1600 UTC. This timing pattern closely agrees with the average CG flash densities from the multi-year climatology by Holle (2014). The cumulative NDLN to ENTLN ratios were nearly similar for a few hours, but NLDN had nearly 1.38 times more detections in the hour preceding 0100 UTC. For total lighting, a slight offset was noted in the diurnal cycle as the relative minima and maxima occurred near 1500 and 2300 UTC, respectively. Separation of the ENTLN dataset into CG and IC components for every hour suggested the IC (CG) portion to be consistently very large (very small) with a range between 85 to 91% (9 to 15%). Interestingly, the maximum (minimum) in CG (IC) ratios coincided with the lowest frequency of total lighting during the morning.

Finally, matching reports and lightning was accomplished through a direct grid-point to grid-point comparison and application of a neighborhood approach, with the latter results exhibiting higher domain-wide percentages. More precisely, severe (winter) weather type LSRs consistently (rarely) coincided with CG or IC in 2014, at greater (less) than 97% (1%) of grid-points. Still, an important finding from this work was that incorporating IC in total lightning data led to more matches with LSRs. Spatial plots showed the density of severe LSRs without lightning in the 40-km ROI occurred east of the Rocky Mountains near larger cities with the greatest concentrations in the Mid-Atlantic States. On the other hand, principal locations for winter LSRs with nearby lightning stretched from the Southern Plains northeastward toward the southern Great Lakes, with a secondary maximum over the Rocky Mountains. Again, there tended to be a higher occurrence of lightning coincident with LSRs by including both CG and IC detections in the ENTLN. Future work aims to explore the relative contribution of tornado, wind, and hail LSRs to the overall severe report associations with CG and IC flash datasets. A similar breakdown could also be accomplished for winter weather LSRs to determine whether snow, heavy snow, freezing rain, or sleet reports were most associated with convection.

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REFERENCES

Bothwell, P.D., 2014: Comparison of total lightning and severe weather reports during the 2013 convective season. Preprints, *XV International Conference on Atmospheric Electricity*. Norman, OK.

Bright, D.R., M.S. Wandishin, R.E. Jewell, and S.J. Weiss, 2005: A physically based parameter for lightning prediction and its calibration in ensemble forecasts. Preprints, *Conf. on Meteor. Applications of Lightning Data*, San Diego CA

Crowe, C., P. Market, B. Pettegrew, C. Melick, and J. Podzimek, 2006, An investigation of thundersnow and deep snow accumulations, Geophys. Res. Lett., 33, L24812, doi:10.1029/2006GL028214.

desJardins, M.L., K.F. Brill, and S.S. Scots, 1991: Use of GEMPAK on Unix workstations, *Proc. 7th International Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, New Orleans, LA, Amer. Meteor. Soc., 449-453.

Holle, R.L., 2014: Diurnal variations of NLDN-reported cloud-to-ground lightning in the United States. *Mon. Wea. Rev.*, **142**, 1037–1052.

MacGorman, D.R., and W.D. Rust, 1998: *The Electrical Nature of Storms*. Oxford University Press, 422 pp.

NOAA, cited 2015: Multi-Purpose Weather Products Specification, National Weather Service Directive 10-517 [Available online at: http://www.nws.noaa.gov/directives/sym/pd01005017curr.pdf].

Orville, R.E. and G.R. Huffines, 2001: Cloud-to-ground lightning in the United States: NLDN results in the first decade, 1989-98. *Mon. Wea. Rev.*, **129**, 1179-1193.

Sullivan, B.T., C.J. Melick, R.M. Mosier, I.L. Jirak, and C.D. McCray, 2014: The usefulness of winter weather local storm reports at the Storm Prediction Center. Preprints, *39th Natl. Wea. Assoc. Annual Meeting*, Salt Lake City, UT, Natl. Wea. Assoc., P1.9.

Wilks, D.S., 2006. *Statistical Methods in the Atmospheric Sciences,* 2nd Ed. International Geophysics Series, Vol. 59, Academic Press, 627 pp.