1.2 STATISTICAL PROPERTIES OF ENI IC/CG FLASHES RELATIVE TO NLDN CG FLASHES OVER THE CONUS

Jerome P. Charba*
Frederick G. Samplatsky
Judy E. Ghirardelli
National Weather Service, NOAA
Office of Science and Technology
Meteorological Development Laboratory
Silver Spring, Maryland

Andrew J. Kochenash
Wyle Science, Technology & Engineering Group
Silver Spring, Maryland

Phillip D. Bothwell**
National Weather Service, NOAA
National Centers for Environmental Prediction
Storm Prediction Center
Norman, Oklahoma

1. INTRODUCTION

Cloud-to-ground (CG) lightning flashes have been provided for the contiguous United States (CONUS) from the National Lightning Detection Network (NLDN), developed and operated by Vaisala, Inc. (http://www.vaisala.com/en/products/thunderstormandlightningdetectionsystems/Pages/NLDN.aspx) since 1989. Beginning in May 2013 Vaisala added in-cloud (IC) flash data over the CONUS (private communication with Ken Goss of Vaisala), which together with CG flashes are called total lightning (TL). CONUS TL data based on a somewhat different technology have also been provided in recent years by Earth Networks, Inc. (ENI;http://www.earthnetworks.com/OurNetworks/LightningNetwork.aspx).

In this study, NLDN CG and ENI CG and IC flash data from recent archives are gridded and various derived statistical parameters are compared. [NLDN IC data are not included since an archive is not available under the current contract Vaisala has with the National Weather Service (NWS).] Also shown are example CG and IC flash maps to aid interpretation of the statistics. The purpose is to determine how the CONUS NLDN and ENI flash data compare with one another. This is important to the NWS because accurate, stable IC/CG flash data are needed, especially for forecast/warning operations and modelling applications.

2. DATA SAMPLES AND ANALYSES

The NLDN and ENI archives used in this study are for 01 January 2012 to 01 January 2015. (ENI advised the lead author that the quality of earlier archived ENI TL data is deficient, and thus these were not used.) Because of the shortness of the sample, the data are pooled by season, where April - September defines the warm season and October - March defines the cool season.

The analyses of the data initially involved its gridding, whereby daily (1200 UTC - 1200 UTC) flash counts are tabulated for 10 km square grid boxes. Fig. 1 shows comparative NLDN and ENI maps of means of these daily CG flash count grids for the full warm seasons of 2012 - 2014; these maps are consistent with documented lightning climatology maps (e.g., Orville et al. 2011). Note from the NLDN map that the data are missing over much of Canada, which is due to geographical coverage restrictions in the current Vaisala - NWS contract, and CG counts are anomalously low or missing near the western and southern fringes of the grid. Thus, for derivation of grid-wide NLDN

* *Corresponding author address:*
Dr. Jerome P. Charba, National Weather Service
1325 East West Highway, Room 10204
Silver Spring, MD 20910-3283
email: jerome.charba@noaa.gov
**Retired

and ENI CG (and IC) summary statistics discussed later, the data are aggregated over the area where the NLDN and ENI CG data coverage is similar in Fig. 1. This area is depicted as shaded in Fig. 2, and henceforth all *"CONUS summary statistics"* are based on data therein.

3. ENI VERSUS NLDN CG FLASH COUNTS

Near the outset of the study ENI informed the lead author that ENI implemented major system upgrades on 04 June 2013 and 04 June 2014 (Christopher Sloop, private communication, September 2014). Fig. 3 shows two 60-day time series of CONUS-aggregated NLDN and ENI daily CG counts, each centered on one of these dates. Note that prior to the 04 June 2013 upgrade ENI CG counts were generally much higher than NLDN CG (baseline) counts, but this large ENI "bias" abruptly ended beginning with this upgrade. Afterward ENI CG counts were quite close to NLDN counts, though still slightly higher generally. Following the second upgrade on 04 June 2014, ENI CG counts continued to be close to NLDN counts but a switch from slightly higher to slightly lower than NLDN CG counts occurred.

Fig. 4 shows NLDN (left) and ENI (right) maps of mean daily CG counts for the warm season prior to the 04 June 2013 ENI upgrade (top) and following the 04 June 2014 upgrade (bottom). The top maps in this figure show ENI with much higher CG counts over most of the grid and the geographical distribution is less uniform than for NLDN. Contrastingly, the corresponding post-upgrade 2014 maps (bottom) show that ENI CG counts are generally closer to NLDN CG counts and the geographical distribution across the grid is more uniform. However, close inspection of the latter maps reveals that over the interior area of the CONUS, ENI CG counts are slightly lower than NLDN counts. Each of the above findings is consistent with findings from Fig. 3. Corresponding maps for the cool season (Fig. 5) exhibit similar features, although (not surprisingly) non-negligible mean daily CG counts are mostly restricted to the southeastern half of the grid and even there magnitudes are far lower than for the warm season.

Daily means of NLDN and ENI CONUS-aggregated CG counts for three within-season subperiods internally bounded by the two ENI upgrade dates are depicted in Fig. 6 for the warm season (top) and cool season (bottom). Note that for the warm season ENI daily mean CG counts were about double those for NLDN before the June 2013 upgrade (left pair of bars in Fig. 6). Afterward, ENI and NLDN counts were much closer to one another, with ENI slightly higher between the two ENI upgrades (center bars) and ENI slightly lower following the 2014 upgrade (right-most bars). The corresponding cool season chart shows similar general trends, except flash count magnitudes are far smaller (expected) and following the second ENI upgrade the ENI count remains very slightly higher (rather than becoming slightly lower) than the corresponding NLDN count. The latter finding could result from relatively good ENI CG detection over the Gulf of Mexico and Atlantic Ocean areas of the grid, as suggested in Fig. 5 (bottom maps), where relatively high cool season CG flash counts appear.

Fig. 7 shows the CONUS daily mean absolute difference (MAD; top) and the root mean squared difference (RMSD; bottom) for NLDN versus ENI CG flash counts for the warm season. Note that MAD and RMSD values are quite large (~110,000 and 130,000 flashes, respectively) before the June 2013 ENI upgrade (left-most bars). Afterward, both parameters dropped to the 20,000 - 40,000 range, which reflects a major improvement in consistency between NLDN and ENI CG flashes. Note that each of these findings is consistent with those from Fig. 3.

Corresponding MAD and RMSD charts for the cool season (Fig. 8) are consistent with those in Fig. 7, but here the MAD and RMSD magnitudes are far smaller -- expected because of lower cool season CG flash counts. One minor difference is that cool season MAD and RMSD values dropped even with the second ENI upgrade, whereas for the warm season these statistics remained about the same with the second upgrade (Fig. 7). A combination of two factors could explain this disparity: (1) flash counts over the CONUS were relatively high during the 2014 warm season (Fig. 6), which is likely to contribute to increased warm season NLDN – ENI flash count differences; and (2) many of the cool season flashes occurred over the Gulf of Mexico and Atlantic Ocean areas of the grid, where CG detection (for either NLDN or ENI or both) may have improved over the course of the 2012-2014 sample) – this should also contribute to decreased cool season NLDN – ENI flash differences.

To aid interpretation of the MAD and RMSD values, Fig. 9 shows paired CONUS maps of NLDN and ENI CG flash count grids for two selected warm season days with extensive 24-h lightning over the CONUS: one for 18 May 2013 in which the CONUS-aggregated daily ENI - NLDN CG count difference was the largest [405,330 flashes; Fig. 9 (top)] and another for 18 May 2013 where this difference was the smallest [7 flashes; Fig. 9 (bottom)]. Close inspection of these map pairs reveals the geographical distributions of NLDN and ENI CG flashes are similar to one another, even for the former date of maximum flash count difference. This suggests CONUS NLDN - ENI flash count differences are dependent mainly on magnitudes of flash counts in locations where lightning occurred in both maps rather than on dissimilar geographical distributions. This agrees with the lead author's experience inspecting a large number (several hundred) of NLDN – ENI maps for time periods of 15 minutes to 24 hours, which is that *NLDN and ENI CG spatial patterns are consistently similar to one another, while the count magnitudes are sometimes substantially different.*

4. ENI IC VERSUS ENI CG FLASH COUNTS

As for CG flashes discussed above, it is important to understand properties of ENI IC flashes in the 2012-2014 archive at hand, including how the ENI upgrades impacted IC flash statistics. Similar to Fig. 3, Fig. 10 shows two 60-day time series of CONUS-aggregated ENI IC and CG counts, each centered on an ENI upgrade date. Note that prior to the 04 June 2013 ENI upgrade IC counts were either about the same or only slightly higher than corresponding CG counts, which is questionable as previous studies based on NLDN CG data together with satellite TL measurements indicate that true IC frequencies are at least several times higher than CG frequencies (see Medici et al. 2015 and references therein). But, the subsequent upgrade resulted in a clear rise in IC counts, such that the average IC level became roughly four times the CG level. However, there is also evidence of a slight coincident drop in CG flashes, which suggests a small fraction of the upward IC surge could have resulted from an ENI change in the flash classification procedure.

The second ENI upgrade on 04 June 2014 resulted in an even stronger increase in IC counts (Fig. 10), whereby the average level of IC flash counts became about eight times CG counts. Also, this IC surge is not accompanied with a trend change in CG counts, which indicates the surge is due solely to enhanced detection of IC flashes.

The geographical distribution of the daily mean ratio of IC to CG flash counts before the first ENI upgrade and following the second upgrade is shown in Fig. 11 for both the warm and cool season. During the warm season prior to the first upgrade (upper left map in Fig. 11) this ratio was three or higher (blue colors) for only a small portion of the CONUS, it was just slightly above one for broad CONUS areas (yellow and above colors in the color bar), and it was even less than one (orange and below colors) over parts of the western US and beyond the CONUS perimeter. Thus, frequencies of IC flashes relative to CG flashes during this period were highly non-uniform across the CONUS and also unrealistically low, as noted earlier. Contrastingly, for the warm season following the second ENI upgrade Fig. 11 (upper right map) shows that the mean IC/CG ratio sharply increased, such that it even exceeds 20 in localized areas mostly over the central and northern CONUS. Further, the geographical distribution of this ratio is now rather uniform across the CONUS. [Note that the IC/CG peak over the Central and Northern Plains is consistent with long term IC/CG climatological studies (see Medici et al. 2015 and references therein).] Similar general trends are also evident for the cool season (Fig. 11; bottom), though the IC/CG magnitude is non-negligible mainly over the lower-right half of each grid. The very low IC/CG in the upper-left half of each grid is due to low flash counts there, as noted previously for CG flashes.

Daily means of ENI CONUS-aggregated IC versus CG counts for the three warm and cool season sub-periods are shown in Fig. 12. For the warm season prior to the first ENI upgrade (the left-most pair of bars in the upper chart), we find the exceedance of IC counts over CG counts is less than a factor of two, which is unrealistically low, as noted before. But, with the first ENI upgrade IC counts surged sharply upward, while CG counts dropped just slightly (center pair of bars), again suggesting most of the IC surge was due to improved detection of IC flashes. The second ENI upgrade ushered another sharp surge in IC flashes, which resulted in CONUS IC flash counts 6 -7 times CG counts (rightmost pair of bars). Further, this surge was not accompanied with a simultaneous reduction in CG flashes, which supports the contention stated previously that it was due solely to improved IC detection. For the cool season, Fig. 12 (lower chart) shows similar trends to those for the warm season, except flash counts are much lower (expected).

Fig. 13 compares ENI 24-h IC and CG flash count maps for the two cases discussed in the previous section [where warm season NLDN and ENI 24-h CG flash count differences were the largest (18 May 2013) and smallest (26 May 2014)]. For 18 May 2013 CONUS-aggregated IC and CG flash counts (not shown in Fig. 13) were (unrealistically) similar (585,596 and 541,136 flashes, respectively). Also, close inspection of Fig. 13 reveals that IC counts relative to CG counts varied strongly across the major lightning feature over the central CONUS, with IC counts exceeding CG counts over the Southern Plains (realistic) and CG counts exceeding IC counts over the Northern Plains (unrealistic). For 26 May 2014, on the other hand, the CONUS-aggregated IC flash count (not shown in Fig. 13) was about six times higher than the CG count (968,306 and 157,556 flashes, respectively), and Fig. 13 shows a realistic, uniform elevation of IC counts over CG counts across the CONUS. Also, the lead author's examination of many other IC and CG maps, both before and after the ENI upgrades and for durations of 15 minutes to 24 hours, revealed findings which are consistent with those from these examples.

5. CONCLUSIONS AND REMARKS

This comparative statistical analysis of daily NLDN CG and ENI CG flashes over the CONUS has shown that prior to the first ENI system upgrade on 04 June 2013 ENI CG flash counts were generally "excessive," based on well established NLDN CG data as ground truth. But, with the first ENI upgrade ENI CG flash counts strongly converged toward NLDN counts and NLDN - ENI flash count differences became relatively small. The second ENI upgrade on 04 June 2014 had relatively little overall impact on the consistency of NLDN and ENI CG flashes, though a slight improvement was evident for the cool season. These conclusions are based on findings from summary statistics and from inspection of many individual NLDN and ENI CG flash count maps involving several time periods in the 15 minute-to-24 hour range.

Each of the two ENI upgrades also had a strong impact on relative counts of ENI IC to CG flashes. Before the first ENI upgrade, IC flash counts were only slightly higher than corresponding CG counts, which reveals an unrealistic distribution of IC to CG flashes. With the first upgrade, ENI IC counts strongly increased to a more plausible relative level, and with the second upgrade, ENI IC counts surged even higher. Presented evidence indicates each of these IC count surges was due to improved IC detection. Also, inspections of many short duration IC and CG flash count maps revealed that ENI IC and CG spatial patterns were consistently similar to one another.

Note that, to date, true IC flash counts are not well established, as present ground-based detection systems for these flashes are rather new compared to well-established detection of CG flashes. It is unfortunate that an archive of NLDN IC flash data was not available for this study, as this would have allowed for an assessment of the quality and stability of Vaisala-supplied TL data for comparison to the assessment performed here for ENI-supplied TL data.

The quality of current and future TL data is a strong concern at the Meteorological Development Laboratory of the NWS, since we are presently undertaking development of two applications of archived ENI TL data. While we have incorporated measures to mitigate potential adverse impacts of changes in properties of ENI TL data revealed in this study, these may not apply to other current or future TL data. Thus, decisions on future providers of TL data to the NWS should carefully consider the ramifications of potential changes in TL data quality.

7. ACKLOWLEDGEMENTS

We are grateful to Christopher Sloop of ENI, who assisted us to improve the quality and completeness of the ENI TL data sample and to gain a better understanding of the data contents by thoroughly answering many questions we posed to him.

8. REFERENCES

Orville, R. E, G. R. Huffiness, W. R. Burrows, and K. L. Cummins, 2011: The North American Lightning Detection Network (NALDN) - Analysis of flash data. *Mon. Wea. Rev.*, **139**, 1305-1322.

Medici, G., K. L. Cummins, W. J. Koshak, S. D. Rudlosky, R. J. Blakeslee,S.J. Goodman, D. J. Cecil, and D. R. Bright, 2015: The intra-cloud lightning fraction in the contiguous United States. *Seventh Conference on the Meteorological Applications of Lightning Data*, Phoenix, AZ, Amer. Meteor. Soc., **348.** (Available online at https://ams.confex.com/ams/95Annual/webprogram/Manuscript/Paper264032/Medici_AMS_Extended_Abstract.pdf)

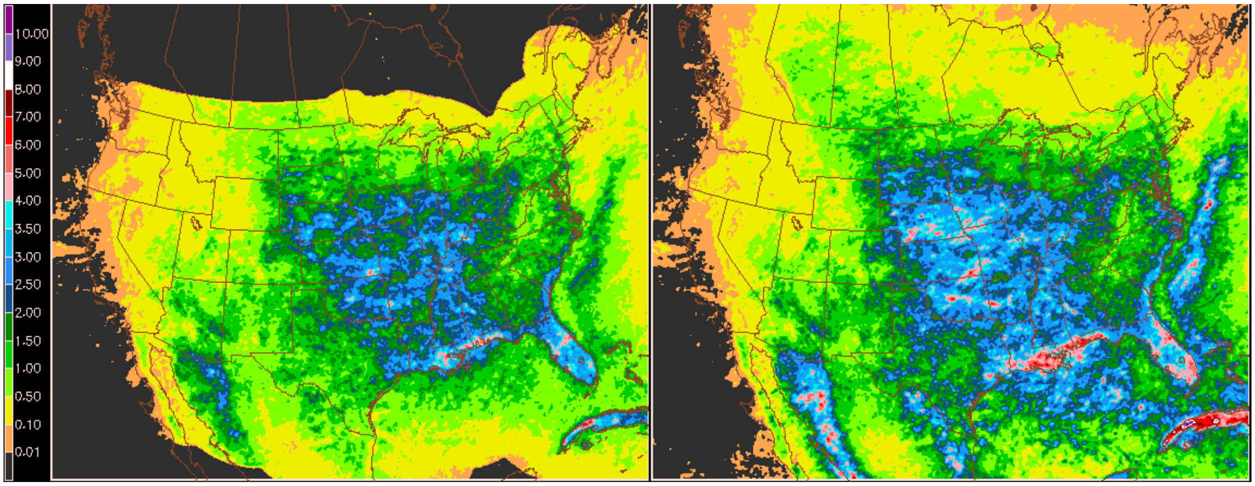

Figure 1. NLDN (left) and ENI (right) mean daily (1200 UTC – 1200 UTC) cloud-to-ground (CG) flash count per 10 km square grid box based on the full 2012 – 2014 warm seasons. Very light spatial smoothing was applied to reduce fine scale variability, which applies to all mean flash count maps in this article.

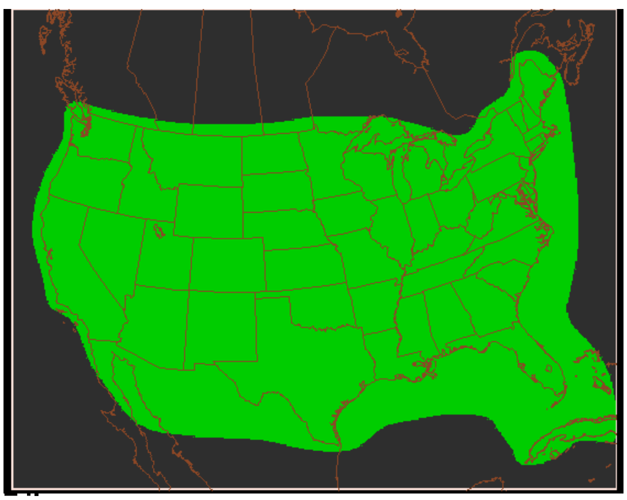

Figure 2. Tabulation grid (bounded by thin white lines) and the "CONUS" area where NLDN and ENI CG flash data coverage is similar (shaded green).

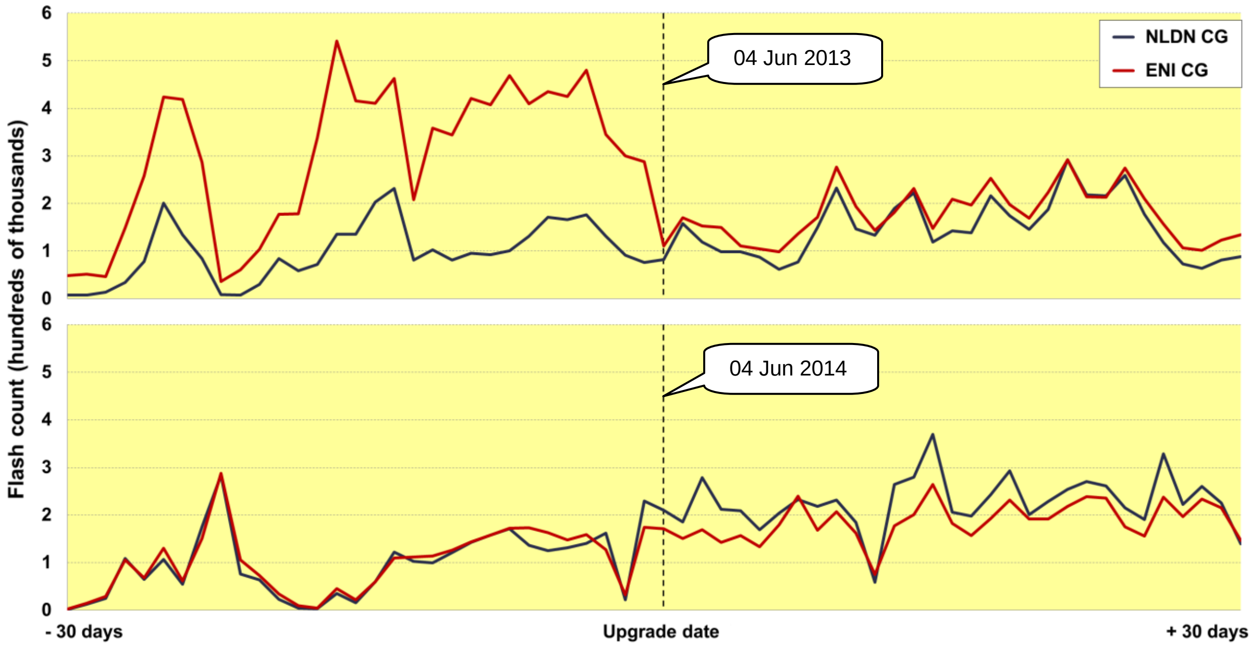

Figure 3. CONUS-aggregated NLDN and ENI CG flash counts for the period 30 days prior to and 30 days after an ENI system upgrade on 04 June 2013 (top) and similarly for 04 June 2014 (bottom). Upgrade dates are indicated by dashed vertical lines.

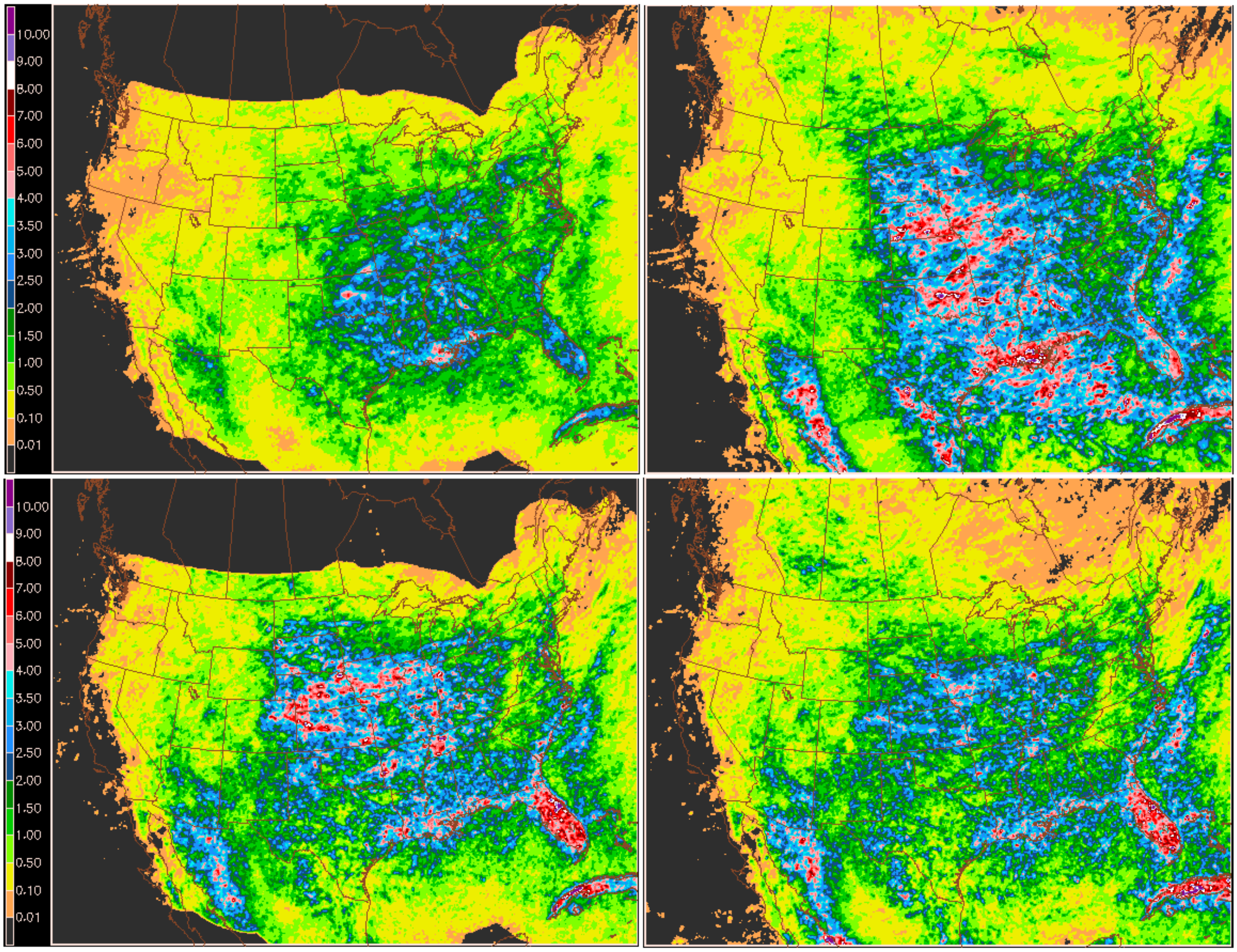

Figure 4. NLDN (left) and ENI (right) mean daily CG count per 10 km grid box for the warm season prior to the 04 June 2013 ENI upgrade (top) and following the 04 June 2014 upgrade (bottom).

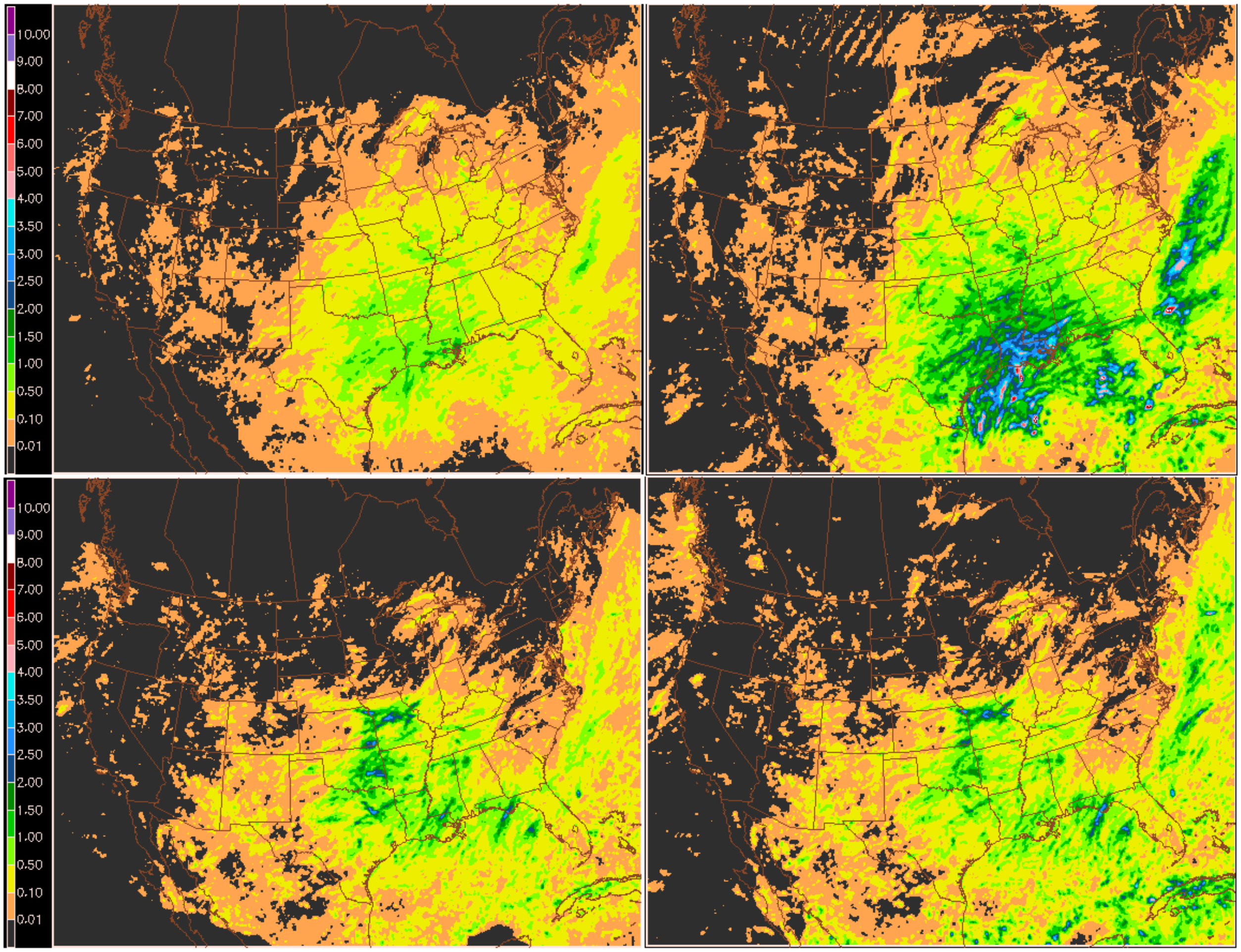

Figure 5. As for Fig. 4 for cool season.

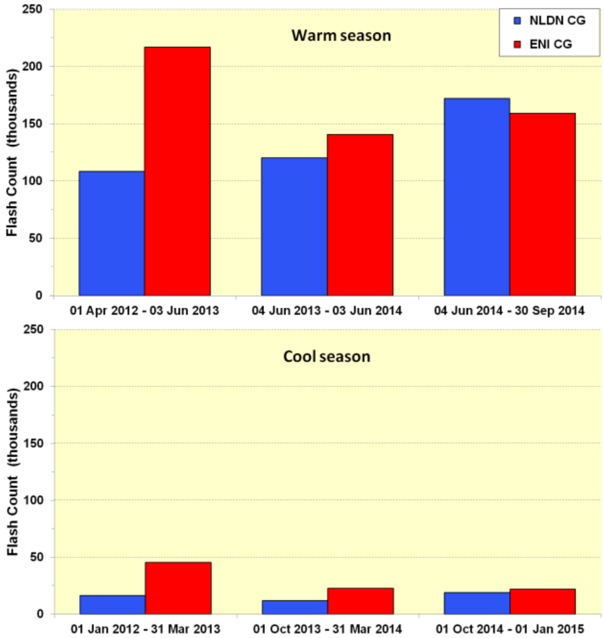

Figure 6. Daily means of NLDN and ENI CONUS-aggregated daily CG flash counts for three warm season (top) and three cool season sub-periods (bottom). The date span of each sub-period is specified along abscissa axis.

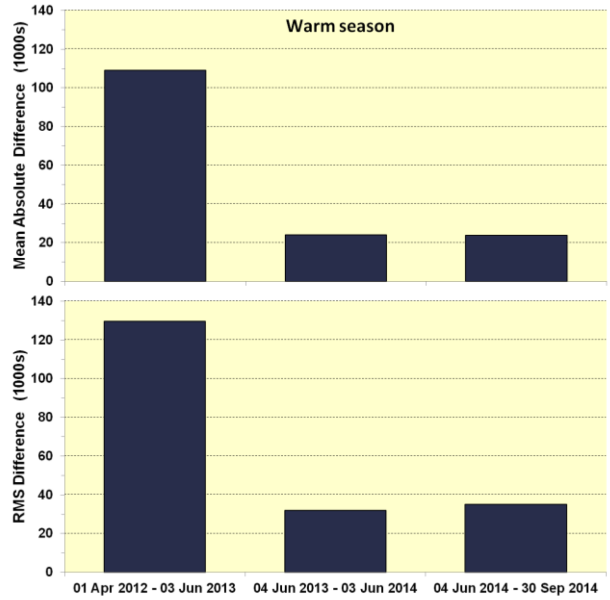

Figure 7. Daily mean absolute difference (MAD; top) and root mean squared (RMS) difference (RMSD; bottom) for ENI versus NLDN CONUS-aggregated daily CG flash counts for three warm season sub-periods. The date span of each sub-period is specified along abscissa axis.

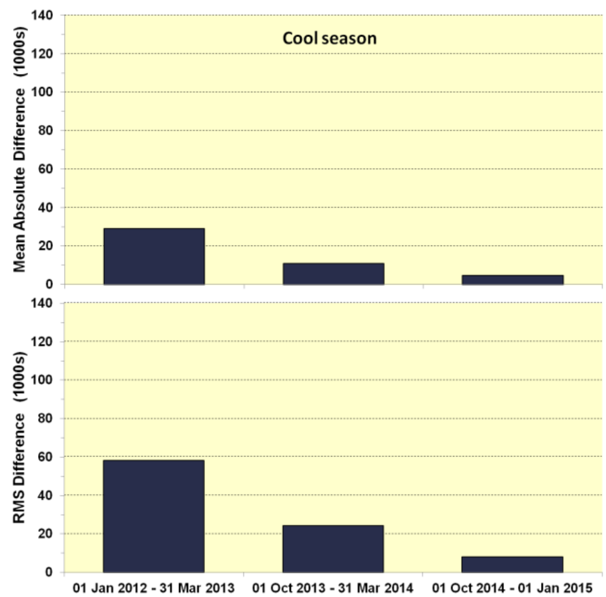

Figure 8. As for Fig. 7 for cool season.

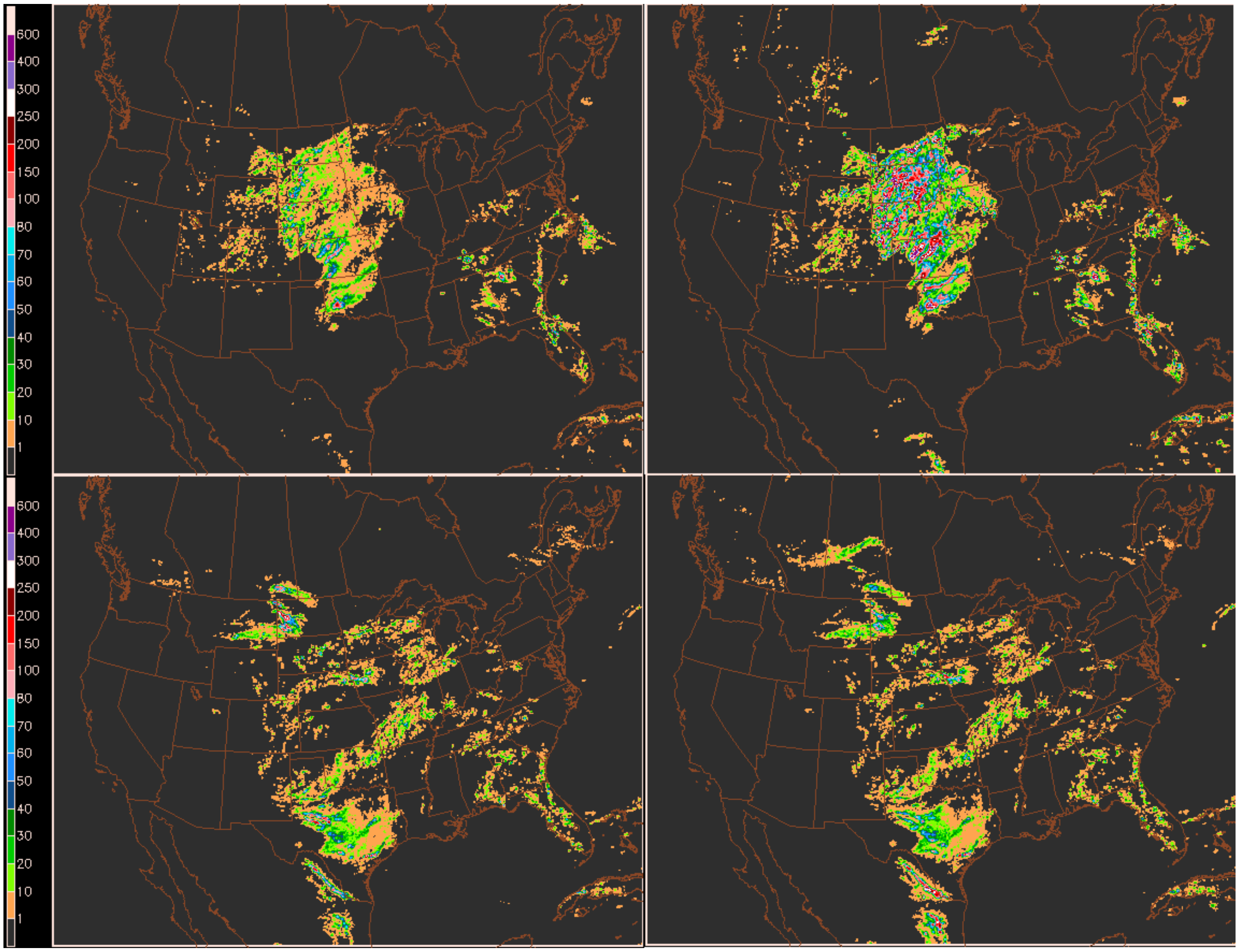

Figure. 9. NLDN CG (left) and ENI CG (right) flash count per 10 km grid box for the 24-h period beginning 18 May 2013 1200 UTC (top) and 26 May 2014 1200 UTC (bottom).

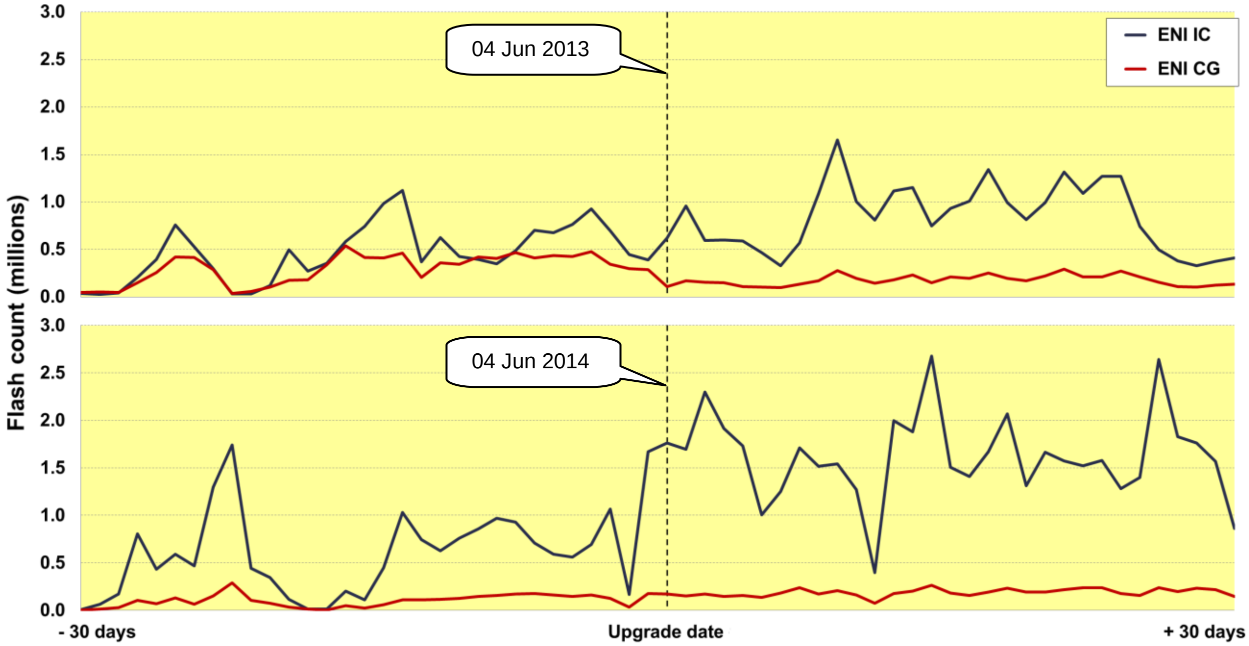

Figure 10. As for Fig. 3, except ENI IC versus CG flash counts and a change in the ordinate scale.

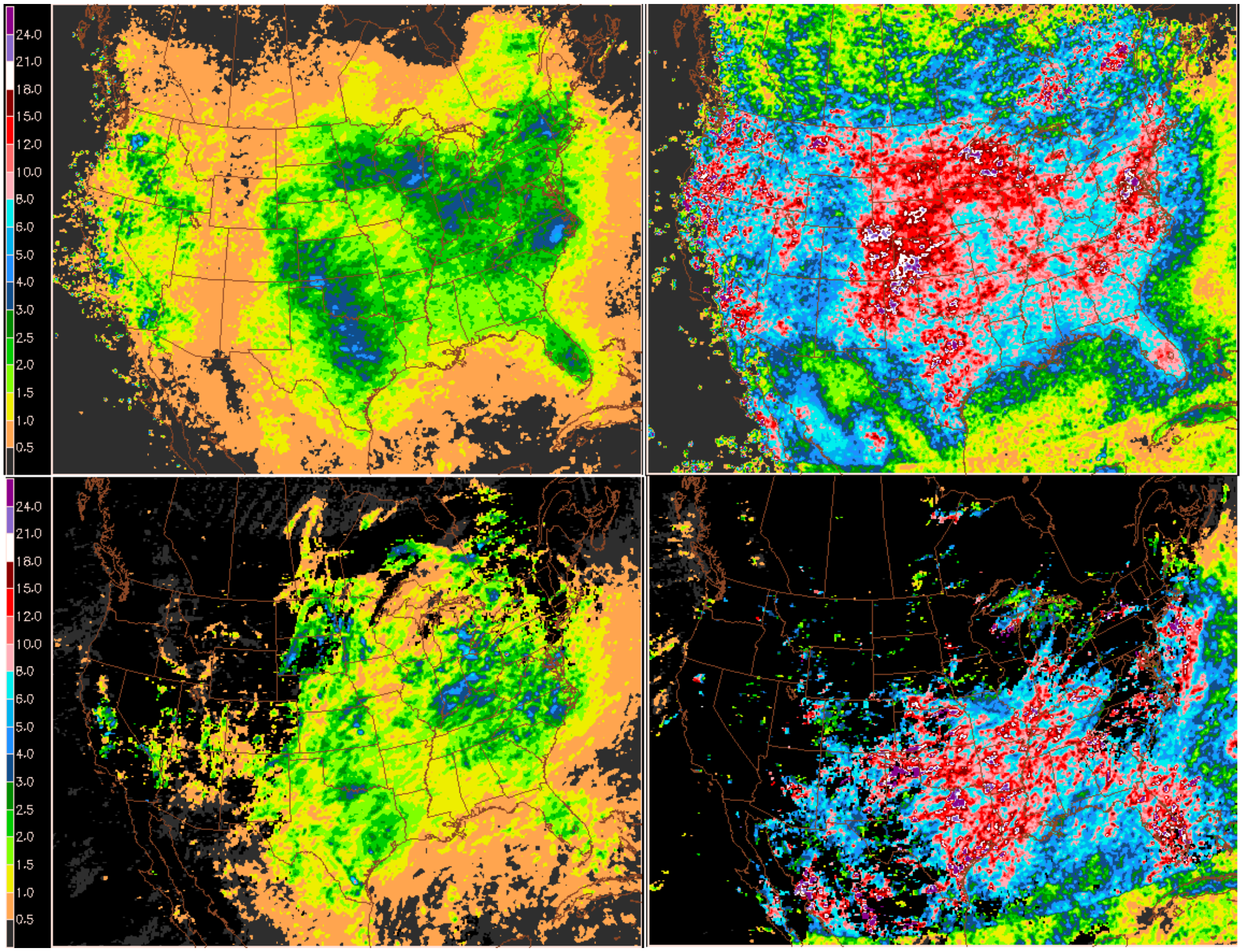

Figure 11. Mean of daily ENI IC/CG flash count per 10 km grid box prior to the first ENI upgrade (left) and following the second upgrade (right) for warm season (top) and cool season (bottom).

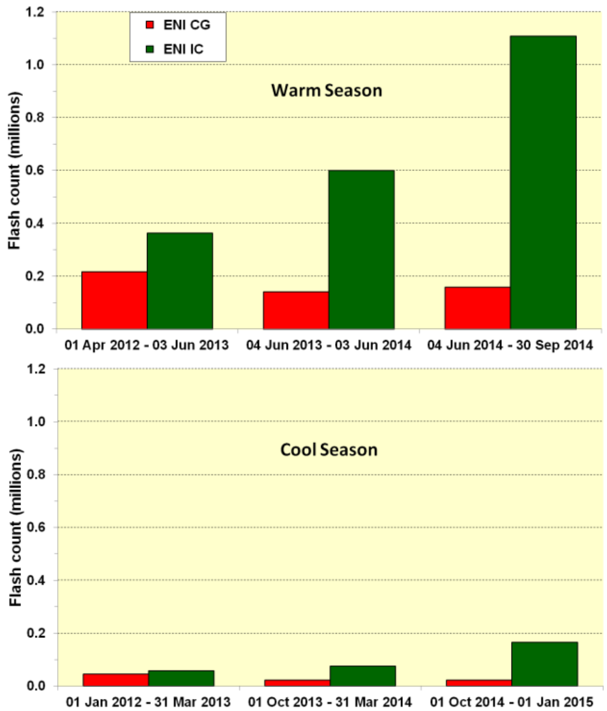

Figure 12. Daily means of ENI CONUS-aggregated daily CG and IC flash counts for three warm season sub-periods (top) and similarly for the cool season (bottom). The date span of each sub-period is specified along abscissa axis.

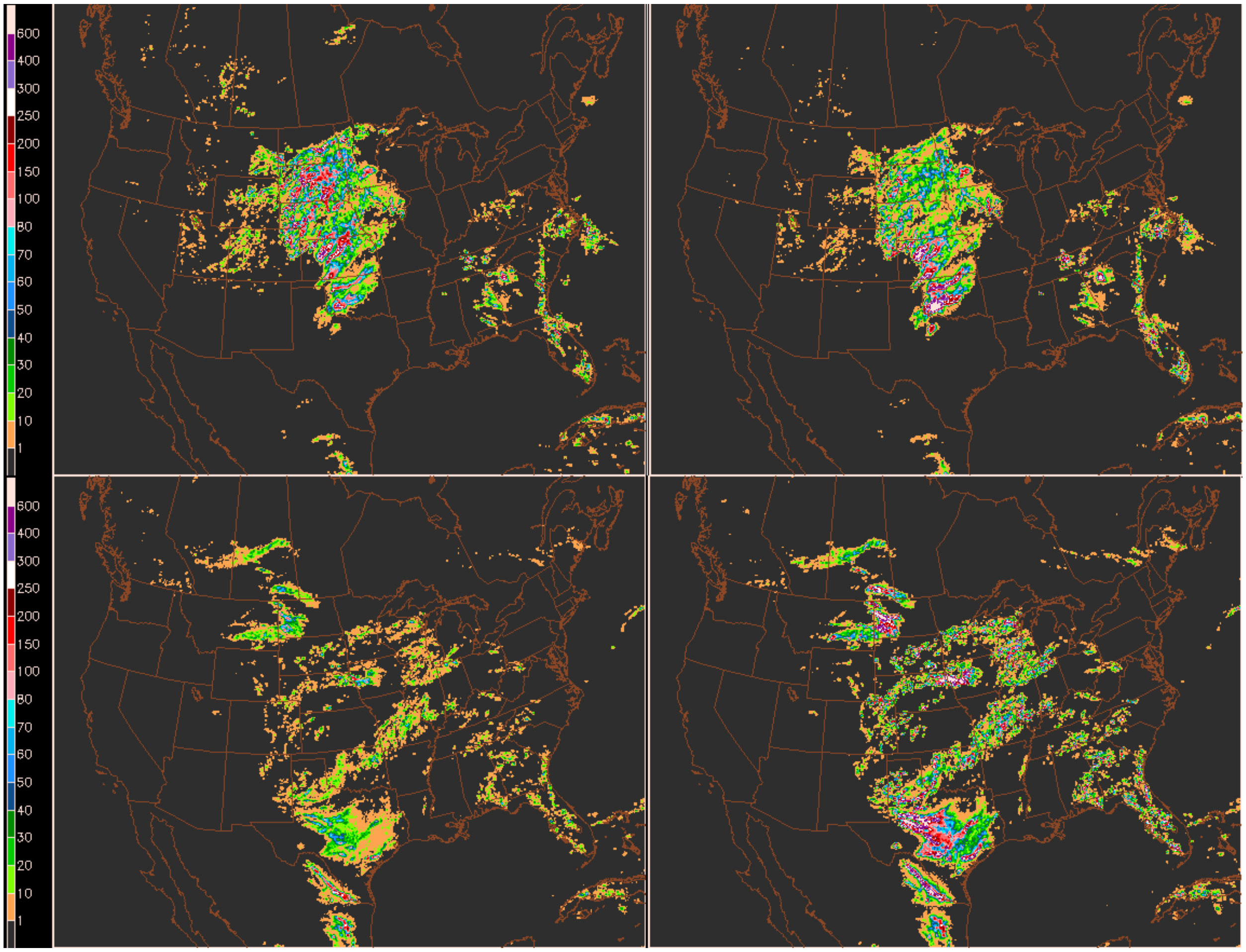

Figure 13. ENI CG (left) and IC (right) flash count per 10 km grid box for the 24-h period beginning 18 May 2013 1200 UTC (top) and 26 May 2014 1200 UTC (bottom).