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THE METEOROLOGY OF THUNDERSTORMS THAT PRODUCE POSITIVE SPRITES, NEGATIVE SPRITES, OR CLOUD-TO-GROUND LIGHTNING WITH LARGE CHARGE MOMENT CHANGES

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1. INTRODUCTION

We present ongoing work investigating the meteorology of thunderstorms that produce cloud-to-ground (CG) lightning with large charge moment changes (CMC), as well as storms that produce either positive or negative sprites and halos. Results to date suggest that ideal positive sprite-producing storms are leading-line/trailing-stratiform mesoscale convective systems (MCSs), as opposed to other MCS organizational modes. Due to their dynamical and microphysical structures, these systems produce high rates of lightning that taps ample stratiform positive charge that is detrained from the leading convective line at high altitudes. This optimizes the number of high-CMC positive CGs, which in turn leads to many positive sprites. By contrast, negative sprites, and large-CMC negative CGs, are much rarer. The few discharges that occur appear to be favored in intense convective cores in large multicell systems with normal-polarity charge structures.
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2. DATA AND METHODOLOGY

Our data sources include the National Severe Storms Laboratory Three-Dimensional Radar Reflectivity Mosaics, the National Lightning Detection Network (NLDN), the Oklahoma and Northern Alabama Lightning Mapping Arrays (LMAs), and the Charge Moment Change Network (CMCN) operated by Duke University. Put together, this instrument suite provides detailed observations of the relationships between lightning and storm structure for sprite and high-CMC producing thunderstorms.

3. CLIMATOLOGY RESULTS

We first focus on short-term climatologies of high impulse CMC (iCMC, the charge moment change within the first 2 ms of the return stroke) strokes as observed by the CMCN. These data have not been adjusted for detection efficiency.

The strong positive iCMC (Fig. 1) strokes cluster in the Great Plains, in roughly the same location as the positive CG percentage and peak current maxima commonly seen in NLDN climatologies (Orville and Huffines 2001), as well as the maximum in mesoscale convective complex (MCC) rainfall and occurrence frequency (Ashley et al. 2003). Seasonal breakdown of these data (not shown) demonstrates a northwestward propagation from the southeastern United States to the northern Great Plains during the transition from the cold season into the warm season, roughly mimicking the same behavior seen in mesoscale convective precipitation systems. There is also a secondary maximum over the Gulf Stream. Overall, this is consistent with a general inference of positive sprite-producing lightning and high-CMC positive CGs being commonly associated with mesoscale convective systems (MCSs; Lyons 2006).

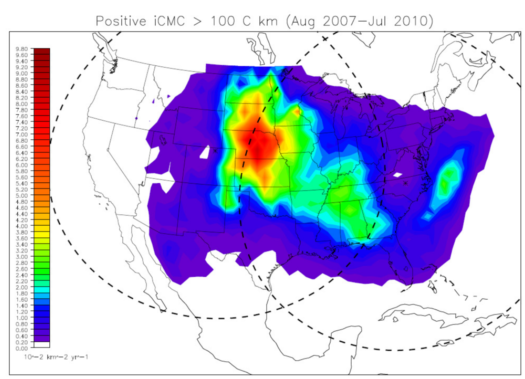

Figure 1. Three years of stroke densities for positive CGs with iCMC ≥ 100 C km.

By contrast, large negative iCMCs are most commonly observed in the southern Gulf Coast, with a secondary maximum also over the Gulf Stream (Fig. 2). The continental maximum does extend partially into the Great Plains, but remains largely southeast of the positive iCMC maximum.

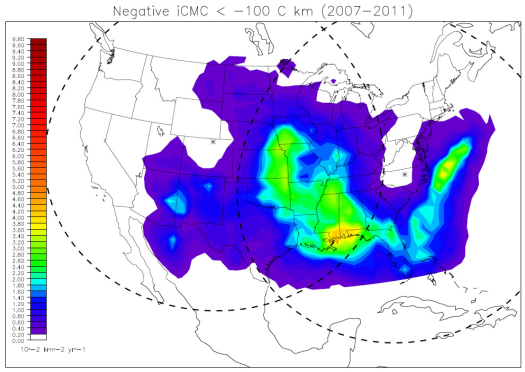

Figure 2. Three years of stroke densities for negative CGs with iCMC ≤ -100 C km.

A northwestward seasonal march is also seen in the negative iCMC data, and both positive and negative high iCMCs peak in the summer (Figs. 3 and 4, respectively), but with a noticeable geographic shift in the locations of their respective maxima. Specifically, Large negative iCMCs are systematically shifted southeastward of large positive iCMCs. This suggests some differences in the meteorology of these different types of flashes, and given the link between CMC and sprites (Pasko 2010), it also suggests differences in the kinds of thunderstorms that produce positive and negative sprites.

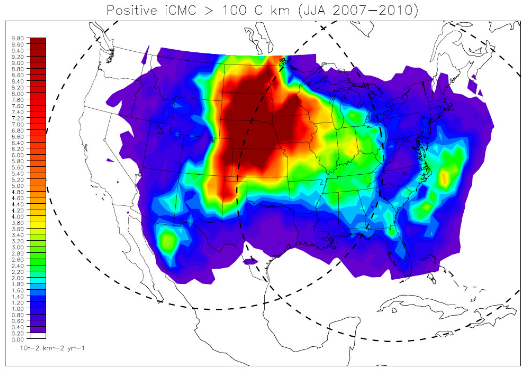

Figure 3. Same as Figure 1 but only for June through August.

Note, in Figs. 3 and 4, the secondary maxima over the North American Monsoon region of the Southwestern United States and Northwestern Mexico, a region known for significant rainfall from mesoscale precipitation systems (Lang et al. 2007).

4. POSITIVE SPRITE RESULTS

Though it is well known that MCSs are closely associated with the occurrence of positive sprites, less research has focused on storm morphological controls on sprite-parent lightning. That is, what is the ideal MCS organizational mode for producing large positive CMC lightning and sprites?

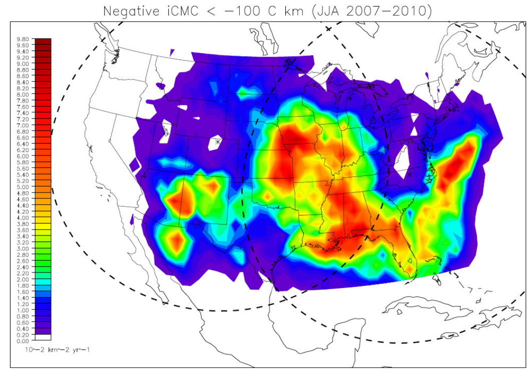

Figure 4. Same as Fig. 2 but for June through August only.

To date, we have examined radar and lightning data for four sprite-producing MCSs: An asymmetric storm (9 May 2007), a large symmetric storm (20 June 2007), an irregular MCS (24 March 2009), and another symmetric case (19 August 2009). The first two cases have been discussed before by Lang et al. (2010, 2011). All of these storms occurred within range of the Oklahoma LMA. Table 1 shows key observations from these cases. Transient luminous events (TLEs; mainly sprites) were observed using Watec cameras in Colorado and Texas. The symmetric cases consistently produced more lightning, more TLEs, and their sprite-parent +CGs tapped positive charge at a higher altitude than their asymmetric/irregular counterparts. In addition, Lang et al. (2011) found the 20 June symmetric cases to have higher stratiform charge density than the 9 May asymmetric case.

Table 1. Key observations from the positive sprite cases in this study.

Date	Observing period (h)	TLEs	SP+CG Altitudes (km AGL)	Peak CG Rates per 10 min)
5/9/07	2	25	5.7	987
6/20/07	4	282	7.8	7605
3/24/09	2.5	23	5.5	343
8/19/09	2.5	34	6.7	1318

Thus, the symmetric leading-line/trailing-stratiform storms (LLTS) produced more lightning and charge at a higher altitude than the other cases, a configuration that should optimize the CMC of the systems' lightning and improve their chances of producing sprites. This provides support for the hypothesis that LLTS MCSs are the optimal positive sprite producers, via their ability to maximize the CMCs of their positive CGs.

5. NEGATIVE SPRITE/ICMC RESULTS

Negative sprites are much rare than positive ones, but those that have been observed have been associated with powerful negative CGs that have extremely high iCMCs and peak currents. Therefore, instead of limiting ourselves just to the small handful of observed negative sprites, we instead are doing case studies of the dozens of high iCMC/high peak current negative strokes observed by the CMCN and NLDN (Fig. 5). These lightning strokes were clearly capable of producing negative sprites, indeed likely to have done so.

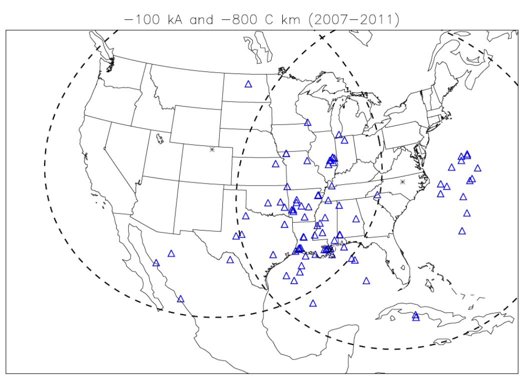

Figure 5. Map of negative strokes with iCMC ≤ -800 C km and peak currents ≤ -100 kA during 2007-2011.

To date we have analyzed 29 potential negative sprite-producing events on 13 different days between 2007 and 2011. Outbreaks occur in the dataset. Two days (5 October 2010 and 9 March 2011) account for 14 of these events, with other days providing 1-2 events each. All but 2 events occurred within 15 km distance of a convective core that had 30 dBZ reaching to at least 12 km MSL on average. The other two occurred within stratiform precipitation regions of MCSs. Twenty-five of 29 events had >50% -CG lightning within 15 km of the event for a 25-minute period surrounding the time of the event. All events occurred within a mix of MCSs, or sub-MCS large multicell convection.

Key differences are clear between these potential negative sprite-producing storms and the positive sprite-producing storms that have been analyzed in this and other studies. For one, the intense negative CGs rarely occur in stratiform regions of MCSs, and indeed do not always occur within MCSs but can be associated with smaller, less organized multicell storms. Very intense convection dominated by negative CG lightning is favored for these types of flashes.

Lu et al. (2012) analyzed several high-iCMC negative CGs and found they typically involve discharging between the upper positive and mid-level negative charge within a normal-polarity thunderstorm tripole, as opposed to more typical negative CGs that mainly involve the mid-level negative and lower positive charge. Our analysis of an intense negative CG within range of the Northern Alabama LMA on 26 March 2011 (Fig. 6), supports their findings as well. Combining Lu et al. (2012) with our results, the emerging evidence suggests that a distinct class of intense normal-polarity thunderstorms produce negative sprites, and that discharging between the upper positive and mid-level negative charge is the key internal thunderstorm process in triggering negative sprites.

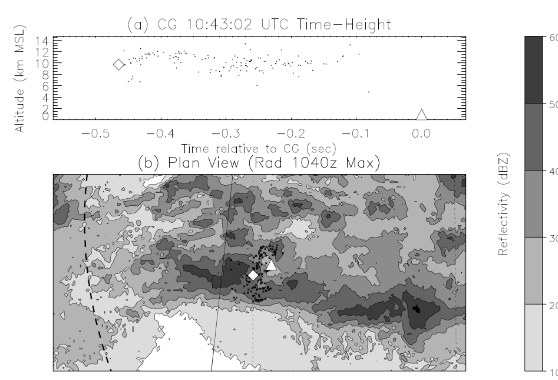

Figure 6. (a) Time-height plot of LMA sources for an intense negative CG (peak current -145 kA, iCMC -974 C km). Diamond is flash initiation and triangle is the CG. (b) Plan view of flash, along with radar data.

6. CONCLUSIONS

There are clear regional differences in positive and negative high-CMC lightning occurrence. Positive events are best found in the Great Plains while negative events are more common in the southeastern United States, particularly the Gulf Coast. We have demonstrated that the observed regional differences appear to be related to key differences in thunderstorm morphology between the types of storms that produce high-CMC strokes and sprites of differing polarities. For high positive CMC and sprites, one would look for large LLTS MCSs, and focus on the stratiform region where sprite-producing positive CGs often come to ground after tapping the enormous charge reservoirs there. On the other hand, for high negative CMC and sprites, the most fruitful candidates are intense, normal-polarity (negative CG dominated) convective cores in multicell systems that are not necessarily MCS scale.

REFERENCES

Ashley, Walker S., Thomas L. Mote, P. Grady Dixon, Sharon L. Trotter, Emily J. Powell, Joshua D. Durkee, Andrew J. Grundstein, 2003: Distribution of Mesoscale Convective Complex Rainfall in the United States. *Mon. Wea. Rev.*, **131**, 3003–3017.

Lang, T. J., D. A. Ahijevych, S. W. Nesbitt, R. E. Carbone, S. A. Rutledge, R. Cifelli, 2007: Radar-observed characteristics of precipitating systems during NAME 2004. *Journal of Climate*, **20**, 1713–1733.

Lang, T. J., J. Li, W. A. Lyons, S. A. Cummer, S. A. Rutledge, and D. R. MacGorman, 2011: Transient luminous events above two mesoscale convective systems: Charge moment change analysis. *J. Geophys. Res.*, **116**, A10306, doi:10.1029/2011JA016758.

Lang, T. J., W. A. Lyons, S. A. Rutledge, J. D. Meyer, D. R. MacGorman, and S. A. Cummer, 2010: Transient luminous events above two mesoscale convective systems: Storm structure and evolution, *J. Geophys. Res.*, **115**, A00E22, doi:10.1029/2009JA014500.

Lu, G., S. A. Cummer, R. J. Blakeslee, W. H. Beasley, and S. A. Weiss, 2012: Lightning morphology and impulse charge moment changes of high peak current negative strokes. Submitted to *J. Geophys. Res.*

Lyons, W. A. (2006), The meteorology of transient luminous events—An introduction and overview, in NATO Advanced Study Institute on Sprites, Elves and Intense Lightning Discharges, edited by M. Fullekrug et al., pp. 19–56, Springer, New York.

Orville, Richard E., Gary 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.

Pasko, V. P. (2010), Recent advances in theory of transient luminous events, J. Geophys. Res., 115, A00E35, doi:10.1029/2009JA014860.

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