P1.2 EXAMINING A POSSIBLE RELATIONSHIP BETWEEN POSITIVE DOMINATED STORMS AND CLOUD-TOP ICE CRYSTAL SIZE

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1. INTRODUCTION

In a recent paper by Carey and Buffalo (2007), it was shown that thunderstorms with an anomalously large percent positive cloud-to-ground lightning strikes (CGs) tend to occur under certain thermodynamic conditions. In particular, storms with higher cloud bases and smaller warm cloud depths have a greater likelihood of having a larger percent positive CGs. Likewise, Lindsey et al. (2006) show that similar thermodynamic conditions lead to thunderstorms with particularly small cloud-top ice crystal sizes. Climatologies shown in each paper reveal that the regions of largest percent positive CGs overlap with the areas having smallest cloud-top crystals, but the spatial correlation is not exact. It stands to reason that a temporal correlation may exist between "positive" thunderstorms and storms having small cloud-top ice crystals. Sherwood et al. (2006) show that areas in the world with maxima in total lightning flash rate also have minima in cloud-top particle size, but they don't consider CG flashes or lightning polarity.

This paper aims to look more closely at this possible correlation by comparing thunderstorm polarity with satellite-retrieved ice crystal size. Section 2 reviews the climatologies; section 3 explains the methodology; section 4 presents the results; section 5 offers some discussion.

2. CLIMATOLOGIES OF POSITIVE LIGHTNING AND ICE EFFECTIVE RADIUS

Fig. 1 shows the mean percentage of warm season +CG lightning from 1989-1998 (Fig. 2 from Carey and Rutledge (2003)), and Fig. 2 is the mean summertime GOES-12-retrieved thick ice cloud effective radius (adapted from Lindsey and Grasso (2007)). Percentage of positive CGs shows a distinct maximum from northeastern Colorado extending northeastward into western Minnesota. Eastern Colorado is also within a minimum of ice effective radius, but areas to the northeast into the upper Midwest have significantly larger effective radii. An east/west gradient across Kansas is present in both climatologies.

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The fact that there are both similarities and differences between the two maps suggests that some of the microphysical processes responsible for storm polarity and cloud-top ice crystal size may be shared. However, it is impossible to make any definite conclusions based on the climatologies alone.

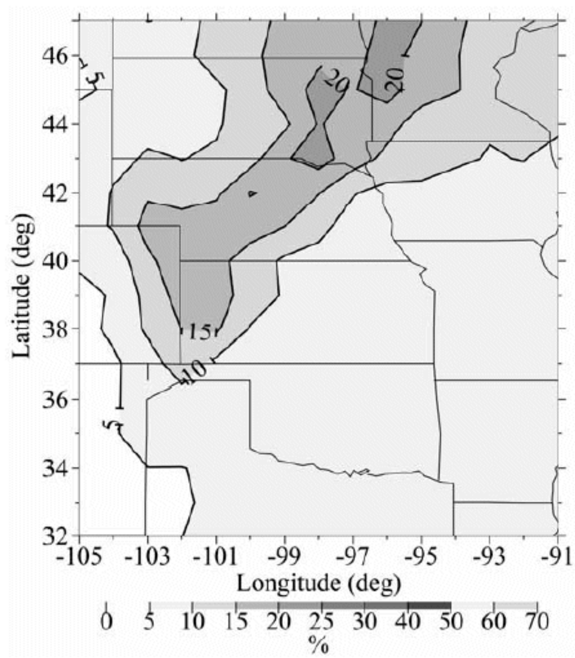

Figure 1. The mean percentage of +CG lightning from April-September during 1989-1998. (Fig. 2 of Carey and Rutledge (2003)).

3. METHODOLOGY

Beginning on 29 May 2007 and continuing through 28 August 2007, daytime 30-minute GOES-12 data was collected and saved. Within each image, an algorithm searched for adjacent pixels whose 10.7 µm brightness temperatures were colder than -40 ˚C, and whose visible albedo exceeded 60% (Lindsey and Grasso 2007). These pixels were defined as a single cloud. Next, the 3.9 µm reflectivity of each pixel in the cloud was used to retrieve a thick ice cloud effective radius, following the methodology discussed in Lindsey and Grasso (2007). Pixel effective radius values were then averaged, providing a single estimate for each cloud. Additionally, each cloud was required to contain at least 36 pixels and no more than 1500. These requirements eliminated tiny clouds and excluded larger cloud systems (such as Mesoscale Convective Systems) and groups of storms whose anvils had merged. The goal is to identify relatively small, isolated, convective storms.

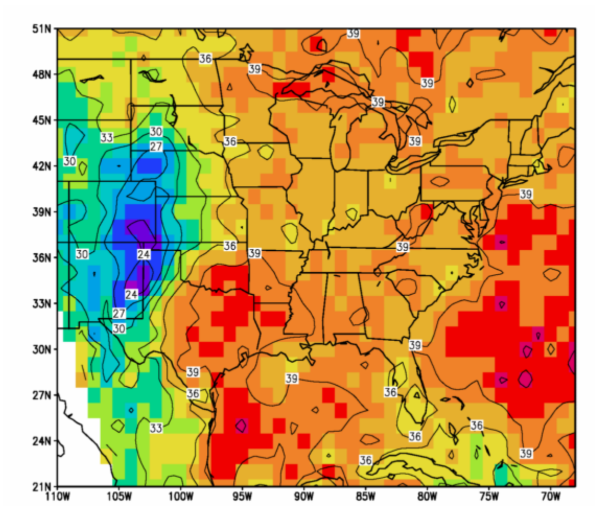

Figure 2. Mean GOES-12-retrieved effective radius (microns) for thick ice clouds from May, June, July, and August of 2000, 2003, and 2004. Colors and contours show the same data. (Adapted from Lindsey and Grasso 2007).

Next, National Lightning Detection Network (NLDN) data were obtained from Vaisala for this same time period over a region in eastern Colorado, Kansas, and parts of Oklahoma and Nebraska (see Fig. 3). Following Cummins et al. (1998), only cloud-to-ground (CG) lightning with a peak current greater than 10 kA were counted as a positive strike. For every cloud identified by the procedure above, a search was conducted for CGs about a radius around the cloud center (the search distance was determined by the number of pixels composing the cloud), and a time window of 15 minutes and after the satellite scan. This method may misidentify some CGs with their associated cloud, but any errors will probably not significantly alter the results.

Following Carey and Buffalo (2007), we define a "positive" storm as one in which at least 25% of the CGs lowered positive charge to the ground within the 30-minute window described above. A "negative" storm is one in which less than 25% of the CGs were positive. In addition, for each cloud at least 10 total CGs must occur within the 30-minute window in order to enter into the analysis. Finally, long-lived storms which meet the above requirements may appear multiple times in the analysis throughout their lifecycle.

4. RESULTS

Fig. 3 shows the region of study, which was split into 8 geographical boxes by latitude/longitude. In each box, the total number of observed positive and negative storms over the duration of the study are indicated (and the % positive storms for reference). The fourth value is the mean effective radius of all the storms in each region for the entire summer. There were no positive storms observed in the southeastern portion of the domain, but several were located in the western and northern areas. This distribution is consistent with the climatology provided in Fig. 1. In general, the regions observing positive storms had smaller mean effective radii, although the smallest mean occurred in extreme southeastern Colorado and southwestern Kansas, a region with no positive storms. The distribution of mean effective radii was also fairly consistent with the climatology shown in Fig. 2.

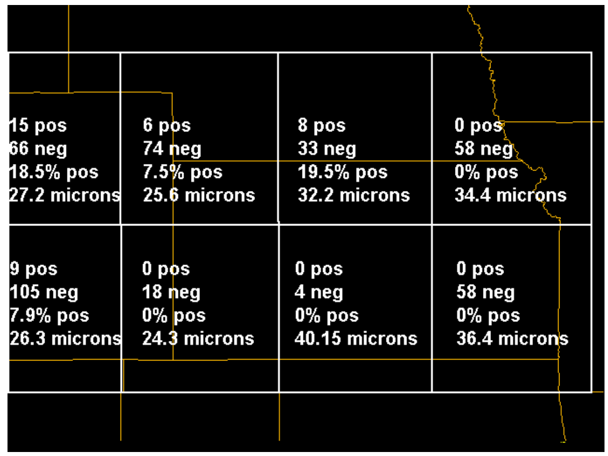

Figure 3. Number and percentage of positive (defined as >25% positive cloud-to-ground strikes) and negative storms, and the average GOES-retrieved ice effective radius for those storms, during the summer of 2007 in 8 geographic regions in and near Kansas.

A composite analysis was performed by separating all positive and negative storms, then calculating the mean effective radius for each group; the results are shown in Table 1. Using all possible times, there was virtually no difference in effective radius between the positive and negative storms. Inspection of the data suggested that storms occurring the afternoon hours may show a bigger difference, so the same analysis was performed using only the data after 2000 UTC. A difference became evident, but given the relatively large amount of variance, the difference was not statistically significant. Further filtering showed that using the afternoon data from May (last 3 days) and June only provided the best separation; positive storms had a mean effective radius of 23.3 µm, compared to 27.4 µm for the negative storms. Using a difference mean's t-test, this difference was 90-95% significant.

As a final comparison, satellite data was obtained for the cases identified by Carey and Buffalo (2007) during the International H_2O Project (IHOP) in 2002. Their Table 1 identifies 9 mesoscale regions on six different days which had greater than 25% positive strikes (4 regions) and less than 25% positive strikes (5 regions). For the positive regions, all satellite pixels satisfying the same requirements discussed above were selected, and their effective radius was averaged. Likewise, a mean effective radius was also obtained for the negative regions. The results are shown in Table 2.

	Pos. Storms	Neg. Storms	Significant?
Mean Effrad - all times	29.1	29.2	no
Mean Effrad - after 20Z	26.1	27.9	no
Mean Effrad - May/June after 20Z	23.3	27.4	90-95%

Table 1. Mean effective radius (µm) of the positive and negative storms for various filtering methods, and whether a difference of means t-test determined statistical significance or not.

Positive	
Date	**Mean Effrad (µm)**
15-Jun-02	23.43
19-Jun-02	14.84
23-May-02	28.74
24-May-02	23.74
Negative	
12-Jun-02	19.03
15-Jun-02	31.91
23-May-02	32.42
24-May-02	26.86
4-Jun-02	34.01

Table 2. Mean effective radius (µm) from the Positive and Negative mesoscale regions provided by Carey and Buffalo (2007) in their Table 1.

In general, the negative regions have storms with larger effective radii, and the positive regions have storms with smaller effective radii. Exceptions occur with the positive regions on 23 May and the negative regions on 12 June. However, on 23 May storms in the positive region had smaller effective radii than in the negative regions, but only by about 5 microns.

5. DISCUSSION

The results presented above suggest that there may be a weak correlation between positive lightning and cloud-top ice crystal size. However, it should be stressed that this certainly does not imply a cause/effect relationship. It could very well be that some external factor is an important player in both physical mechanisms. We can nonetheless speculate about what mechanisms may be responsible.

In both Lindsey et al. (2006) and Carey and Buffalo (2007), the lifted condensation level (LCL) is shown to be associated with small cloud-top ice crystals and positive storms, respectively. Storms with high cloud bases generally have less available water vapor, so for a given concentration of cloud condensation nuclei (CCN), the cloud droplets of these storms will be more numerous and smaller than in clouds with lower bases. Smaller droplets mean a reduced collision efficiency, which reduces the rate of rain droplet generation. In addition, the collision efficiency between ice particles (including graupel) and cloud droplets is small, so with a sufficiently intense updraft, many tiny droplets can be lofted to the -40 ˚C level where they freeze homogeneously. The resulting population of ice crystals is correspondingly small. A second effect of smaller cloud-base droplets is that the cloud liquid water content is larger in the upper portions of the storm (around -20 ˚C), which may favor positive charging of graupel and positive CGs (this was also discussed in Williams et al. 2005). As noted by Carey and Buffalo (2007), aerosols may also play a role by increasing the cloud droplet number concentration near cloud base.

The climatology maps presented in Figs. 1 and 2 imply that the full explanation between positive storms and cloud-top ice crystal size is more complex. Eastern South Dakota and western Minnesota see many positive storms, yet these areas often have relatively large cloud-top ice crystals. Additionally, northeastern New Mexico often has storms with very small ice crystals, but they tend to be negative dominated storms.

Table 1 shows that a significant effective radius difference between positive and negative storms only exists in the May/June period after 2000 UTC. It is possible that this result simply means we are lacking sufficient data, but it could also mean that some fundamental change in the environment occurs near the end of June or the beginning of July. A more comprehensive study (larger domain and more than just 1 summer) is needed to further investigate this idea.

6. ACKNOWLEDGEMENTS

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