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Effect of pollution from Central American fires on cloud-to-ground lightning in May 1998

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Abstract. In the spring of 1998, numerous fires from seasonal biomass burning in Central America, mainly in Mexico and Guatemala, produced aerosol particles that were advected into the central plains of the United States. The effects of the fires continued from approximately April 9 through June 11. The most intense smoke concentration was on May 8 as seen from a NASA Shuttle mission. Characteristics of cloud-to-ground (CG) lightning flashes recorded by the National Lightning Detection Network were examined for May 1998 by subtracting the lightning characteristics for May 1995-1997, and 1999. This produces "difference value" maps with approximately 100 km resolution for polarity, peak currents, and multiplicity. Several significant differences are revealed. The percentage of positive flashes increased by a factor of two. Median first stroke peak currents have been calculated for both positive and negative flashes. For negative flashes, the median peak current decreased during the fire period. For positive flashes, the median peak current increased by over 20 kA in Texas, Oklahoma, Kansas, Arkansas and Nebraska. Mean multiplicity values, or the number of strokes per flash, were calculated. Positive flash multiplicity did not change. Mean multiplicity values for negative flashes, however, changed dramatically. For a region including Texas, Oklahoma, Kansas, and Louisiana multiplicity values for negative flashes decreased from 2.8 to 1.0-1.4 strokes per flash. The data analyzed were a corrected set from which we had deleted positive flashes with peak currents less than 10 kA, thus removing most of the intracloud contamination. Further studies may reveal the relation between the effect of pollution and aerosol size on the characteristics of CG flashes.

1. Introduction

In the spring of 1998, numerous fires in Central America produced aerosol particles that were advected into the central plains of the United States. Rodgers and Bowman (2000) studied these particles and verified that they were a source of pollution throughout Texas and parts of the USA central region. The contamination from the fires continued from April 9 through June 11 and the National Lightning Detection Network (NLDN) recorded the cloud-to-ground lightning during this time. An important paper on this event was published by Lyons et al. (1998) who reported on the enhanced positive lightning in thunderstorms associated with the smoke plumes propagating across the central United States. They found the percentage of positive lightning was triple the climatological norm and the positive peak currents were reported to be double the expected value. In this contribution, we follow up on the initial report by Lyons et al. by extending the analysis to negative flashes, the negative peak currents and the multiplicity of negative and positive flashes. In addition, we take into account the contamination of the May 1998 lightning data set with intracloud flashes by deleting positive flashes having peak currents less than 10 kA. In this way, we minimize the effect of intracloud flashes on the data set, a potentially serious contamination problem (Cummins et al., 1998; Wacker and Orville, 1999a, b). We compare the characteristics of the May 1998 lightning in the United States with the characteristics recorded in May 1995-1997, and May 1999. We do this by subtracting from the May 1998 data, the average lightning characteristics of May 1995-1997, and May 1999. This produces "difference value" maps that are presented and discussed in Figs. 1-3. Significant differences, not previously reported, are noted in the central plains region of the United States.

Annual climatology studies show wide geographical variation of lightning characteristics. Orville and Huffines (1999) report summaries of flash density, positive flash density, percentage of positive flashes, peak currents, and multiplicity for 1995 through 1997. For the United States the percent of positive flashes in May ranges from 14.7 (1995) to 12.6 (1997).

The examination of flash characteristics in this study included the percentage of positive flashes, the median peak currents and flash multiplicity. Calculations and results are presented for geographical areas within the continental United States.

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2. Data

Measurements of aerosol particulate matter (PM) smaller than 10 μm in diameter, known as PM10, are available on the World Wide Web at http:/ /capita.wustl.edu/Central-America/Resources/Data/Data.html. Concentrations are monitored using a beta-gauge in Brownsville, Corpus Christi and Austin, Texas. There are also reports from St. Louis, Missouri. Average PM10 concentrations in Texas range from 10-50 μg/m3 with a daily maximum of 150 μg/m3 (Kayin 1999). The Center for Air Pollution Impact and Trend Analysis (CAPITA) reported smoke aerosols in the United States from April 9 until June 11, 1998.

During the month of May 1998, peaks in the PM10 concentration were observed. On May 9th, Brownsville observed 580 $\mu g/m^3$. This peak was a maximum of the two-day peak period from May 8 through May 10 where high levels were noted in Brownsville and Austin. These two cities also experienced another rise in concentration for May

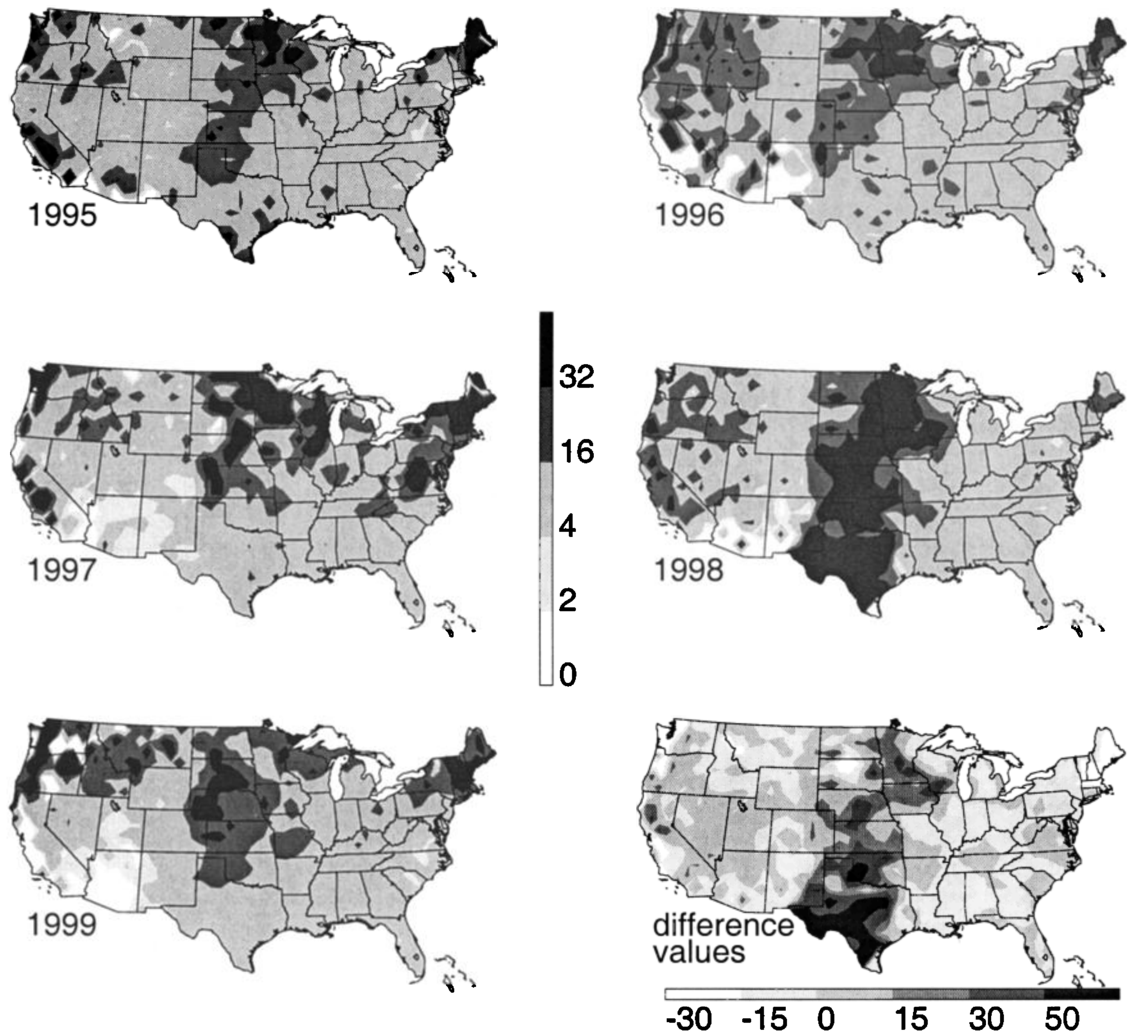

Figure 1. Percentage of positive flashes and average differences for May 1995-1999. Percent positive values for each year are plotted separately. Low values in light shades. High values (greater than or equal to 32%) are in black. Difference calculation values, shown in the lower right, display 1998 deviation from the average of the other years. Dark shade difference values depict an increase in percent positive in 1998. Light shades depict a 1998 decrease.

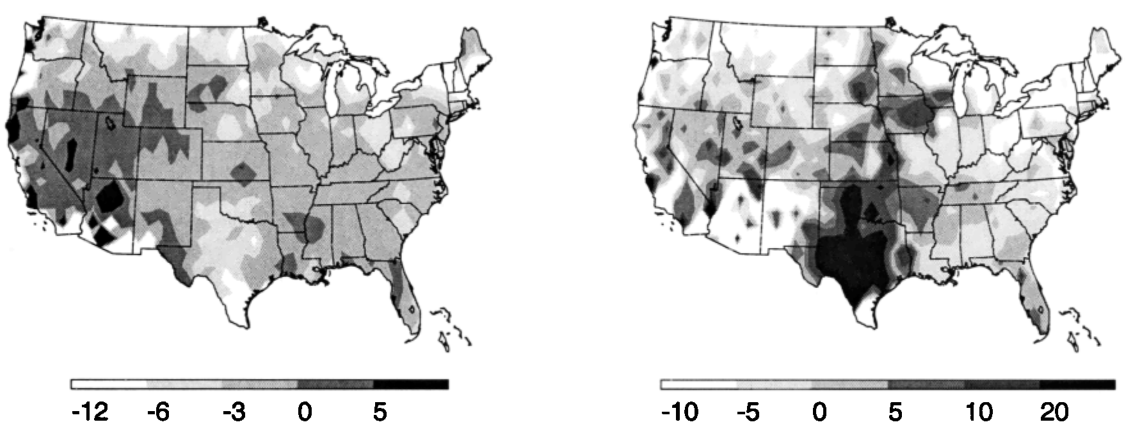

Figure 2. Median peak current difference values. Values for negative flashes on the left side and positive flashes on the right side. Difference calculated by subtracting from the 1998 data the overall median of the years 1995, 1996, 1997, and 1999.

13 through May 15. PM10 concentration levels reached 170-200 μ g/m^3 (Kayin 1999). Further north, in St. Louis, reports of elevated PM10 values were found on May 14 through the end of the month. While PM10 particles are not CCN (cloud condensation nuclei) size, they are good markers of where CCN are located.

Cloud-to-ground lightning data were obtained by the National Lightning Detection Network (NLDN) and acquired from Global Atmospherics, Inc. The NLDN consists of 106 sensors (Cummins et al. 1998). Flash data include the location, time, polarity, peak current and multiplicity (number of strokes) of the flash. We examined the percentage of positive flashes, median peak current values and multiplicity in the continental United States. Although the NLDN data are available from 1989, we considered only the years 1995 through 1999. This is because of a network upgrade in 1994 that is discussed by Cummins et al. (1998). Detection efficiency ranges from 80 to 90% (Idone et al. 1998) and so corrections for detection efficiency have not been made. Lightning analyses were completed for May of each year (1995-1999). A grid resolution of 1.0-degree was used for our analysis.

3. Results

Analysis for May in each of the years 1995 through 1999 has been broken into three sections. We consider first the percentage of positive flashes, followed by investigations of the median peak current and finally the mean multiplicity values, all separated by polarity. We have computed differences by subtracting from the 1998 mean, the average computed value of 1995, 1996, 1997, and 1999. For example, values greater than zero will show an increase in 1998. Likewise a decrease in 1998 will be shown by a value less than zero.

a. Percent positive

The percentage of positive CG lightning is shown in Fig. 1 for May of each year. Throughout the five years, regions of high percent positive (greater than 16%) are observed. However, in 1998 a large area in the south-central plains region is consistently above 32%. The last portion of Fig. 1, lower right corner, shows the 1998 difference from the average of 1995, 1996, 1997 and 1999. The percent positive increased above 50% in central and western Texas. Values above 15% are found throughout the plains. However, to the west and east of this region of increase, values range from – 15% to 15% with a somewhat random spatial pattern.

b. Median peak current

Difference calculations have been made for median peak currents. Fig. 2 shows the results of this analysis. Negative flashes are on the left and positive flashes on the right. Negative median peak currents decreased in many areas of the south-central plains and southeastern United States. The decrease did not exceed 12 kA and remained mainly between a zero and 3 kA difference. A 1998 increase is seen in isolated areas of Texas, Kansas and Louisiana and more consistently in the western United States. Positive flashes, shown on the right of Fig 2, show a high peak current increase in 1998 with *increases* of more than 20 kA in Texas, Oklahoma and Kansas. These geographical areas typically have median peak positive currents of no more that 20-30 kA (Orville and Huffines, 1999; Orville and Huffines, 2000).

c. Mean multiplicity

Mean multiplicity difference values are presented in Fig. 3. Negative flashes, shown on the left, show a decrease in 1998. This represents a decrease in the number of strokes in a flash. The region of greatest decrease is in Texas. The negative mean multiplicity decreased by up to 1.5 strokes per flash. Positive flashes, by contrast and shown on the right, had a small multiplicity and possibly insignificant increase in 1998.

4. Discussion

Were the 1998 transport and smoke production, part of the annual agricultural cycle common to Central America, unusual? To answer this question, Rogers (2000) and Rogers and Bowman (2000) used the Total Ozone Mapping Spectrometer (TOMS) aerosol index to measure biomass aerosols and analyze this event. Comparison between the TOMS aerosol product and air parcel trajectories computed

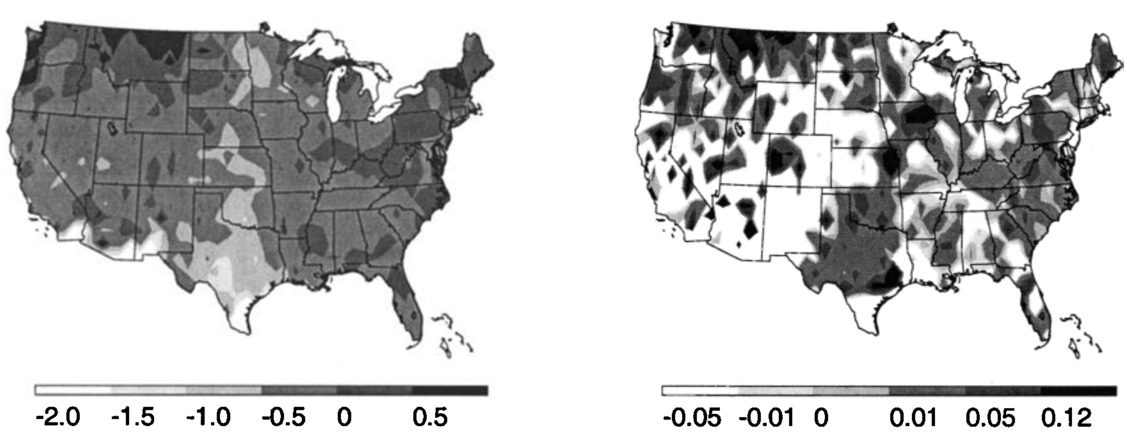

Figure 3. Mean multiplicity difference values. Values for negative flashes on the left side and positive flashes on the right side. Difference calculated by subtracting from the 1998 data the average of the years 1995, 1996, 1997, and 1999.

from assimilated winds verified that the trajectories adequately represent the smoke transport. Analysis of the TOMS data and the trajectories indicated that the source region of the smoke was influenced by two prevailing transport regimes: one northward and one westward. The transport alternated between the two flow patterns, which is also evident in mean wind fields calculated by Rogers for corresponding time periods. In order to determine whether the 1998 transport was unusual, Rogers and Bowman computed a twenty-year transport climatology using assimilated winds. Statistical analysis of the transport shows that May 1998 and the climatology contain similar patterns of northward and westward flow regimes in the area surrounding the smoke's source. The northward flow regime in 1998, however, was the strongest of the twenty-year period analyzed. The vertical flux of air parcels was also unusual during May 1998 with convergence near the 800 mb level whereas, in the climatology, the vertical motion is usually upwards throughout the lower troposphere. In addition to unusually strong northward transport in 1998, the smoke production in the source region was large compared to the Nimbus 7 TOMS aerosol. We conclude that the combination of the strong northward transport and the strength of the source were unusual and indeed affected the discussed variation in lightning characteristics.

5. Conclusions

Cloud-to-ground flash characteristics for May 1998 show differences from the May mean of the surrounding four years (1995-1997, 1999). The percentage of positive flashes increased above 50% and the median positive peak current increased by 20 kA above the background value of previous years in the lower central United States. Negative flashes, on the other hand, decreased in their median peak current and their mean multiplicity. The physical reasons for these changes are unknown. We present the observations in the belief that they will stimulate further study and investigation. Further exploration of microphysical processes may reveal a relationship between pollutants and thunderstorm electrification.

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