Aerosol Association with Severe Weather in Oklahoma

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1. Introduction and Objectives

Aerosol particles may serve as cloud condensation nuclei (CCN) and therefore play an important role in modulating cloud microphysics. Clouds forming in regions of high CCN concentration have been observed to contain higher concentration of small cloud droplets (Twomey 1974), suppressing precipitation and delaying the warm-rain process. This increases cloud water content, leading to higher liquid droplet and ice crystal number concentration, which enhances latent heat release and helps invigorate convection (Rosenfeld 1999; Andreae et al. 2004; Lin et al. 2006; Rosenfeld and Bell 2011). A major source of aerosols reaching the Southern Great Plains is from the emission of biomass burning particles from the wildfires of Central America, especially southern Mexico and the Yucatán Peninsula. These wildfires are common during the northern tropical dry season which runs from March to early June (Reid 2004, Wang et al. 2006). Wang et al. (2009) reported that the ideal synoptic conditions needed to transport smoke particles into the Southern Great Plains from this source region is having strong southerly airflow from the Gulf of Mexico at low-levels, which is produced in the presence of an approaching mid-latitude trough carrying a southward-moving cold front along with a Bermuda high to the east. The primary objectives of this study are to determine the impacts of Central American biomass burning aerosols on convective storms over the Southern Great Plains, particularly in Oklahoma; the synoptic regimes common during different aerosol categories; and the microphysical changes in thunderstorms between days of different aerosol concentration using polarimetric radar data.

2. Methods

Since one of the primary objectives of this project to identify the impacts of Central American biomass burning particles on convection in the Southern Great Plains, the most common biomass burning particle concentrations in that region were identified. Southern Mexico and the Yucatán Peninsula were the regions from which biomass burning particles were most likely to come. Most of the landscape in this region of focus is savanna. Echalar et al. (1995) investigated the biomass burning particles emitted from forest and savannah fires. It was found that fine potassium, fine zinc and bromine were the biomass burning chemicals most commonly emitted from the burning of savannas with organic carbon being the predominant chemical produced from the burning.

Two sites in western Oklahoma were used to produce the biomass burning particle climatology: Wichita Mountains (located in southwestern OK in Comanche County) and Ellis (located in Northwest OK in Ellis County). The aerosol data was obtained from the Federal Land Manager Environmental Database (FED). Organic carbon, fine potassium, fine zinc, and bromine were the chemicals used to

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construct an eleven-year climatology (2002-2012) of the biomass burning particle concentrations. An average concentration of the biomass burning particles in western Oklahoma (figure 1) was obtained for each of the days there was data (every three days) using both sites. Once prevalence of biomass burning particles was identified for each day, days were classified into high (upper 30%), medium (middle 40%), and low (lowest 30%) biomass burning particle concentration. Only March through June was considered since this is climatologically the convective season in the Southern Great Plains.

On days with storms in the study area, severe hail (1"+) and wind reports (50kts+) were obtained using the National Climatic Data Center Database. To provide evidence that a change in the distribution of hail size and wind speed is partially a function of aerosol concentration, days with similar thermodynamic and dynamic environments were examined and chosen as case study days. These parameters were obtained using the Storm Prediction Center (SPC) mesoanalysis. The thermodynamic parameters chosen were surface-based convective available potential energy (CAPE) and mid-level CAPE while the 0-6 km shear was chosen as the dynamic parameter. Since there were only eleven years of data available and a select number of months for each year was chosen, the sample hail size and wind speed from the case study days produced were limited. To produce a large enough sample size from the available data, the bootstrapping technique method was applied. This method was applied 1000 times and for all the sample hail sizes and wind speeds in each aerosol category.

The hypothesis reached in much prior research is that higher aerosol concentration produces smaller cloud droplets within developing clouds, delaying the warm rain process and aiding in convective invigoration. Using polarimetric radar data, one can infer information about the microphysical processes within thunderstorms. Dual polarization radars emit and receive electromagnetic radiation with both a horizontal and vertical polarization. As a result, information about hydrometer size and structure can be inferred from dual polarization radar variables. Two polarimetric variables that will be used to examine the storm cloud microphysics between days of different aerosol concentration and a similar synoptic setup are differential reflectivity (Z_{DR}) and correlation coefficient (ρ_{hv}). Z_{DR} is a measure comparing the horizontally-polarized return signal to the vertically-polarized return signal and thus gives an estimate of the oblateness of hydrometers in a given sample volume. ρ_{hv} is a measure of the correlation between the horizontally and vertically returned power signals and thus can prove useful in identifying whether there is a uniform droplet size distribution or there is a mixture of droplet size within a given volume. Thunderstorms occurring near the Cheyenne, Wyoming radar (KCYS) on June 15th and June 21st, 2013 were examined. June 21st presented itself as a high aerosol day compared to June 15th as a result of a series of wildfires occurring in Colorado and smoke being advected into eastern Wyoming and western Nebraska.

Figure 1: Area of Study

3. Results

Figures 2a and 2b show the distribution of hail size and wind speed as a function of aerosol concentration respectively, after applying the bootstrap technique. It was found that larger hail size and higher wind speeds occurred with higher aerosol concentration, suggesting that aerosols may have played a role in altering the storm microphysics. Figures 3 to 5 show the average 850 mb wind and height patterns for each of the aerosol categories respectively. The 850 mb flow was stronger, and a western trough was more pronounced, with higher aerosol concentration. The combination of these factors facilitated the transport of biomass burning particles originating from Central America.

Figure 6a and 6b show the particulate matter of 2.5 micrometers or less (PM 2.5) and particulate matter of 10 micrometers or less (PM 10) respectively for Laramie County, WY for June 15th and 21st. Based on the figures, June 21st had approximately a 50% increase in PM 2.5 concentration and approximately a 175% increase in PM 10 concentration compared to June 15th suggesting that smoke particles from the Colorado wildfires were advected into the region. Figure 7 and 8 show the polarimetric radar data of a storm for June 15th and June 21st respectively at approximately the same location relative to the updraft region and at the same elevation from the surface. Examining the radar images, key differences are noted in Z_{DR} and ρ_{hv}.. Lower Z_{DR} and higher ρ_{hv} values occurred on June 21st, the high aerosol day, suggesting that there is a higher concentration of smaller cloud droplets.

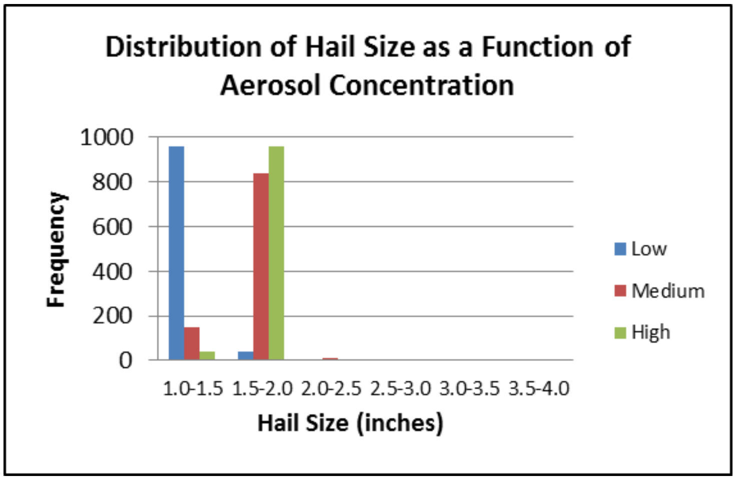

Figure 2a: Distribution of hail size using bootstrapping technique

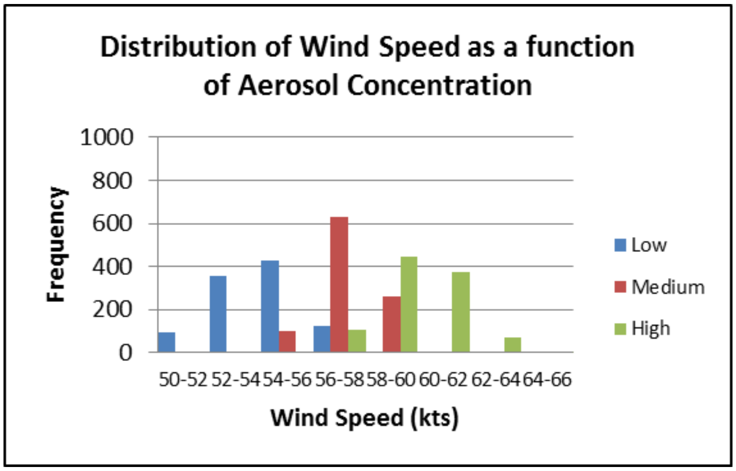

Figure 2b: Distribution of Wind Speed using bootstrapping technique

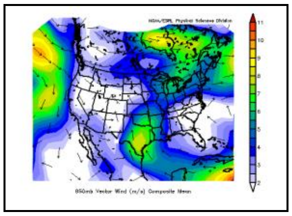

Figure 3a: 850 mb wind for low aerosol days

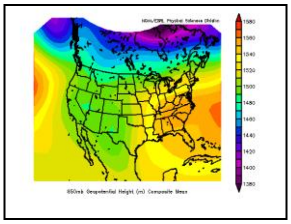

Figure 3b: 850 mb height pattern for low aerosol days.

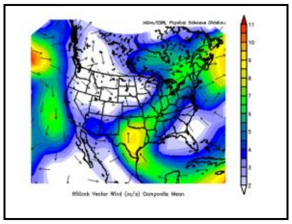

Figure 4a: 850 mb wind for medium aerosol days

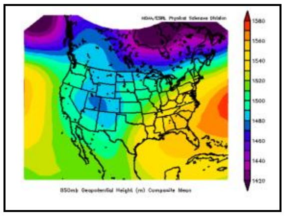

Figure 4b: 850 mb height pattern for medium aerosol days

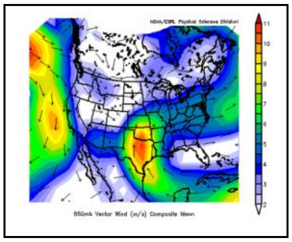

Figure 5a: 850 mb wind for high aerosol days.

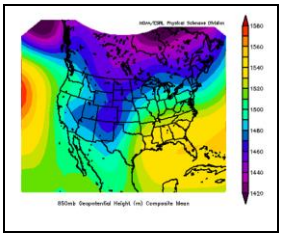

Figure 5b: 850 height pattern for high aerosol days.

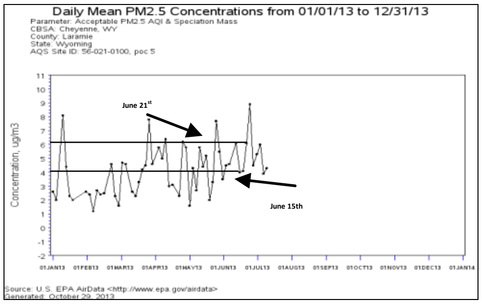

Figure 6a: PM 2.5 concentration for Laramie County, WY for June 15th and June 21st, 2013

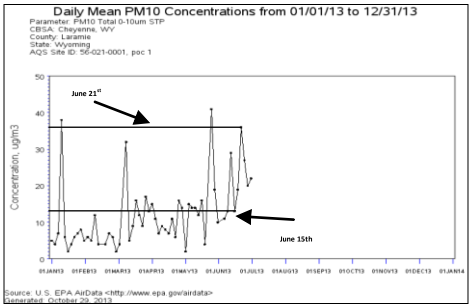

Figure 6b: PM 10 concentration for Laramie County, WY for June 15th and June 21st, 2013

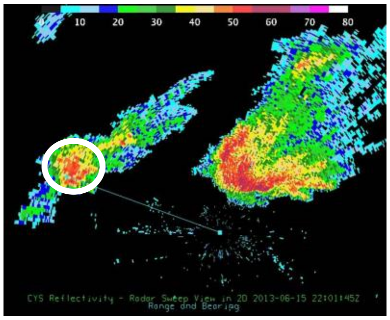

Figure 7a: Radar Reflectivity of a storm near the Cheyenne, WY, WSR-88D radar (KCYS) at 22:01 UTC on 15 June 2013 at 1.5 km above the surface.

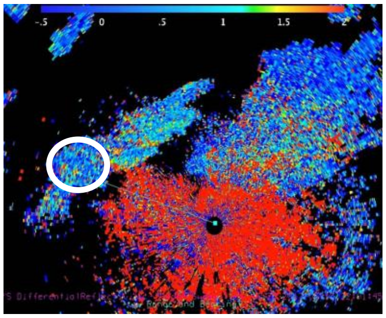

Figure 7b: Differential Reflectivity of the same storm as figure 7a.

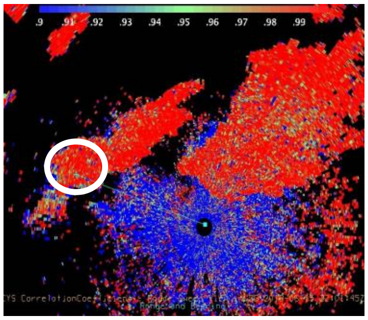

Figure 7c: Correlation Coefficient of the same storm as figure 7a.

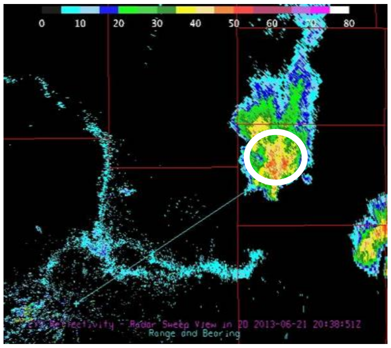

Figure 8a: Radar Reflectivity of a storm east of the Cheyenne, WY WSR-88D radar (KCYS) at 20:38 UTC on 21 June 2013 at 1.5 km above the surface.

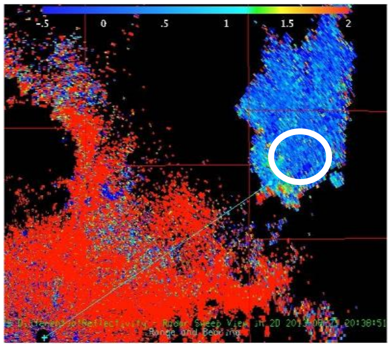

Figure 8b: Differential reflectivity of the same storm as figure 8a.

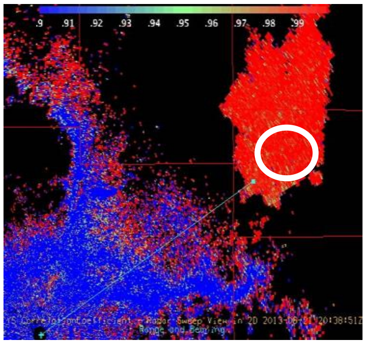

Figure 8c: Correlation Coefficient of the same storm as figure 8a.

4. Conclusions

A new technique to identify days with a high concentration of biomass burning aerosols was developed by using organic carbon, potassium, zinc, and bromine as the predominant tracers. Once prevalence of biomass burning particles was identified for each day, days were classified into high (upper 30%), medium (middle 40%), and low (lowest 30%) biomass burning particle concentration. Days with severe thunderstorms and with similar thermodynamic (CAPE) and dynamic (shear) environments were identified. A composite synoptic regime was obtained for each aerosol concentration category. Differential reflectivity and correlation coefficient were also examined to compare the microphysics for thunderstorms that occurred between days of different concentration. Using the bootstrapping technique, it was found that larger hail size and stronger wind speeds occurred with higher aerosol concentration. The average 850 mb flow was stronger, and a western trough was more pronounced, with higher aerosol concentration. Comparing the microphysics of thunderstorms occurring near Cheyenne, Wyoming, on two different aerosol concentration days, it was found that lower differential reflectivity values and higher correlation coefficient values occurred during the higher aerosol day suggesting that a larger concentration of smaller cloud droplets was present. In future work, other synoptic regimes will be examined for each aerosol category, and another pair of days with different concentration will be examined to determine if the same general microphysical pattern is noted.

References

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