Analysis of Aerosol Number Size Distributions and Hygroscopic Growth Factors as functions of Ambient Relative Humidity during the North American Monsoon

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ABSTRACT

This study examines the behavior of particulate matter in El Paso Texas during the North American Monsoon. A laser particle counter was utilized to record size segregated surface measurements of particulate number densities within the accumulation and coarse modes ($d = 0.3$ μm – 10.0 μm). Changes in particle number size distributions as a function of relative humidity for case studies during the 2005 – 2007 monsoon seasons have been analyzed. It is intended to investigate the evolution of aerosol number size distributions in the presence of increasing relative humidity typical of the monsoon system. Hygroscopic growth factors of aerosols as a function of relative humidity for accumulation (0.15 μm < r_0 < 1.5 μm) and coarse (r_0 > 1.5 μm) modes have been calculated according to Hänel, 1976.

I. INTRODUCTION

Since the early-seventies, studies have shown that aerosols can modify cloud microphysical characteristics by serving as cloud condensation nuclei (CCN). Consequently, in a polluted environment, clouds will contain an elevated number of small cloud droplets for a fixed amount of water vapor compared to clean or unpolluted clouds. This redistribution of water vapor near the cloud base might modify other cloud processes e.g. coalescence and rainout efficiencies, which may in turn lead to changes in precipitation efficiency [Twomey, 1974, Freud, 2008].

On the other hand, a reasonable question arises; how would the presence of elevated ambient relative humidity (RH) modify the size distribution of atmospheric aerosols. Several studies have analyzed the effects of RH on the growth of atmospherics aerosols. In the late seventies, based on observations and theoretical framework, Hänel, 1976, proposed a model to describe the growth of hygroscopic aerosols as a function of RH. He defined the increase in particle size as the ratio of the size of the particle over its size in the dry state $\left(\frac{r}{r_0}\right)$. Hänel noted that below a certain RH the $\left(\frac{r}{r_0}\right)$ ratio is independent of the size of dry particles (r_0). However, for moderate to elevated RH, accumulation and coarse mode particles were found to experience a larger hygroscopic growth than fine mode particles.

Observational and modeling studies have analyzed hygroscopic growth of aerosol particles as a function of high RH. These studies characterize the behavior of atmospheric aerosol samples collected in field experiments and laboratory generated particles. Wex et al., 2008, published a compilation of studies that analyze hygroscopic growth of different particle species, from atmospheric samples and synthetic particles with the Leipzig Aerosol Cloud Interaction Simulator and a high humidity tandem differential mobility analyzer at very large RH, 99.5% and 98% respectively. Computer simulations were carried out to reproduce measurements. Hygroscopic growth data was extrapolated to the supersaturation regime with a simple form of the Köhler equation with a reformulation of the Raoult term so that only a single ρ_{ion} (ionic density) term was unknown. For most particles, the change was small (15-30%), but dry particles grew by a factor of ≥2 due to the presence of slightly soluble succinic acid. Modeled S_{crit} and d_{crit} closely resembled measurements.

Hygroscopic growth factors of aerosols were derived from in situ measurements at the rural station of Xinken in the heavily polluted Pearl River Delta region of China in 2004. A Humidifying Differential Mobility Particle Sizer was used to measure particle size distributions in the 30 – 500 nm range at predefined RH (30%, 57%, 78% and 91%). Observed mean descriptive Hygroscopic Growth Factors (DGF) were size dependent, at 91% RH DGF ranged from 1.2 to 1.57. Particles within the accumulation mode exhibited the largest hygroscopic growth (1.57) while Aitken mode particles had lower growth. Factors influencing hygroscopic growth included chemical composition, transport, and planetary boundary layer development [Eichler et al., 2008].

Characterization of aerosol particles is of great importance for the analysis of their forcing on weather and climate. The geographical location of the border community of El Paso, Texas provides a fertile ground for aerosol characterization and indirect forcing investigations. El Paso, Texas and neighboring towns comprise an industrial community which lies within the Chihuahuan desert [Figure 1].

Figure 1. Study region after an original map by R. Schmidt, 1979.

This region is distinguished by numerous dust sources that favor dust storms whenever dry conditions and strong winds prevail. Figure 2 is a satellite image of a typical dust storm in this region captured by the MODIS sensor onboard AQUA on December 15, 2003.

Dust sources within this region load mineral aerosols into the atmosphere throughout the year. In addition to anthropogenic aerosols, mineral aerosols are responsible for poor air quality in far-west Texas, southern New Mexico and northern Chihuahua [Dominguez et al., 2007].

Studies have analyzed the hygroscopic capacity of sulfate-coated mineral dust. They have found that these particles can be effective Cloud Condensation Nuclei and may affect cloud formation and precipitation [Parungo et al., 1992, Levin et al., 1996]. Perhaps Chihuahuan desert dust aerosols may become coated by sulfates making them hygroscopic and thus affecting cloud properties.

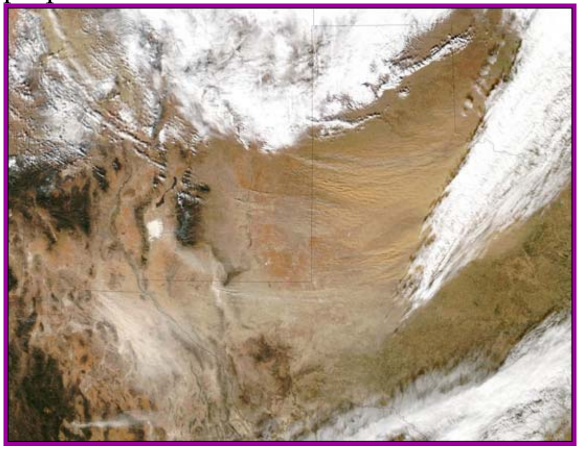

Figure 2. Dust Storm over West Texas and NW Mexico.

Previous studies have found that dust storm frequency is at its maximum during the spring months [Apodaca et al., 2007, Navlan et al., 2007]. However, dust storms can also occur during the summer and are associated with convective activity typical of the North American Monsoon (NAM) system, especially in the early part of the monsoon. Figure 3 shows the monthly distribution of maximum recorded PM2.5 in El Paso, TX for the period of 2000 to 2007.

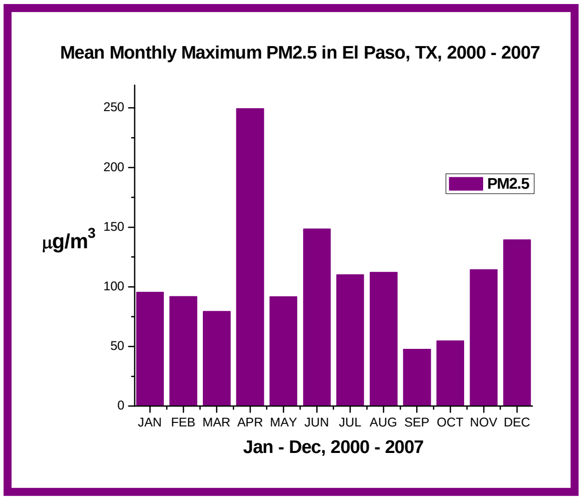

Figure 3. Mean monthly maximum PM2.5

The NAM system delivers about 35% to 45% of the annual rainfall in the southwest US and about 60% to 70% of northwestern Mexico [Higgins et al., 2000]. During the NAM season, the frequency of incoming convective systems into this region is highest. These convective systems carry the potential of producing strong surface level winds that can lift aerosols up to the cloud base and increase the potential for cloud-aerosol-chemical interactions. El Paso, Texas is characterized by a semi-arid climate with an average relative humidity that jumps from 28% in the spring to 49% in the summer monsoon [Navlan, 2007].

Aerosol Number Size Distributions (ANSD) were measured with the CLiMET-550 Laser Airborne Particle Counter (LAPC). This instrument measures size differentiated atmospheric particle number densities within six size channels ranging from $d = 0.3$ μm - 10μm. RH and surface temperature data were obtained from a monitoring station from the Texas Commission on Environmental Quality (TCEQ). All measurements were taken within the University of Texas at El Paso (UTEP) campus (31.79N, 106.5W) for the months of June – September, 2005 – 2007. Hygroscopic growth factors for aerosols as a function of RH were calculated following the method by Hänel, 1976. Trajectories of air masses were computed with the NOAA/ARL Hybrid Single Particle Lagrangian Integrated Trajectory model to investigate source of moist air masses that may have fueled Convective/Dust storms. Moisture sources that fuel NAM convection include the Gulf of Mexico (GoM), the Gulf of California (GoC), and the tropical Pacific Ocean (PO). Measurements and subsequent calculations were performed to evaluate the evolution of ANSD's and hygroscopic growth as a function of RH during the NAM.

II. MEASUREMENTS

In order to understand the behavior of particulate matter during dust storms, the evolution of ANSD's has been measured continuously since June 2005 from the rooftop of the physics department at UTEP. Size differentiated atmospheric particles have been measured with the CLiMET-550 LAPC within six size bins (0.3μm, 0.5μm, 1.0μm, 3.0μm, 5.0μm, and ≥10μm.) In-situ measurements of particulate number densities have allowed the identification of dusty conditions which have been corroborated with PM2.5 and PM10 measurements from a Continuous Air Monitoring Station (CAMS12) from TCEQ/EPA within the UTEP campus.

Measurements of standard meteorological variables e.g. RH, wind speed and wind direction have been obtained from CAMS12. Case studies during the 2005 – 2007 NAM seasons have been identified where dust storms may have been produced by convective thunderstorm outflow boundaries. On these case studies precipitation amounts were insignificant. In these cases, ANSD's were plotted against RH and changes in ANSD's and hygroscopic growth factors were calculated.

III. DATA ANALYSES AND CALCULATIONS

Changes in ANSD's and hygroscopic growth as a function of RH are examined. A total of twenty case studies for the months of June – September, 2005 – 2007 were selected. However, analyses of ANSD's and HGF's of seventeen case studies are presented here due to completeness of data sets for these dates. In several of these cases, a dramatic loss in the number of particles of the CLiMET-550's 0.3μm channel was accompanied by a rise in the number of particles of the other 5 channels. On these events, RH reached, at least, 30% and higher. In addition, surface precipitation was naught or negligent. A simple equation to describe the dependency of particle radius with RH has been given by Kasten, 1969 [$r \cong r_0(1-f)^{-\varepsilon}$] where f is the ambient RH, r_0 is the equivalent radius of the dry particle, and ε characterizes the condensation activity of the particle. ε is a function of f and r_0, but it can be approximated by a constant for each aerosol type. From measurements and calculations, Hänel, 1976, concluded that the Kasten equation has universal character for the areas he investigated. $\varepsilon = 0.23, 0.20$ and 1.7 for urban, continental and marine aerosols respectively [Oshlakov, 2001]. The types of aerosols that are primarily emitted in El Paso, Texas and surrounding areas include urban and continental (mineral) type aerosols. An average value for ε of 0.215 was used in this study. Hygroscopic growth factors $\left(\frac{r}{r_0}\right)$ were calculated for each of the 17 case studies selected for which data was complete. In addition, trajectories of air masses for twenty cases studies were computed with the NOAA/ARL HYSPLIT model to investigate trajectories of moist air masses that may have fueled Convective/Dust storms.

IV. RESULTS

Twenty Convective/Dust storm case studies were identified for the period June – September, 2005 – 2007 (NAM seasons). However, analyses of ANSD's and HGF's of seventeen case studies are presented here due to completeness of data sets for these dates. It was found from HYSPLIT - trajectory analysis that the source of moisture for these Convective/Dust storms was in 45% of the cases the GoC (9 cases), in 35% of the cases the GoM (7 cases), and 20% other, e.g. the tropical P O (4 Cases). Figure 4 shows the moisture source distribution for these case studies.

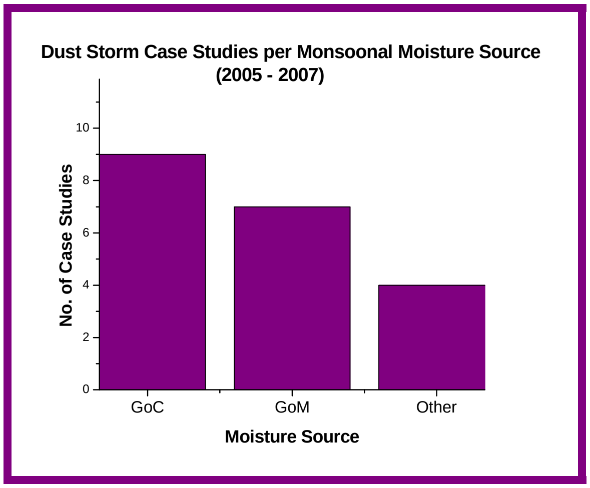

Figure 4. Dust storms per moisture source.

Out of these 20 dust storm case studies, 8 occurred in June, 3 in July, 3 in August, and 6 in September. Dust storm frequency is highest in June (Early NAM season) as found in previous studies [Apodaca et al., 2007, Navlan et al., 2007]. Figure 5 shows the monthly distribution of dust storms per month for the 2005 – 2007 NAM seasons.

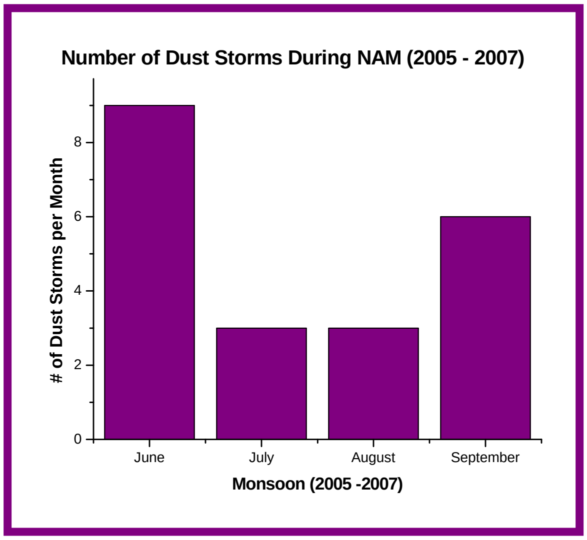

Figure 5. Number of dust storms per month.

Hygroscopic Growth Factors and Percentile Growth

HGF's and Percentile Growth (PG) of aerosols as function of RH were calculated for 17 cases studies. It was found that average HGF's ranged from 1.09 to 1.37. Average PG ranged from 10% to 20%.

Sample Case Studies

Analyses of three cases studies are presented here, one for each year (2005 – 2007). These dates are clear examples of dust storms produced by convective thunderstorms. They were associated with moisture inflow from the GoC, or the GoM during the NAM. The dates presented here are August 11, 2005, June 26, 2006 and 06/20/07.

August 11, 2005

ANSD's from the CLiMET CI-550 LAPC were analyzed. An interesting feature can be noted in figure 6. RH started to increase at nearly 18:00 hours LST, the number density of the 0.3μm channel ($r_0 =$ 0.15μm) dropped while the number densities of the other five size bins rose dramatically. HYSPLIT trajectory analysis indicated that winds were approaching from the GoC [Figure 7]. Average HGF's and PG were calculated for the duration of the Convective/Dust storm. RH ranged from 49% to 56% for the duration of the event. HGF ≈ 1.18, while PG ≈ 18.63%.

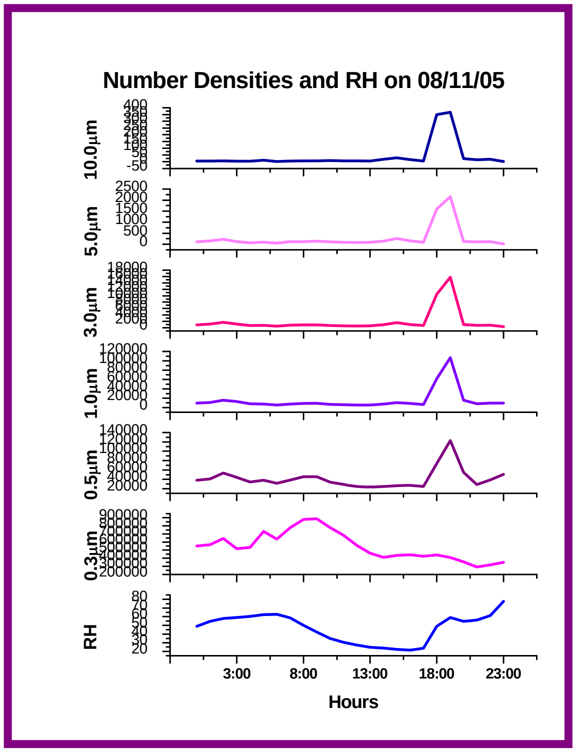

Figure 6. ANSD's and RH on August 11, 2005 at the UTEP campus.

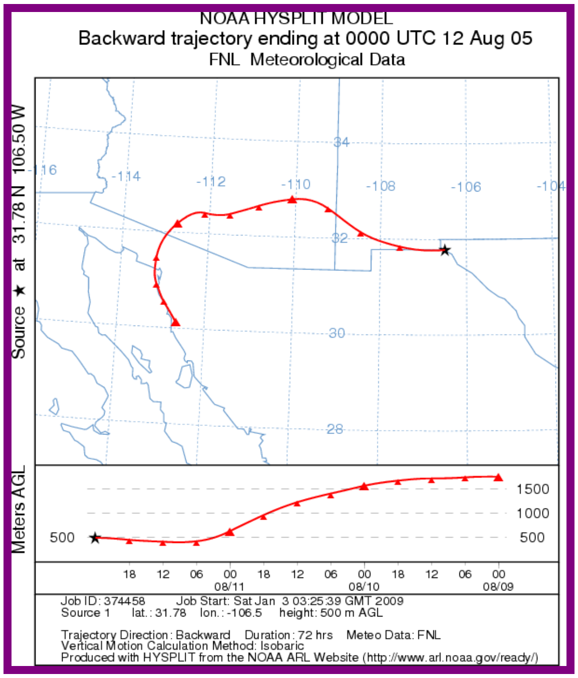

Figure 7. HYSPLIT trajectory for August 11, 2005.

June 21, 2006

On this case RH started to increase around 19:00 LST. A dramatic loss in number density in the 0.3µm channel was experienced while aerosol number densities in the other five size bins rose [Figure 8]. HYSPLIT trajectory analysis revealed that winds were from the GoC [Figure 9]. Average HGF's and PG were calculated for the duration of the Convective/Dust storm. HGF ≈ 1.04, while PG ≈ 5% only.

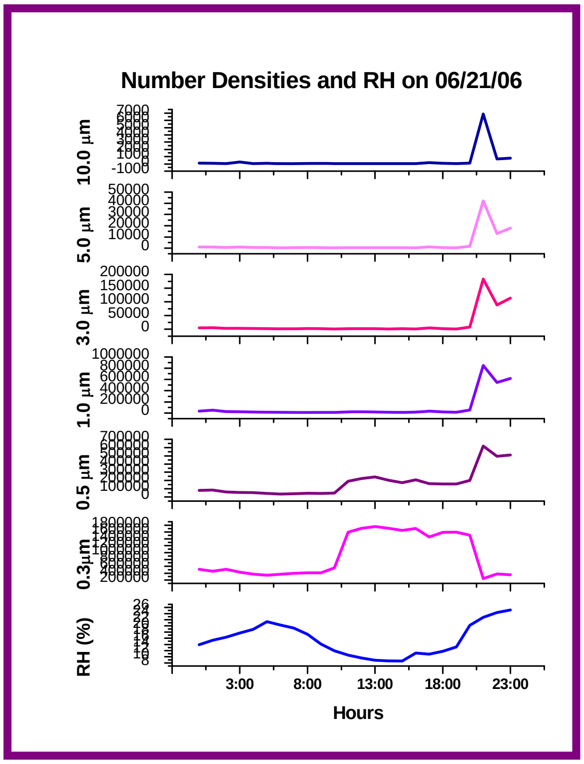

Figure 8. ANSD's and RH on July 21, 2006 at the UTEP campus.

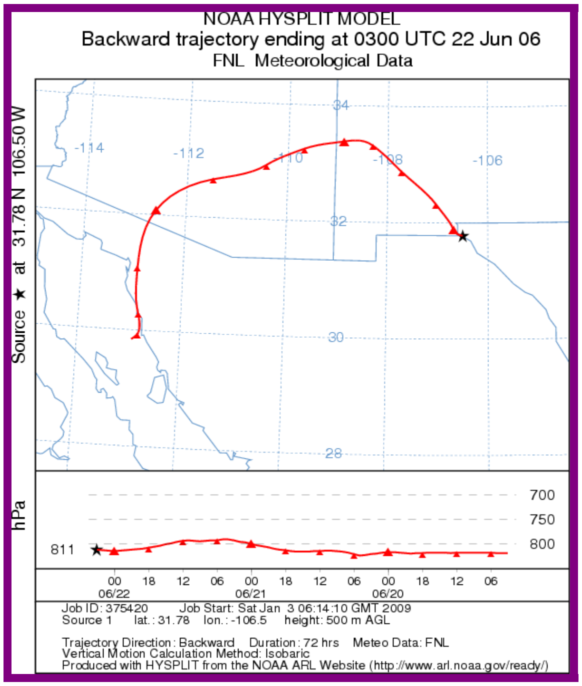

Figure 9. HYSPLIT trajectory for July 21, 2006.

June 20, 2007

This is an interesting case study because convective activity usually occurs after 17:00 hours. However, in this case convective clouds were noticeable at around 13:00 hours LST. RH started to increase at 13:00 then dropped to rise again at 16:00. Number densities increased in all size bins. However a bi-modal ANSD can be seen in size channels 0.3µm to 1.0µm. Coinciding with a bi-modal rise in RH. This distribution starts to fade with increasing particle size [Figure 10]. From HYSPLIT trajectory analysis; winds approached El Paso, TX from the GoM [Figure 11]. Average HGF ≈ 1.11 and PG ≈ 11.14%.

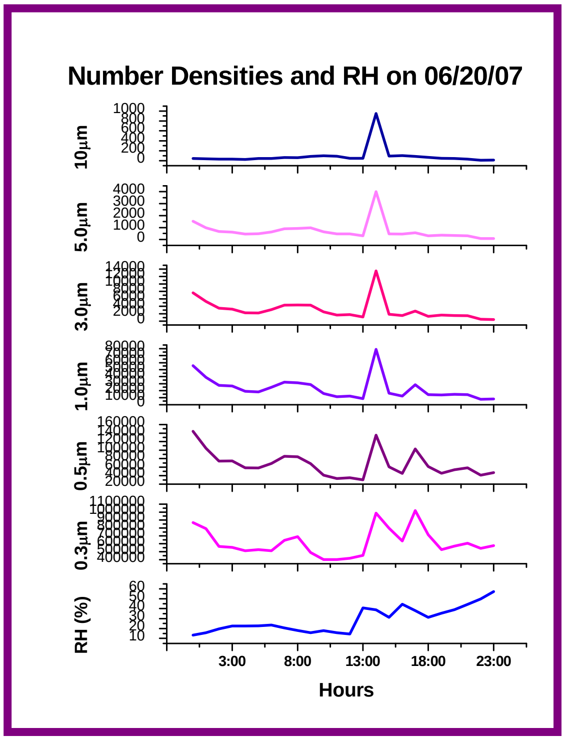

Figure 10. ANSD's and RH on June 20, 2007 at the UTEP campus.

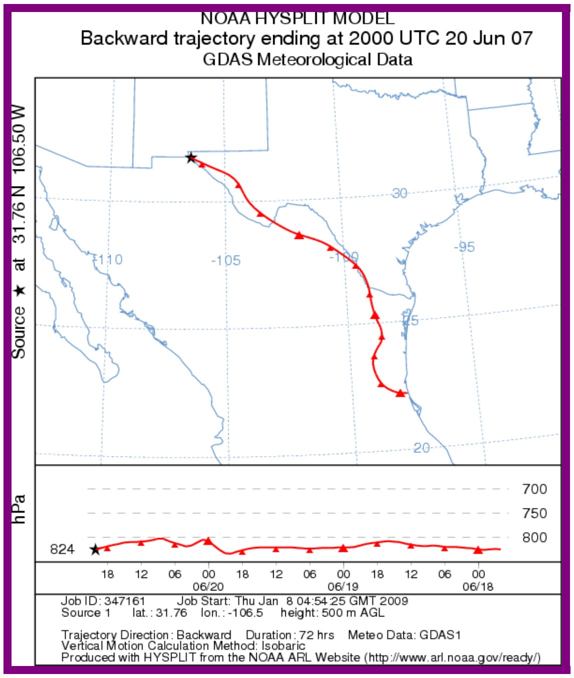

Figure 11. HYSPLIT trajectory for June 20, 2007.

V. SUMMARY

ANSD'S within the accumulation and coarse modes were measured with the CLiMET CI-550 ALPC from the rooftop of the Physics Department at the University of Texas at El Paso for the 2005 – 2007 NAM seasons. HGF's and PG were calculated as a function of increasing RH typical of the NAM system. HYSPLIT trajectory analysis was conducted to investigate the source of moisture fueling Convective/Dust storms. It was found that the source of moisture for Convective/Dust Storms was in 45% of the cases the GoC, 35% the GoM, and 20% other source (e.g. Tropical Pacific Ocean). Dust storm frequency is highest in June, that is, in the early stages of the monsoon as found in previous studies. Increases in number densities with increasing RH were observed for most size bins, except for the 0.3μm size bin, which in some cases, dropped with increasing RH. This behavior, perhaps suggests that some of the particles within this size bin grew in size and contributed to the rises observed in the rest of the size channels. Calculated average HGF's ranged from 1.09 to 1.37 while average PG ranged from 10% to 20% for all seventeen cases with complete data.

VI. REFERENCES

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