J3.12 A SYNOPTIC CLIMATOLOGY OF BLOWING DUST EVENTS IN EL PASO, TEXAS FROM 1932-2005

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1. INTRODUCTION

We have compiled a synoptic climatology of significant blowing dust events at El Paso, Texas, based on observational data from the El Paso International Airport from 1932 through 2005. 1093 cases were documented based on visibility reductions of 6 miles or less for duration of 2 hours or more. Blowing dust is a common phenomenon at El Paso, Texas, and in the surrounding Chihuahuan Desert lowland areas, especially in the spring season: during the months of March, April, and May there is a 42% chance of encountering blowing dust on any single day (Figure 1) based on the monthly frequency distribution of dust events. Blowing dust has always been a prominent and noteworthy feature in El Paso, Texas, as noted in a news article reporting on a storm in 1895 (Cox, 2005): "A Big Blow hit El Paso late on the night of April 4 (1895)…by the midnight the anemometer at the Weather Bureau registered 50 mph and continue to gain strength…The wind took down many of the city's scarce trees and ripped away telegraph, telephone and power lines, leaving the city without electric lights."

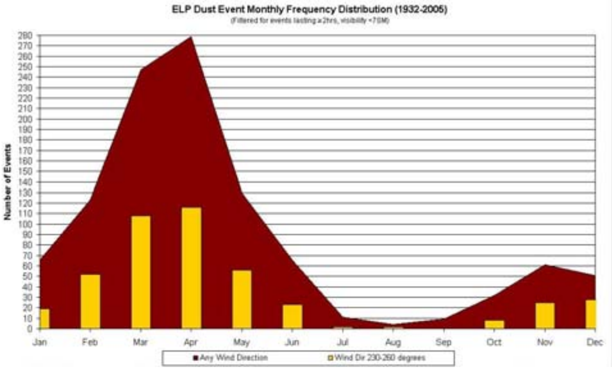

Figure 1. Dust event monthly frequency distribution at El Paso, 1932- 2006.

The importance of aerosols introduced into the atmosphere through local and widespread dust storms has long been recognized in the scientific community and the general public (e.g., Morales, 1979: Wigner and Peterson, 1987). Blowing dust is one of the more prominent meteorological phenomena in the El Paso area. El Paso averages 14.5 significant dust events vents per year; their consequences range from simple irritations and increased particulate matter concentrations to serious disruptive events aggravating respiratory health problems, and even can turn deadly in fatal collisions in near-zero visibility on city roadways and highways in the surrounding desert.

A dust database (Hardiman, 2004) was initially compiled from a variety of weather records in various formats including the original volumes of hand written weather records and scanned copies of observations from the El Paso airport (1932-1948) available from the NCDC (National Climatic Data Center) and local archives of manually taken surface observations, as well as from ASOS (Automated Surface Observation Station) data available in electronic media format. Here we describe some of the preliminary findings on El Paso's dust climatology, and the description, forecasting, and weather hazards posed by dust storms in the El Paso region.

2. PHYSICAL OVERVIEW OF THE EL PASO NATIONAL WEATHER SERVICE FORECAST OFFICE COUNTY WARNING AREA (CWA).

2.1 *Physiography*

The County Warning Area (CWA) of the National Weather Service (NWS) Weather Forecast Office (WFO) in El Paso, Texas, (ELP) for all practical purposes is the northern portion of a semicircle extending in approximately a 200 km radius from El Paso (Figure 2). El Paso sits on the Rio Grande in the northern portion of the Chihuahuan Desert of North America. The mountain ranges of the Gila Wilderness, forming the southeastern edge of the Mogollon Rim and Colorado Plateau, border the CWA to the distant northwest, with the Sacramento Mountains and the Lincoln National Forest bordering the CWA to the distant northeast. The southernmost extension of the North American Rocky Mountains extends southward in the CWA including the San Andres, Organ, and Franklin Mountains: the Franklin Mountain chain terminates in El Paso, bisecting the city in half. Thus the CWA has extensive physical and climatological diversity. Elevations range from near 1070 meters in the lowlands

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near El Paso to approximately 2500 meters in the Gila Wilderness and 3650 meters in the Sacramento Mountains. The Franklin Mountains rise to around 2200 meters elevation in the El Paso area. The desert lowlands that comprise much of the CWA and surround the El Paso metropolitan area in all directions except to the immediate north demonstrate at times extreme variability in their range of meteorological parameters.

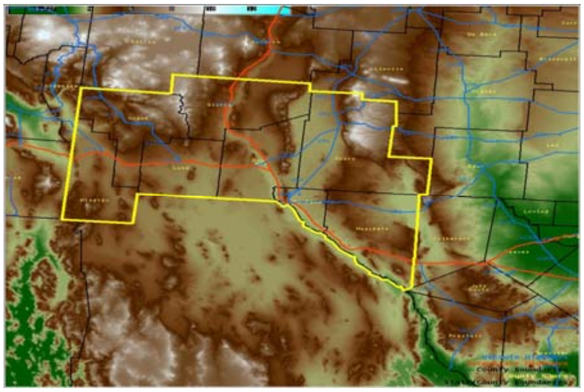

Figure 2. The El Paso county warning area.

2.2 *Climatology*

El Paso has average daily maximum temperatures of 35 degrees Celsius in June and 19 degrees Celsius in January, with an all time high of 45.5 in June 1994. Overnight minimum temperatures average 0.5 degrees Celsius in January and 20.6 in June. The coldest temperature recorded in El Paso was -8 in January of 1962. Precipitation is typical for a semiarid/arid regime, with 24 cm annually including 13 cm of accumulated snowfall. There are on average 53.8 days of measurable rain per year, including 36.4 thunderstorm days occurring primarily in the months of June through September. The mean wind speed is 4.0 m/s with a peak gust of 33.6 m/s observed in January of 1996. El Paso is known as the “Sun City,” averaging some 84% of possible sunshine per year; Sellers (1965) shows the El Paso area as receiving an average annual horizontal ground-level solar radiation of approximately 200 kilolangleys per year, near the maximum for the Western Hemisphere.

It can be said that El Paso experiences three monsoon regimes (in the sense of prevailing wind change) with a dominant northerly wind flow in the cooler seasons of October through February, a shift to west-southwest in the spring or peak dust season of March into early June, and another distinct shift to prevailing southeast winds in the classic monsoon (rainy) season of July through mid September. It is this monsoon rainy season that brings El Paso and the surrounding region some 50+% of its annual rainfall. Annual average relative humidity for the El Paso area is 42%, rising to 49% in the summer monsoon season and falling to an average of 28% in the spring dusty season. El Paso, based on its seasonal wind shifts noted above, has a distinct cool season from November to February when snow is possible in the desert lowlands, a rainy season from July to around mid September, and a characteristic dusty season during March until mid May.

Blowing dust and blowing sand are arguably the most unpleasant features of the weather in El Paso. While wind velocities are not excessively high, the soil surface is dry and loose and natural vegetation in the Chihuahuan Desert is sparse, so moderately strong winds can raise considerable dust and sand. The Chihuauhan Desert region has been indicated from a relatively long-term analysis of satellite data to be one of the dust “hotspots” of North America (Prospero *et al*., 2002). Dust storms are most frequent in March and April, and also comparatively rare in the summer monsoon season (with the exception of convectively-driven events which will be discussed later).

3. CLASSIFICATIONS AND DIAGNOSTICS OF DUST EVENTS

3.1 *Classification*

We classify blowing dust events in the El Paso area into two broad generic categories: Type (1) Synoptic Scale (non-convective), and (2) Mesoscale (convectively driven events). The Synoptic Scale events can be further broken down into two subtypes: (1A) Pacific cold fronts moving in general from west to east, and (1B) backdoor cold fronts which arrive from an easterly direction.

Of the synoptic events, subtype A is most common, producing the most dust storms, particularly in the spring months. Synoptic scale dust events are most frequent in the late winter and spring seasons (64% occur during February through May) but also occur in the late fall and early winter seasons as early as November. They result from Pacific upper level troughs and their associated surface cold fronts traversing the region with strong winds. The strongest events are associated with surface cyclogenesis over northeast New Mexico (Rivera Rivera, 2006) which tightens the surface pressure gradient producing strong gusty west to southwest winds across dry, exposed desert soils. This along with ample solar radiation permits sufficient dry convection which vertically mixes the dust in the planetary boundary layer and occasionally into the free troposphere where it may be transported long distances.

Figure 3 shows a typical Pacific cold front approaching the El Paso area where blowing dust would occur ahead of the front in the warmer air. Note in particular the orientation of the surface low associated with this type of cold front. This surface low is commonly referred to as the “Albuquerque Low” which generally tracks along the Colorado-New Mexico border into the Texas Panhandle area then northeastward. This positioning (as seen in Figure 3) of the surface low will align the surface gradient wind from a west to southwest direction and thus tap the many dust sources in the area. Figure 4 shows a typical 500 mb upper trough associated with the surface pattern in Figure 3. The contours are lines of constant geopotential along which the geostrophic flow is aligned fairly parallel to these lines. Thus a typical scenario is an upper air trough approaching Ell Paso with increasing winds aloft. Maximum winds aloft will occur when the jet stream winds are directly overhead. Often various positive vorticity disturbances will rotate around the trough. As the upper trough moves the surface front forward, the surface low (wave) on the front can become enhanced by the positive vorticity advection and further deepen and strengthen the low (thus in turn) increasing the gradient and causing even stronger winds at the surface (Waters, 1970). In addition, if there is little cloud cover to inhibit solar radiation during daytime hours, the typical morning surface inversion will break around midmorning and in the warm air ahead of the front, and a mixing process will gradually bring down the higher momentum winds aloft. The process will continue until frontal passage when colder air arrives, stopping mixing. When the surface low moves far enough east out of the area, surface pressure gradients will be reduced and winds will correspondingly decrease. This represents an idealized depiction of the process which in reality is far more complicated with many different variations on this scenario either inhibiting or enhancing the winds. For example, when the front arrives during the night, less mixing occurs, producing less dust.

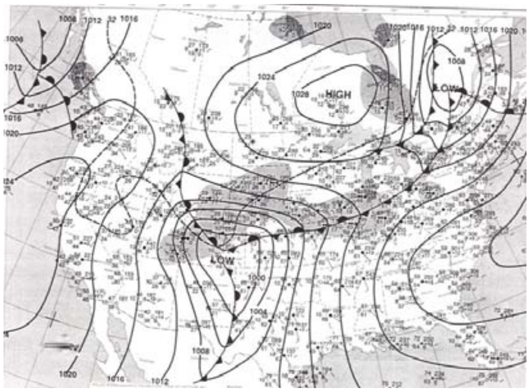

Figure 3. Pacific cold front crossing region.

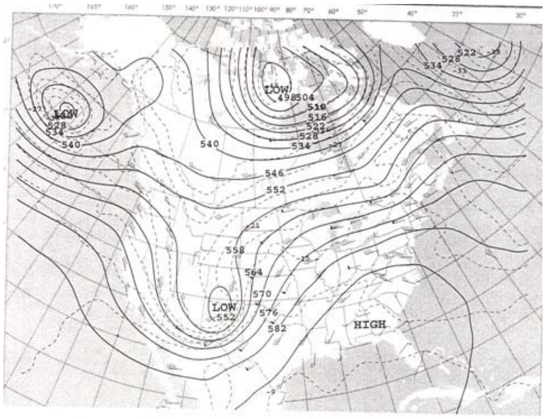

Figure 4. Upper air pattern associated with Figure 3.

Subtype A dust storms generally rely on a single point source or fairly concentrated finite areas of dust sources which then eventually yield their dust to the atmosphere when the winds exceed the friction velocity associated with at particular source (COMET, 2003). When the surface winds are aligned directly over a playa (dry desert lake bed, an intense dust source in this and other regions: Prospero *et al*., 2002) the corresponding reduction in visibility can be quite rapid. However, if the area of maximum winds is outside of the dust source, or the wind direction makes too large an angle of attack with the source, the blowing dust can advect into El Paso rather than be directly transported downstream. These advective type storms have more of a diffuse appearance and can occur with wind velocities of only 15 – 30 kph. These events do not generally restrict the prevailing visibility to less than 10 kilometers. A very strong and persistent Subtype A storm can raise dust in the warm air ahead of the front (assisted by the upward vertical velocity of the positive vorticity advection (Bluestein, 1992)) to a depth of 3000 to 4500 meters above mean sea level. Traces of the dust can also rise to as high as almost 10 kilometers (AFCCC, 2004, and personal observations of the authors). The synoptic pattern associated with this type of event will often produce standing waves east of the region's mountains and produce the characteristic lenticular or rarely rotor clouds.

Occasionally, where these waves intersect the land surface on the lee side of the mountains, linear sources of blowing dust are developed. In fact many dust sources in the region (playas or dry lake beds) are located to the lee of mountain ranges. One could speculate that many of the Chihuahuan Desert's dust sources are enhanced by the mean prevailing flow relative to the topography which in turn dictates where the mountain wave will touch down (such as Lake Lucero on the extreme west northwest edge of the White Sands National Monument, a regular dust source: Cahill *et al.*, 2005). Areas downstream from mountain passes, gaps and canyons may experience an enhancement of blowing dust due to an increase in the surface wind speed due to the Bernoulli funneling effect. This enhancement can increase winds coming out of the gap ~50%, and has been observed on the lee side of the Franklin Mountains in El Paso east of Transmountain Pass and also in the Tularosa Basin of New Mexico east of the San Augustin Pass on White Sands Missile Range (Novlan, 1982).

Subtype B storms, on the other hand, are not associated with a single source of dust in or near the region, but apparently accumulate lifted dust as the move down the Great Plains before pushing westward into New Mexico. Dust may be advected into the El Paso region from the Southern Great Plains, one of the most frequent dust-producing regions of the United States (Orgill and Sehmel, 1976). Figure 5 shows a typical backdoor frontal pattern (Continental Polar and rarely in winter Continental Arctic fronts) moving into the El Paso area from the east. Note the reversal of the pressure gradient from that of Subtype A. These fronts are characterized by their hazy appearance in the atmosphere, which is often one way to distinguish (lacking other obvious meteorological indicators) that a frontal passage has occurred (Novlan, 1982). Generally the dust associated with Subtype B events does not often reduce the prevailing visibility to less than10 km; however, if the winds are strong (usually 40 – 50 kph) along the initial edge of the front, there will be a short period of reduced visibility in blowing dust which then will eventually improve to a general hazy condition. Occasionally, it was been observed (Novlan, 1982) when the prevailing surface winds persist from the northeast for at least 2 hours with a velocity of 30 kph or more, a blowing dust event (fine white gypsum aerosols) will occur south of the White Sands National Monument reducing visibilities to less than10 km. On the other hand, If the wind direction is from a west to southwest direction, and the storm has sufficient upward vertical velocity, a Subtype A event can transport the white gypsum over the Sacramento Mountains, depositing fine white gypsum powder on the communities of Cloudcroft and Ruidoso, New Mexico. During an extreme event in 1977, gypsum dust advected over the Sacramento Mountains was deposited hundreds of kilometers to the northeast near the New Mexico- Texas border (Savage, 1981).

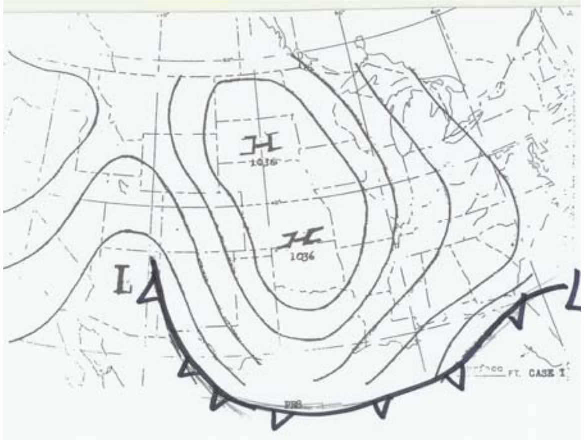

Figure 5. “Backdoor” front approaching forecast domain.

Mesoscale or convective (Type 2) dust events can occur whenever there is convection present (dry or wet), but are more common in the summer monsoon season. Type 2 dust events are less frequent in the El Paso area than synoptic events. They comprise only 4.3% of all the significant dust events (visibility < 10 km and duration 2 hours or more) in the record, primarily due to their short temporal persistence and limited spatial extent, but nevertheless have serious impacts. They can originate from (1) thunderstorm outflow boundaries (gust fronts), (2) dry microbursts, (3) wet microbursts, or some combination thereof Such events are commonly known as “haboobs” (named after their Arabic origin) in the deserts of the Southwest United States (Idso *et al*., 1972) (Figure 6).

Figure 6. A haboob (convective, Type 2) dust event.

Most convective weather in the El Paso area is concentrated in the summer monsoon season when synoptic patterns such as moderate to strong fronts are not prevalent but rather the weather is governed by the position of the Subtropical high aloft and the mean position of the Bermuda surface high. Mesoscale features such as outflow boundaries, weak backdoor frontal boundaries dominate the weather forcing, often augmented by outflow boundaries from overnight Mesoscale Convective Systems and Mesoscale Convective Complexes, and very subtle (often difficult to detect) upper air disturbances in the subtropical air mass. In addition, the elevated levels of moisture in the monsoon season resulting in higher dewpoints, higher soil moisture, and occasional standing water in areas after previous flash flooding or heavy rainfall, all add to the difficulty in raising dust with brief thunderstorm winds. Nevertheless, in areas ahead of a thunderstorm producing strong outflow winds, blowing dust can become a serious hazard. It some respects type 2 dust events may pose a greater safety hazard than the dust events of type 1, as synoptic dust events usually provide much more lead time to forecast, whereas the mesoscale nature of thunderstorm outflows provide very little to no lead time, a sharp boundary between clear and dust-laden air, and winds that change direction very rapidly and gust to high velocities suddenly reducing visibility to near zero. These events may cause a serious traffic hazard as well as significant safety issues to aviation.

3.2 Diagnostics and forecasting of dust events

For an optimal dust event, all meteorological variables (minimal cloud cover, low relative humidity, maximum surface winds, frontal passage, upper trough passage, maximum temperature, maximum winds aloft, and an upward vertical velocity field) must come together in phase. In general, as the upper air system approaches, upper level winds become more westerly to southwesterly aloft over the Central and Southern Rockies. Conservation of potential vorticity starts to lower pressure east of the mountains in Colorado and in New Mexico, forming the surface lee trough. This begins the process of establishing the surface pressure gradient over New Mexico. Ideally, an upper level trough with an associated Pacific cold front at the surface would be located over Utah and Arizona in the early morning hours. Surface winds begin to back ahead of the front to a southwesterly direction as winds aloft increase due to the approaching jet stream. Provided there is minimal to no cloud cover, the surface temperature inversion will then break around 1000 local time. This will establish a dry adiabatic lapse rate from the surface to the top of the former inversion, producing a mixing layer. This layer then will continue to expand aloft as solar heating of the surface progresses during the day. This mixing layer can reach heights of 3 to 4..5 kilometers above mean sea level in the spring and even as high as 6 km in the summer (See Figure 7). Thus a mechanism is established to mix down higher momentum winds to the surface. As the Pacific cold front approaches the area and dynamic and thermal processes induce upward vertical motion, a surface wave of low pressure develops on the front along the Colorado-New Mexico border (Albuquerque low) (Waters, 1970). The surface pressure gradient begins to tighten even more as the Pacific cold front approaches El Paso, thus increasing the surface winds and aligning them to the dust sources. If the frontal passage is as close as possible to the time of maximum surface heating, and the upper air trough passes shortly thereafter with the maximum jet stream aloft, then essentially all ingredients have come together in phase to produce the optimum blowing dust scenario.

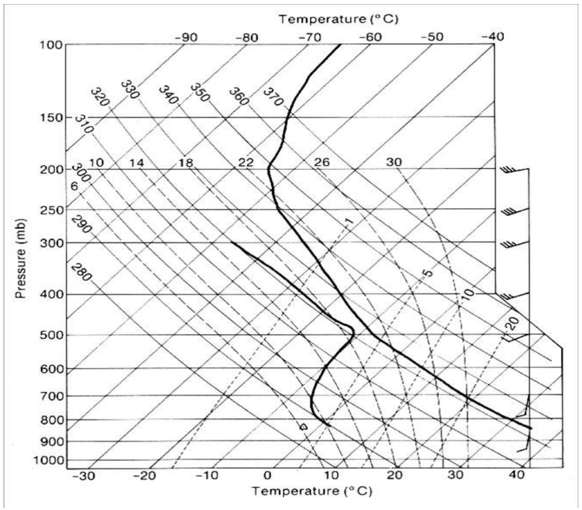

Figure 7. Mixing layer.

There are many variations and permutations possible of the combinations of meteorological variables associated with dust events, including the timing of the various parameters. For example, an event may start at night which may not result in any significant blowing dust. Often sufficient cloud cover may delay the start of or prevent altogether the dust storm itself. Different combinations may result only in a partial and or less intense event. All these possibilities have to be considered and often pose a significant forecasting. Dust storms will also be optimized in a zone of maximum winds in the lower atmosphere with converging jet streams at 200- 250 mb (polar front jet north and the subtropical jet south) over the El Paso area.

Because of the dryness of desert air, there is a wide diurnal temperature difference. Rapid heat loss at night from strong radiative cooling tends to lower the inversion and settle the dust: as a result, dust storms generally subside soon after sunset (COMET, 2003). When a surface-based inversion forms, dust lifting is suppressed. During the day, a 20-knot wind may raise dust, but at night it may not (COMET, 2003). However, for dust already suspended above the surface layer, a surface-based inversion will have little effect on its continued advection. Furthermore, if winds are sufficiently strong, they will inhibit formation of an inversion or even remove an existing one.

Visibility forecasting for dust events is generally very difficult. On the edges of blowing dust and within approximately 175 km downstream, horizontal ground level visibility is generally on the order of 0.8- 5 km. Beyond that distance, visibility quickly returns to 3.2 – 8 km. Visibility may remain at 5 – 9 km in dust haze and resuspended dust for days after an intense dust event. Intense dust storms reduce visibility to near zero in and near source regions with visibility improving away from the source. Dust settles when winds drop below the speed necessary to carry the particles, but some level of dust haze persists nearly constantly in the region during the dry season. Small particles restrict visibility more than large particles. In general, however, the worst visibility occurs within 6 meters of the surface (COMET, 2003).

Strong winds by themselves are not sufficient for a significant dust event: the wind must be sufficiently turbulent to loft dust, and it must occur in a reasonably unstable environment. Dust mobilization is proportional to the flux of momentum, or stress, into the ground. Friction velocity, a single parameter incorporating wind speed, turbulence, and stability, is a useful predictor of dust emission. Friction velocity is currently computed for many numerical weather prediction models, such as NOGAPS (Navy Operational Global Atmospheric Prediction System). NOGAPS is a global forecast model that is spectral in the horizontal and energy-conserving finite difference (sigma coordinate) in the vertical (COMET, 2003). A friction velocity of 60 centimeters per second is typically associated with west Texas dust storms (Singh, 1994). NOGAPS friction velocity products are thus very useful for dust forecasting.

Convective (type 2) blowing dust is often associated with dry micobursts that are most prevalent in the transition period between the end of the dry spring season and the start of the summer monsoon. During this period, there may be enough moisture aloft to produce an elevated thunderstorm but insufficient moisture in the lower levels to maintain the rainfall to the ground. These thunderstorms are very high based and often present a fibrous appearance, These “dry thunderstorms" produce occasional cloud to ground lightning but very little to no rain. A typical inverted V upper air sounding (Wakimoto, 1985) is characteristic of the dry microbursts and often produces sudden winds of 60 to 100 kph (Figure 9). Rain falls from the high level cloud base but it is evaporated by the dry air below before reaching the ground, converting the liquid rain into wind energy. The strength of the resulting gusty winds is related to the area of the dry area in the sounding below the mid level moisture and often may be approximated as proportional to the surface temperature - dewpoint spread, which during dry spring conditions in the area may approach 35 degrees Celsius The resulting dust storms are usually quite localized, ephemeral and not long lasting.

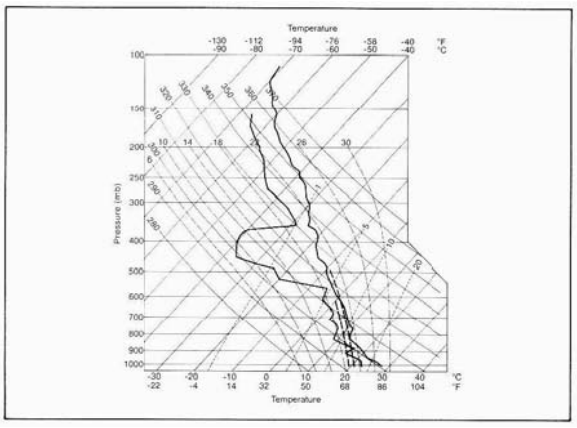

Figure 8. Sounding associated with wet microburst.

Wet microbursts result from a much wetter environment and a different type of upper air sounding (see Figure 8) (Caracena *et al*., 1987). Here, drier air in the mid layers of a very moist to saturated air mass in the lower levels of the atmosphere initiates a chain type evaporative reaction producing intense cooling and dropping a massive "water balloon" which upon hitting the ground spreads out rapidly with potentially damaging, severe wind gusts that may produce blowing dust ahead of the outflow. Usually the atmosphere is very moist in these environments and dust is brief and limited in extent, confined to the drier regions downstream from the microburst. In the hybrid case of the two microburst types a lasting, consistent environment for the thunderstorm outflow may be produced, creating ample blowing dust on and behind the leading edge of the outflow.. These events are on the average persist for much shorter time periods than Type I events and generally shallow, with a dust layer less than 1.2 km deep. However, their sudden (often surprise) nature can prove fatal to ground and air traffic.

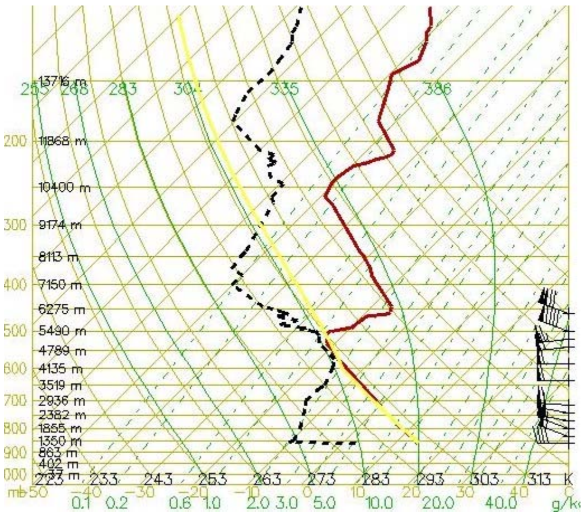

Figure 9. Sounding associated with dry microburst.

4. METEOROLOGICAL PARAMETERS ASSOCIATED WITH DUST EVENTS

4.1 *Relative Humidity*

Figure 10 shows that relative humidity in the 15-20% range is the most frequently observed during dust storms. This is in comparison to El Paso's average annual relative humidity of 41% and an average humidity of 28% during the driest month of April: dust events are clearly associated with drier than average air.

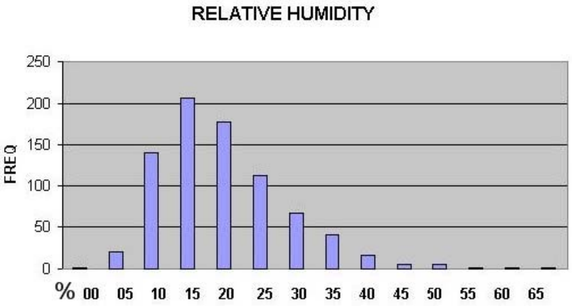

Figure 10. Relative humidity associated with El Paso dust events.

4.2 *Wind*

Figures 11 and 12 show the distribution of the mean wind speed and peak gust respectively observed during non-convective dust events in El Paso. Dust episodes are shown to be normally distributed around a mean wind of 43 kph and the gust speed normally distributed around a mean of 61 kph.

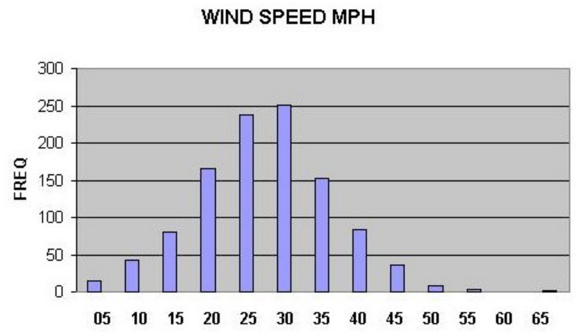

Figure 11. Wind speed associated with El Paso dust events.

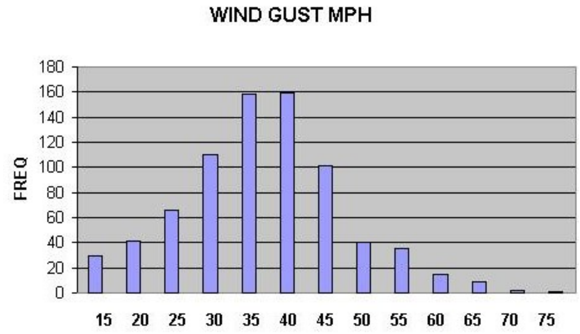

Figure 12. Peak gust associated with El Paso dust events.

Figure 13 shows a wind rose providing the mean wind direction associated with dust events at El Paso from 1932- 2005. These wind vectors, when worked backwards, can point in the direction of the more significant upwind dust sources in the Chihuahuan Desert (e.g. Rivera Rivera, 2006). Note the easterly spike in the wind rose suggestive of the Type 1B frontal events. Of particular interest is Figure 14, showing the wind rose during the 1930s, depicting peaks in prevalence in winds from a northeast direction. These data reflect that the "Dust Bowl" storms which originated over the southern Great Plains of the United States were advected into El Paso via the Type 1B process discussed above. A predominance of these events was apparently caused by a very persistent La Nina pattern which set up a prevailing ridge aloft over the western United States (Schubert *et al*, 2004). Such a synoptic setup would establish a marked persistent north to northwest flow aloft over the Rockies, creating a mechanism for a high frequency of backdoor fronts to tap the dust of the Great Plains and advect it into the Chihuahuan Desert region.

4.3 *Particulate Matter Concentration*

The concentration of airborne particulate matter with a size up to 10 micrometers (PM10) in El Paso on windy days is a clear proxy for blowing dust. PM10 data are collected and maintained by the Texas Commission on Environmental Quality (TCEQ), which maintains several PM10 monitoring sites around the El Paso metropolitan area. Dust events are clearly reflected in the TCEQ data, as denoted distinctly in a three-site composite for El Paso on 15-16 Dec 2003 (Figure 15). Figure 16 (TCEQ data for Dec 26 2003) nicely shows the inverse relationship between visibility and the PM10 concentration. Recent data suggests that when the PM10 concentration exceeds approximately 500 micrograms per cubic meter, the visibility falls below 10 km, becoming officially "obscured" for aircraft operations. PM10 values of 1000 micrograms per cubic meter are associated with surface visibilities of less than 5 kilometers. Figure 17 (TCEQ data for Dec 26 2003) illustrates the relationship between the peak wind gust and PM10 concentration. Note the lag time between the start of the rise in peak gusts and the start of the rise in PM10 concentration.

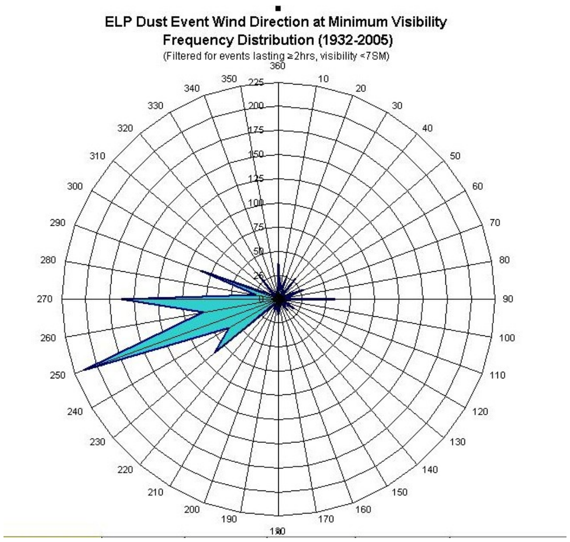

Figure 13. Wind direction associated with El Paso dust events.

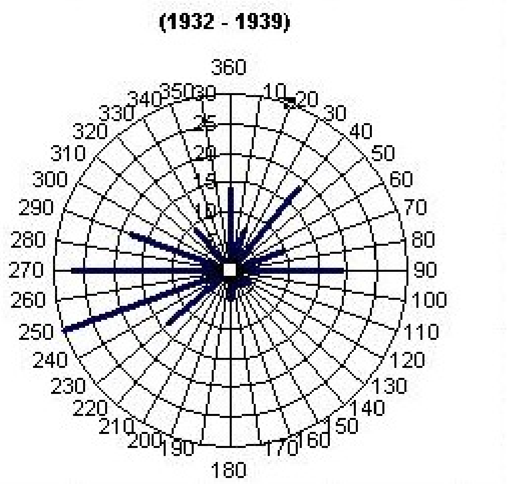

Figure 14. Wind direction associated with El Paso dust events during the Dust Bowl era.

4.4 *Precipitation*

Figure 18 shows the simultaneous plots of precipitation amounts and dust storm events chronologically from 1932 to 2005. Note that there is a

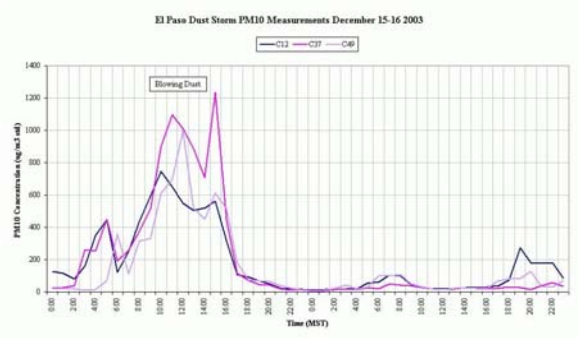

Figure 15. PM10 concentrations on 15- 16 Dec. 2003.

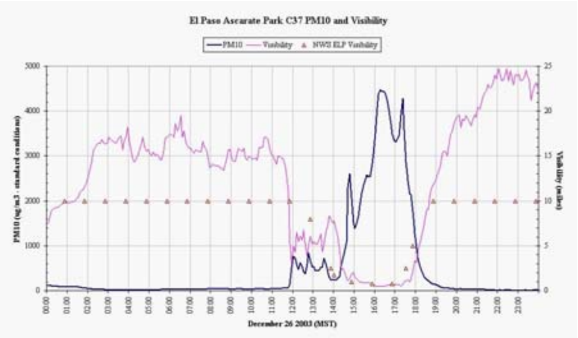

Figure 16. PM10 concentration vs. visibility on 26 Dec. 2003.\

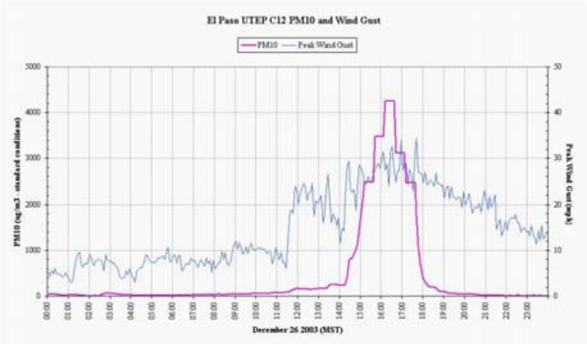

Figure 17. PM10 concentration vs. peak gust on 26 Dec. 2003.

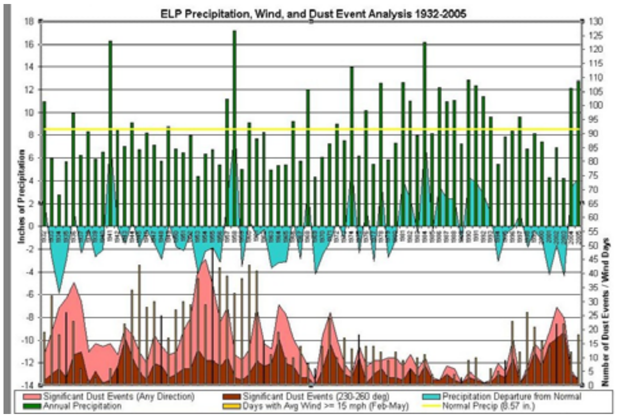

Figure 18. Precipitation vs. dust, 1932- 2005.

95% correlation with years having below normal rainfall amounts and above normal dust event days. Also it is noted that approximately one year after some El Niño events (Okin and Reheis, 2002), dust events have possibly increased in relative frequency in the El Paso; for example, in the years following the 1957-1958, 1987-1988,1992-1993, and 1997-1998 ENSO (El Niño-Southern Oscillation) events.

4.5 *Visibility*

Figure 19 shows a plot of observed wind speeds at minimum visibility times. Flight category definitions for visibility are as follows (NOAA-NWS Instruction 10-813):

VFR VISUAL FLIGHT RULES: Visibility greater than 5 miles.
MVFR MARGINAL VISUAL FLIGHT RULES: Visibility 3 miles to less than 5 miles.
IFR INSTRUMENT FLYING RULES: Visibility 1 mile to less than 3 miles.
LIFR LOW INSTRUMENT FLYING RULES: Visibility less than 1 mile.

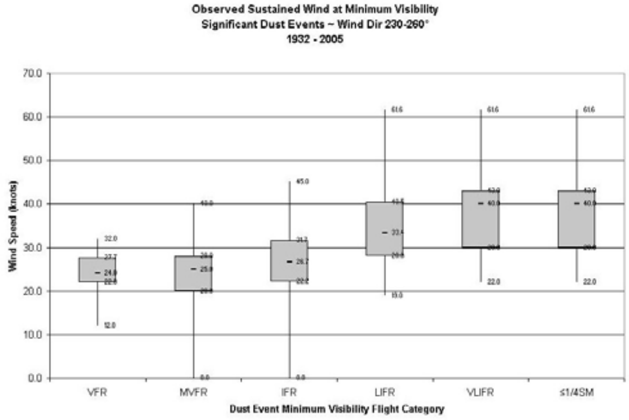

Figure 19. Observed wind speeds at time of minimum visibility.

These data have led to the development of a power fit equation which can be used as a guide to predict the minimum visibility at El Paso International Airport given the wind gust forecast:

V = (2^8)*(2^-(vg/4))

where V is the minimum visibility in miles and vg is the wind gust in knots.

The idea of forecasting minimum visibility based on peak wind was originally developed by the first author for White Sands Missile Range in nearby New Mexico (Novlan, 1982). In general for the 1970s through the early 1990s a fairly linear relation existed; however, from 1994 through 2003 when each year had a rainfall deficit with the exception of 1998, the cumulative effect of the drought led to drier soils along with reduced vegetation (in effect an increase in desertification in and around El Paso), and the thresholds for low visibilities as related to peak gusts dropped approximately 10 knots. In other words, where normally a 40 knot (20.5 m/s) wind gust would normally produce a minimum visibility of 3 miles (5 km), the visibility now would drop to 1-2 miles (~1.5 - 3 km). While during typical years a peak gust of 30 knots (15 m/s) would produce an obstructed visibility of 6 miles (10 km) (Novlan, 1982), during an extended period of very dry years a gust of 20-25 knots (10- 13 m/s) would initiate the production of blowing dust.

Figure 20 shows that the duration of non-convective (Type 1) dust events has an exponentially decaying temporal distribution, with the lasting an average of 3 to 4 hours. Appendix I presents an hour-by-hour climatology of the prevalence of restricted visibility from blowing dust in El Paso for each month. Clearly, late afternoon in the early spring is the favored time for dust in the El Paso area.

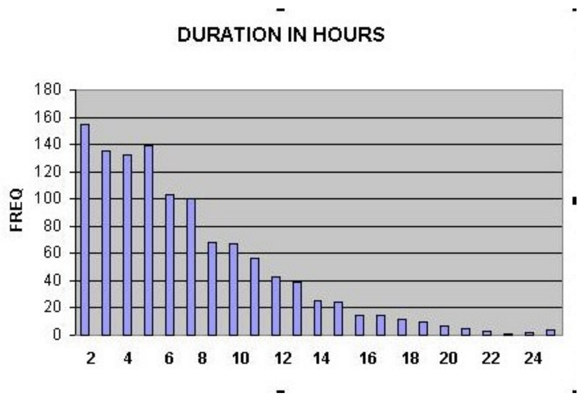

Figure 20. Duration of El Paso dust events.

4.6 *Satelilte and Radar Signatures*

In addition to reducing visibilities and creating a brown sky, dust events may be detected through satellites (e.g. Rivera Rivera *et* al., 2006) and radar. Figure 21 shows a dust storm in the El Paso area on 12/26/2003 (courtesy TCEQ) as seen from GOES imagery.

Figure 22 shows a dust storm as viewed from the MODIS satellite on 12/15/2003 at 2000z over the El Paso area. This photo is very typical of the development of dust events in the region, as dust plumes emanate from one or more point sources and fan out in a conical Gaussian plume fashion (COMET, 2003). Figure 23 shows a 11-12 micron GOES satellite imagery two day progression of a narrow dust plume that grew in time and moved southward from southern New Mexico into the El Paso area. The 11-12 micron difference image is an excellent tool in monitoring the initiation and expansion of dust events when such events are otherwise difficult to detect in the standard infrared or visual bands.

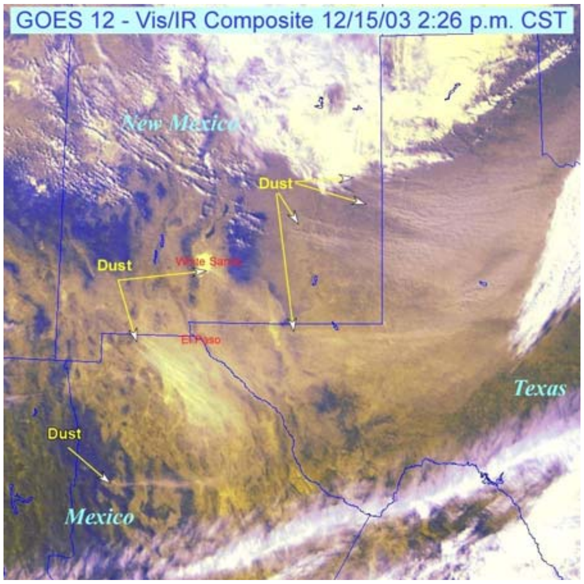

Figure 21. GOES composite of the 15 Dec. 2003 dust event.

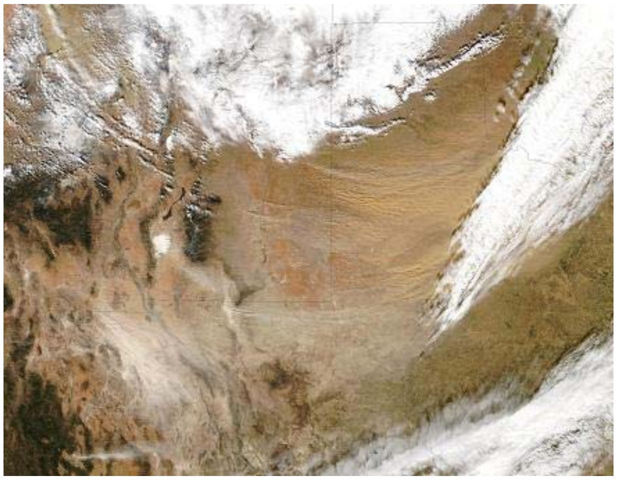

Figure 22. MODIS image of the 15 Dec. 2003 dust event.

Even the Weather Surveillance Radar 88Doppler (WSR88D) can detect dust events as shown in Figure 24. The radar is in clear air mode which is slower and picks up more scatterers- in this case, dust particles.

5. AN IDEALIZED FORECAST MODEL FOR BLOWING DUST IN THE EL PASO AREA

Appendix II represents an “idealized” dust event as observed at El Paso International Airport during the spring. It is based on the April 7, 1957 event. The individual elements are meant to be interpreted in a relative sense to demonstrate the interaction of cloud cover, inversion breaking, dryness, frontal passage, etc. The optimal event will allow frontal passage near maximum temperature time and allow no cloud cover to interfere with inversion breakage around midmorning. There are many variations upon this idealized scenario-constituting the very challenge of weather forecasting. Such a template may serve as a strategic forecast aid

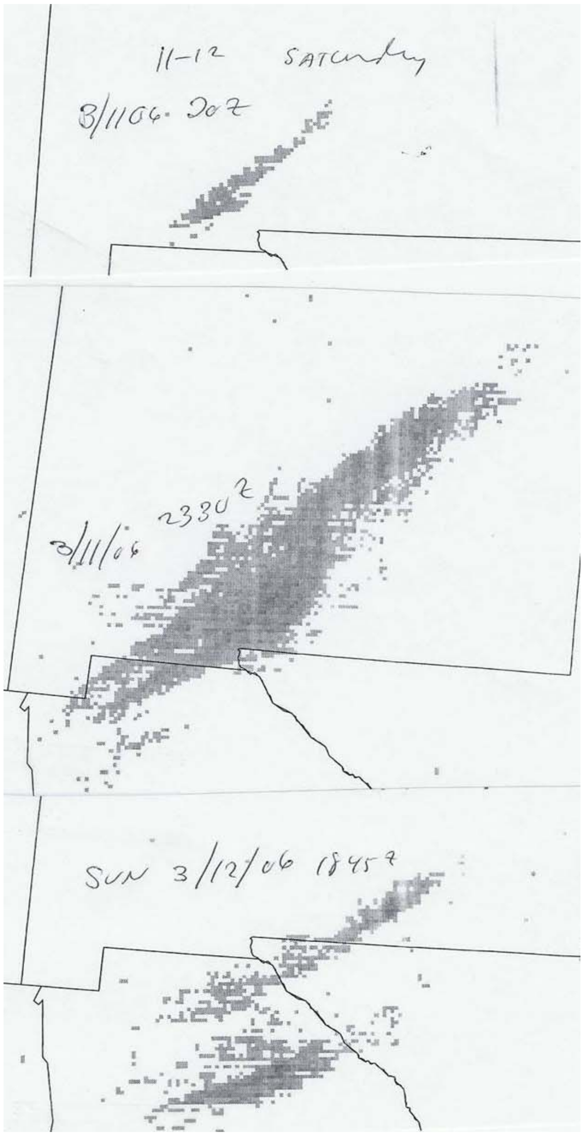

Figure 23. 11-12 micron product showing advecting dust.

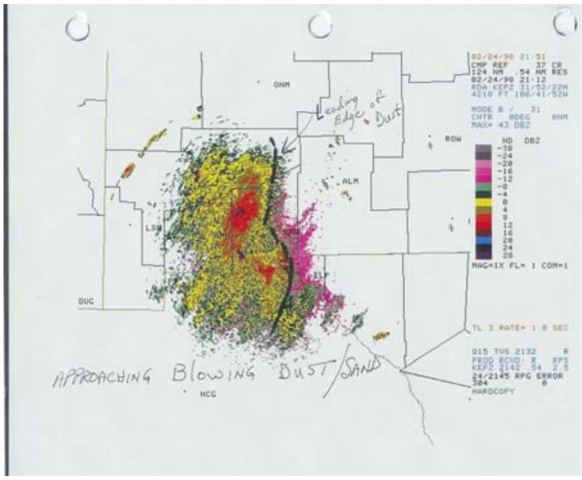

Figure 24. Blowing dust/sand visible on ELP WSR88D.

providing a baseline reference for forecasting non-convective blowing dust events, keeping in mind that modifications may be needed.

6. DUST STORM SAFETY

6.1 *Vehicular hazards*

Blowing dust constitutes a serious safety hazard in the El Paso metropolitan area as well as many other desert cities worldwide. Airborne soil particles can reduce visibility, cause respiratory problems, and have an abrasive affect on machinery. Dust storms, even if brief and spatially localized, must be taken especially seriously because of blinding conditions on local highways. Dust storms have been attributed to many motor vehicle collisions resulting in loss of property, injury and death: since the 1990s, the El Paso WFO area has averaged between 1 and 2 traffic fatalities annually directly attributed to dust storms. Figure 25 shows an area of the Chihuahuan Desert west and northwest of El Paso where many major roadways including Interstate 10 west of Las Cruces to the Arizona state line are frequently closed due to dust storms. Numerous signs along this and other roads (Figure 26) advise of the dust hazard.

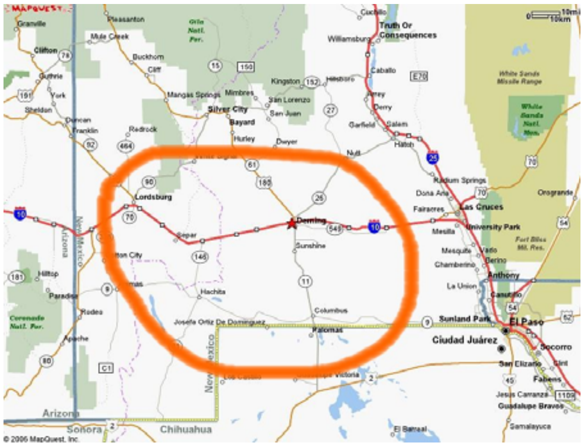

Figure 25. Dust hazard region in southwest New Mexico.

Figure 26. Sign along U.S. Highway 62/82 E of El Paso.

The NWS has compiled a brief list of driving safety procedures to employ during a dust storm (U.S. Department of Commerce- NOAA NWS, 1982). For example, drivers are advised to never stop on the pavement. Motorists are warned to ensure that they turn off their headlights when pulling off a roadway during a dust event. In the past, drivers have pulled off the roadway with their lights on: vehicles approaching from the rear and using the advance car's lights as a guide have inadvertently left the roadway and in some instances collided with the parked vehicle. When stopped in a dust storm, drivers are warned to turn off all lights including brake lights and set the emergency brake, reducing the possibility of a rear-end collision. If conditions prevent pulling off the road, motorists are advised to proceed at an appropriately reduced speed with lights on, using the center line as a guide.

6.2 *National Weather Service products*

A number of advisories, watches, and warnings are issued by the National Weather Service for events related or conducive to blowing dust and sand. They are broadcast on NOAA Weather Radio as well as local radio and television stations. They include the following products:

Wind Advisory:
Issued for sustained winds 25 to 39 mph and or gusts to 57 mph. Issuance is normally site specific.

High Wind Watch:
Issued when there is the potential of development of high wind speeds that may pose a hazard or be life- threatening. The criterion is the potential for sustained non-convective winds greater than or equal to 40 mph and or gusts greater than or equal to 58 mph.

High Wind Warning:
Issued when high wind speeds may pose a hazard or be life threatening. The criterion for this warning is sustained non-convective winds greater than or equal to 40 mph lasting for one hour or longer, or winds greater than or equal to 58 mph for any duration.

Blowing Dust or Sand Advisory:
Issued when strong winds over dry ground with little or no vegetation can lift particles of dust or sand into the air. A concentration reducing the visibility to 1 mile or less often poses hazards for travelers.

Dust Storm Warning:
Same as a blowing dust advisory except visibilities are expected under ¼ mile to near zero.

Airport Wind Warning (AWW):
Issued for El Paso International Airport for winds sustained at or above 20 knots with gusts to 30 knots or greater, or sustained winds of 30 knots or greater. Start/Stop times, duration of the event and visibility restrictions (< 7 mi) are also included.

These warnings, watches, and advisories and geared to larger scale events that are relatively extensive in time and space. For highly localized events, such a microburst that may be or is causing blowing dust, the Special Weather Statement product will convey the message for the shorter term and less extensive event:

Special Weather Statement:
Not an advisory or warning as such but a statement of “heads up” or description of actual significant weather in progress that is not severe but could cause hazards to public safety in a localized area of time and space. For example, if blowing dust was very localized and confined to a small portion of Interstate 10 in rural Hudspeth County for one or two hours, a Special Weather Statement would be used rather than a Blowing Dust Advisory.

In the event of a forecasted major wind and dust event, the National Weather Service tries to give as much advance advisory as possible starting with a discussion in the Area Forecast Discussion and key phrases in the public Zone Forecasts, such as “windy with patchy areas of blowing dust,” etc., and then step up the products accordingly. Depending on the magnitude of the winds involved, Special Weather Statements or a High Wind Watch would be issued first, following through with a Wind Advisory, High Wind Warning, Blowing Dust Advisory, and/or Dust Storm Warning as appropriate.

The National Weather Service in El Paso will make an attempt notify various emergency dispatch services such as the Texas and New Mexico Departments of Public Safety, local, county, and state law enforcement agencies, and the Departments of Transportation in Texas as well as in New Mexico for anticipated dust events. The FAA tower and airport operations at El Paso International Airport are notified with as much advance notice as possible if an AWW will be issued.

7. CONCLUSION

Dust storms are a common occurrence in the El Paso area. Most local residents are well aware of the consequences of blowing dust and have learned to adapt quite well to this and other weather hazards in the desert Southwest, including flash floods, high winds, and very hot temperatures. Nevertheless, with increasing population density and a more mobile society, dust storms may pose an increasing natural hazard. An evaluation of the synoptic climatology of blowing dust in a desert city such as El Paso may aid the meteorological community in the diagnosis and prognosis of these events, and raise the public’s awareness of potential dust hazards and their causes in order to help residents be better prepared for action when needed, especially in the area of ground and air transportation.

A better understanding of the synoptic climatology of dust events and their local source areas could lead to better dust forecasting with positive economic effects. For example, improved dust forecasting could enable more precise terminal aerodrome forecasts for aircraft, reducing the amount of time significant visibility obscurations are forecast which in turn would mean less time aircraft operations would have to seek alternative landing sites and add extra fuel (fuel loading). The overall climatological distribution of the various meteorological variables associated with blowing dust events can serve as a basis to formulate forecasting templates for these storms and even potentially act as a guide for long term planning to avoid scheduling of dust sensitive events during times of high probability.

8. ACKNOWLEDGEMENT

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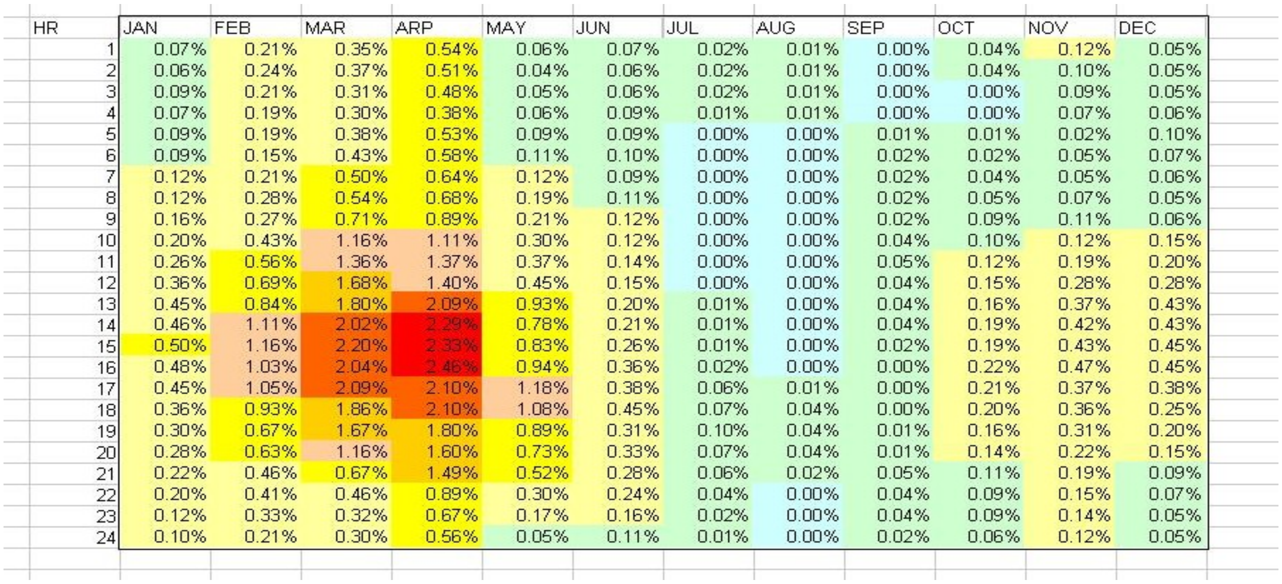

HR	JAN	FEB	MAR	ARP	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.07%	0.21%	0.35%	0.54%	0.06%	0.07%	0.02%	0.01%	0.00%	0.04%	0.12%	0.05%
2	0.06%	0.24%	0.37%	0.51%	0.04%	0.06%	0.02%	0.01%	0.00%	0.04%	0.10%	0.05%
3	0.09%	0.21%	0.31%	0.48%	0.05%	0.06%	0.02%	0.01%	0.00%	0.00%	0.09%	0.05%
4	0.07%	0.19%	0.30%	0.38%	0.06%	0.09%	0.01%	0.01%	0.00%	0.00%	0.07%	0.06%
5	0.09%	0.19%	0.38%	0.53%	0.09%	0.09%	0.00%	0.00%	0.01%	0.01%	0.02%	0.10%
6	0.09%	0.15%	0.43%	0.58%	0.11%	0.10%	0.00%	0.00%	0.02%	0.02%	0.05%	0.07%
7	0.12%	0.21%	0.50%	0.64%	0.12%	0.09%	0.00%	0.00%	0.02%	0.04%	0.05%	0.06%
8	0.12%	0.28%	0.54%	0.68%	0.19%	0.11%	0.00%	0.00%	0.02%	0.05%	0.07%	0.05%
9	0.16%	0.27%	0.71%	0.89%	0.21%	0.12%	0.00%	0.00%	0.02%	0.09%	0.11%	0.06%
10	0.20%	0.43%	1.16%	1.11%	0.30%	0.12%	0.00%	0.00%	0.04%	0.10%	0.12%	0.15%
11	0.26%	0.56%	1.36%	1.37%	0.37%	0.14%	0.00%	0.00%	0.05%	0.12%	0.19%	0.20%
12	0.36%	0.69%	1.68%	1.40%	0.45%	0.15%	0.00%	0.00%	0.04%	0.15%	0.28%	0.28%
13	0.45%	0.84%	1.80%	2.09%	0.93%	0.20%	0.01%	0.00%	0.04%	0.16%	0.37%	0.43%
14	0.46%	1.11%	2.02%	2.29%	0.78%	0.21%	0.01%	0.00%	0.04%	0.19%	0.42%	0.43%
15	0.50%	1.16%	2.20%	2.33%	0.83%	0.26%	0.01%	0.00%	0.02%	0.19%	0.43%	0.45%
16	0.48%	1.03%	2.04%	2.46%	0.94%	0.36%	0.02%	0.00%	0.00%	0.22%	0.47%	0.45%
17	0.45%	1.05%	2.09%	2.10%	1.18%	0.38%	0.06%	0.01%	0.00%	0.21%	0.37%	0.38%
18	0.36%	0.93%	1.86%	2.10%	1.08%	0.45%	0.07%	0.04%	0.00%	0.20%	0.36%	0.25%
19	0.30%	0.67%	1.67%	1.80%	0.89%	0.31%	0.10%	0.04%	0.01%	0.16%	0.31%	0.20%
20	0.28%	0.63%	1.16%	1.60%	0.73%	0.33%	0.07%	0.04%	0.01%	0.14%	0.22%	0.15%
21	0.22%	0.46%	0.67%	1.49%	0.52%	0.28%	0.06%	0.02%	0.05%	0.11%	0.19%	0.09%
22	0.20%	0.41%	0.46%	0.89%	0.30%	0.24%	0.04%	0.00%	0.04%	0.09%	0.15%	0.07%
23	0.12%	0.33%	0.32%	0.67%	0.17%	0.16%	0.02%	0.00%	0.04%	0.09%	0.14%	0.05%
24	0.10%	0.21%	0.30%	0.56%	0.05%	0.11%	0.01%	0.00%	0.02%	0.06%	0.12%	0.05%

Appendix I. Hourly and monthly climatology of El Paso dust event occurrence, 1932- 2005.

TIME	SKY	VSBY mi	WX	TEMP F	TD F	WIND DIR	WIND KTS	GUST KTS
600	BKN	10+		57	28	120	5	
700	BKN	10+		60	27	150	7	
800	SCT	10+		63	26	180	10	
900	SCT	10+		64	25	200	15	
930	SCT	10+		66	25	210	20	28
1000	FEW	8		67	25	220	25	35
1030	OBSCD	6	BLDU	68	25	220	28	35
1100	OBSCD	6	BLDU	70	24	220	30	37
1130	OBSCD	5	BLDU	71	24	220	30	40
1200	OBSCD	4	BLDU	75	24	230	32	40
1230	OBSCD	4	BLDU	75	24	230	34	42
1300	OBSCD	3	BLDU	76	23	230	35	42
1330	OBSCD	3	BLDU	66	23	240	35	45
1400	OBSCD	2	BLDU	77	20	240	37	47
1430	OBSCD	2	BLDU	78	18	240	37	47
1500	OBSCD	1.5	BLDU	78	16	240	38	48
1530	OBSCD	1	BLDU	79	14	250	40	50
1600	OBSCD	0.5	BLDU	79	13	250	42	52
1630	OBSCD	1	BLDU	77	15	260	40	51
1700	OBSCD	1	BLDU	76	17	270	38	47
1730	OBSCD	3	BLDU	75	18	270	35	45
1800	OBSCD	4	BLDU	73	20	280	33	43
1830	OBSCD	6	BLDU	70	20	280	30	40
1900	OBSCD	7		63	20	300	30	40
1930	OBSCD	8		62	18	320	27	35
2000	SCT	8		61	15	330	27	37
2030	SCT	10+		60	14	330	25	33
2100	SCT	10+		59	13	340	20	
2130	SCT	10+		57	10	350	15	

Appendix II. “Idealized” dust event construct for El Paso International Airport.