JP2.6 **ANALYSIS OF AIR TRANSPORT PATTERNS BRINGING DUST STORMS TO EL PASO, TEXAS**

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1. INTRODUCTION

The Chihuahuan Desert of North America encompasses a critical climatic boundary region between the subtropics and the middle latitudes (Castiglia and Fawcett, 2006). The area receives most of its annual precipitation in the summer through the monsoon circulation off the Gulf of Mexico (Schmidt, 1986). El Paso, Texas, U.S.A., and Ciudad Juarez, Chihuahua, Mexico (collectively the "Paso del Norte" metropolitan area) comprise the largest metropolitan area in the Chihuahuan Desert, with a population of over 2 million.

Dust storms are one of the principal hazardous weather phenomena in the Paso del Norte. From 1932 through 2005, dust events lasting at least 2 hours were recorded at the El Paso International Airport (ELP) an average of 15 days per year (Novlan *et al.*, 2007). This dust has effects on the local economy and infrastructure, and may adversely affect the health of the Paso del Norte's residents. Blowing dust and related phenomena (dust haze, blowing sand, etc.) are most common in the Chihuahuan Desert lowland areas during the dry season (roughly November through May), during which dust can be raised and/or transported throughout the region by synoptic-scale weather systems (Rivera Rivera *et al*., 2009: Lee *et al*., 2009). During the summer monsoon, thunderstorm outflows (haboobs) entrain and transport dust over more localized areas (convective dust events).

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2. DATA AND METHODOLOGY

2.1 Dust Event Data Extraction

Daily weather records for El Paso, Texas, maintained by the National Weather Service El Paso Forecast Office, Santa Teresa, New Mexico, were examined for the period 2001 through 2005 to determine those days in which blowing dust or related phenomena ("dust events") were present in at least one hourly observation at El Paso International Airport (ELP). This is the same dataset used by Novlan *et al.* (2007). During the 2001- 2005 period, dust events were observed at ELP on 219 days (~12% of all days); 55% of these events were synoptically driven, while 45% of the events were associated with thunderstorm outflows (convectively-driven). Fig. 1 below shows the monthly distribution of these events, illustrating the different seasonality of convective and non-convective (synoptically-driven) dust.

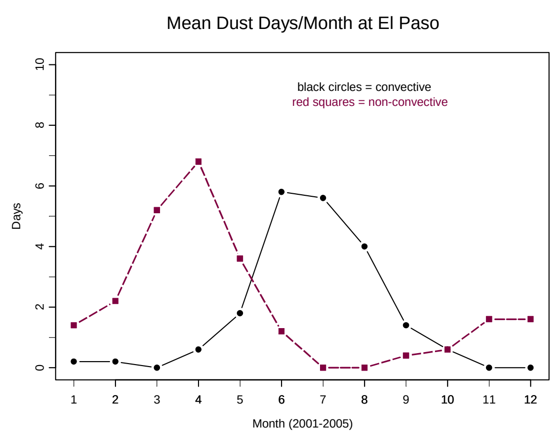

Figure 1. Monthly frequency of dust days at ELP during 2001- 2005, convective and non-convective.

2.2 Back Trajectories

Back trajectories were created with HYSPLIT for each day in the 2001- 2005 period, and then grouped for statistical evaluation of air transport patterns on days in which dust events, convective dust events, and no dust events occurred. A companion paper (Rivera Rivera *et al*., 2009) focuses on the synoptically-driven dust events, and provides additional modeling and interpretation of two major dust outbreaks in April and December 2003. In this preprint, we compare trajectory contour plots for all days with at least one dust observation ("high concentration" days) *vs.* those days in which dust was never observed ("low concentration" days), and further investigate the patterns specifically associated with convective dust events.

The HYSPLIT model (Draxler and Hess, 2004) supports a wide range of simulations related to the long-range transport, dispersion, and deposition of pollutants. The data used to create the back trajectories were gridded meteorological data from either analyses or short-term forecasts from routine numerical weather prediction models from NOAA Air Resource Laboratory. A trajectory was started from the receptor site (El Paso TX, 31.86° N, -106.44° W). Start heights of 100m, 200m, and 500m above ground level at the receptor site were combined, and the air parcel position, referred to as an endpoint, was calculated back in time for 24 hours.

2.3 Statistical Analyses

To investigate the presence of large-scale air transport patterns into El Paso associated with dust event days (synoptically-forced and/or convective) and days without dust, we performed residence time, probability, and source contribution function analyses of the trajectories.

The residence time probability (*Pi,j*) is defined as the number of back trajectory endpoints in a given grid cell (in this case, 0.25 deg latitude by 0.25 deg longitude) over a specified time interval:

$$P_{i,j} = \frac{1}{N}\sum_{t=1}^{T} n_{i,j,t}$$

where *ni,j,t* is the number of endpoints falling in a grid cell at longitude *i* and latitude *j* before the trajectory arrived at the receptor during measurement period *t*, *T* is the total number of time periods, and *N* is the total number of endpoints throughout the domain for all time periods (Ashbaugh *et al*., 1985). Differential and conditional residence time probabilities (Poirot *et al.,* 2001; Schichtel *et al.*, 2006) were computed.

We computed a dimensionless source contribution function (*Si,j*) by normalizing *Pi,j* by a hypothetical probability function of air parcels arriving at the receptor site from all directions equally (Ashbaugh *et al*., 1985). The source contribution function is proportional to (residence time * distance), and serves to take out the otherwise-unavoidable peak at the receptor site. A source contribution function with a value greater than 1 corresponds to a transport pattern that is much more likely than if air arrived from all directions with equal probability.

Probabilities and source contribution functions were determined for all days, all days with dust, days with convective dust events, and days with no dust observed. Positive probability values show those areas where air masses were proportionally more likely to arrive from during a given condition (dust, no dust, convectively-driven dust). Contour plots of the source contribution function and probabilities during days with different types of dust events, compared to those for all days and/or non-dusty days, will illustrate airflow patterns associated with dust entering the Paso del Norte. Higher residence time, source contribution function and probability values over certain regions in the contour plots correspond to a higher likelihood of air parcels arriving from those regions during a certain class of events.

3. RESULTS AND DISCUSSION

Contour plots of the HYSPLIT trajectory endpoints and residence time, source contribution function, incremental probability, and conditional probability showed different airflow patterns during dusty days and with convectively-raised dust, as compared to overall and dust-free day trajectories into El Paso during 2001- 2005.

3.1 Overall Data for El Paso, 2001- 2005

The overall fraction of air mass trajectories arriving in El Paso over the five-year period was shown to be more or less relatively symmetrically distributed around the receptor site, with maxima to the west and east of the city (Figures 2 and 3).

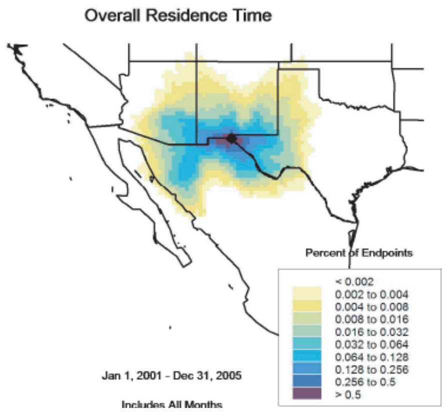

Figure 2. Contour plot of overall residence times for 2001- 2005.

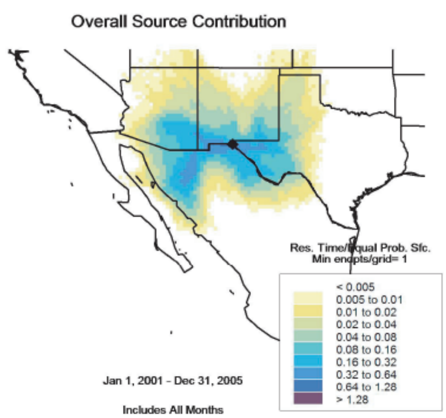

Figure 3. Contour plot of overall source contributions for 2001- 2005.

Overall residence times were skewed to the southwest during high concentration (dust observed) days (Figure 4) but not during low concentration (no dust observed) days (Figure 5).

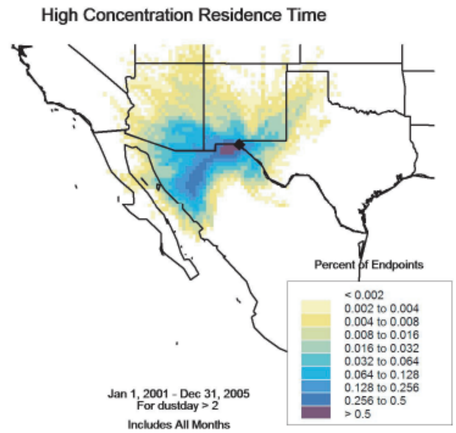

Figure 4. Contour plot of residence times for all days during which dust was observed for 2001- 2005.

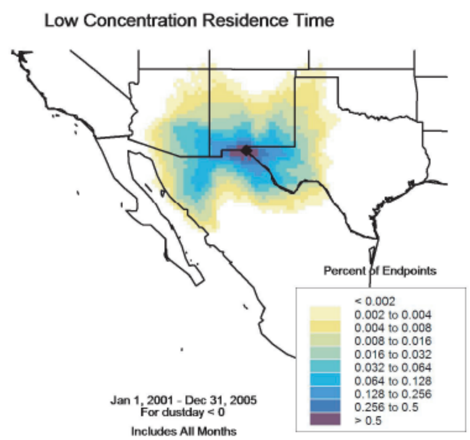

Figure 5. Contour plot of residence times for all days during which dust was not observed for 2001- 2005.

Source contributions for high concentration days (Figure 6) were skewed to the west and southwest. An area with source contribution function >1 (high likelihood) can be seen in northwest Mexico near the eastern slope of the Sierra Madre Occidental mountain range. A slight secondary swath can be seen extending to the northeast into the Texas Panhandle: this trajectory is associated with so-called "backdoor" cold fronts which regularly advect into El Paso. These fronts can occasionally bring dust generated in the Southern High Plains region during the winter and spring (Wigner and Peterson, 1987). Source contributions for low concentration days (not shown) were similar to overall source contributions (Figure 3).

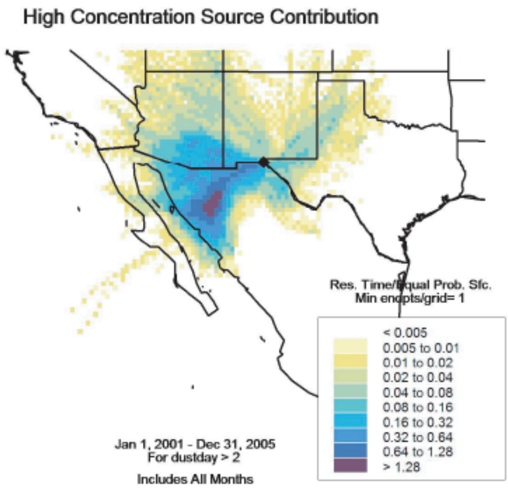

Figure 6. Contour plot of source contributions for all days during which dust was observed for 2001- 2005.

Differential probability contour plots are shown in figures 7 and 8. The differential probability for high-concentration days (Figure 7) was again strongly positively correlated with the region southwest of El Paso: note the negative correlation with all the other immediately surrounding areas. The differential probability for low-concentration days (Figure 8) was most anti-correlated with trajectories arriving from the southwest.

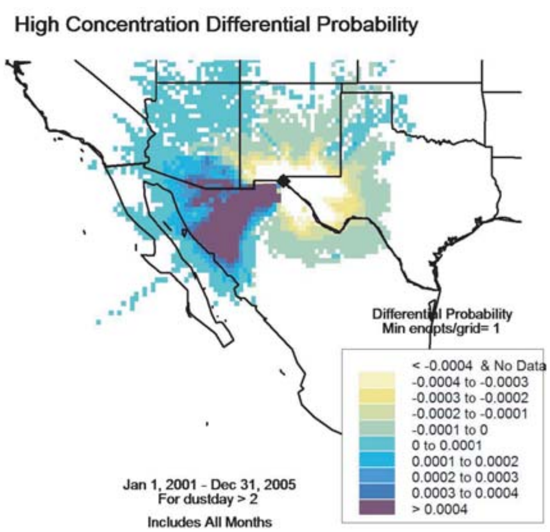

Figure 7. Contour plot of differential probability for all days during which dust was observed for 2001- 2005.

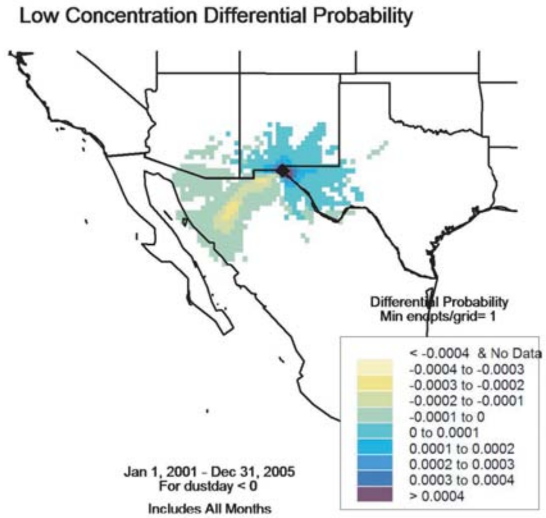

Figure 8. Contour plot of differential probability for all dust-free days in 2001- 2005.

The zone west and southwest of El Paso associated with higher likelihoods of dust is a region with dry lakes (playas), agricultural lands and other known dust source areas (Prospero *et al.,* 2002; Gill *et al.,* 2008; Lee *et al.*, 2009). Dust from these "hotspots" is advected several hundred kilometers or more into the Paso del Norte.

The fastest-moving trajectories for high concentration events (Figures 6 and 7) approached from the Pacific Ocean across Baja California, consistent with deep troughs bearing high-momentum air entering the Chihuahuan Desert from the southwest. Some of these trajectories moved more than 600 km into El Paso from the southwest over a 24-hour period. These fastest-moving (farthest-distance) trajectories bringing dust to El Paso would be consistent with air parcels moving toward cyclones crossing and/or developing northeast of the region. The most intense dust storms in the southwestern Great Plains to the northeast of the Chihuahuan Desert are associated with developing lee cyclones (Wigner and Peterson, 1987; Lee and Tchakerian, 1995). The most intense individual dust events in El Paso at the present day are also associated with cyclones over New Mexico and the Texas Panhandle (Rivera Rivera, 2006; Rivera Rivera *et al*., 2009; Lee *et al*., 2009).

3.2 Convectively-Driven Dust Events

Differential and conditional probabilities for days in which convectively-driven dust events (haboobs) were observed are shown in Figures 9 and 10.

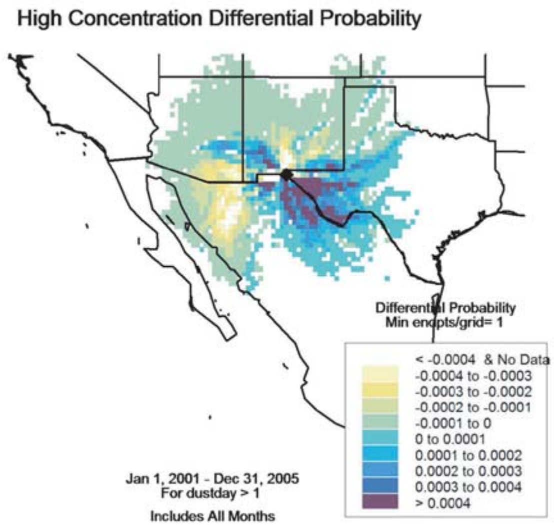

Figure 9. Contour plot of differential probability for all days during which convectively-driven dust was observed for 2001- 2005.

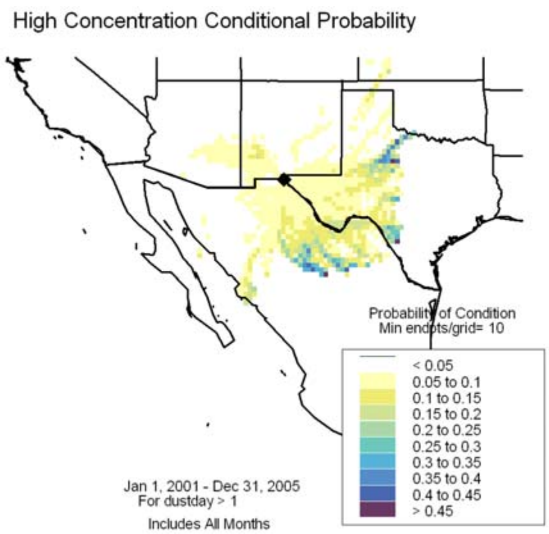

Figure 10. Contour plot of conditional probability for all days during which convectively-driven dust was observed for 2001- 2005.

Note that convectively-driven dust events (occurring primarily during the monsoon) are most associated with air flow from the south and east- from the Gulf of Mexico and up the Rio Grande Valley- as opposed to air flow from the southwest across northwestern Mexico (note the area of negative differential probability in Figure 9). Heavy summer precipitation in the Chihuahuan Desert is often associated with moisture surges advecting from the Gulf of California region (Stensrud *et al.*, 1997) south and southwest of El Paso. However, thunderstorms associated with Gulf of California moisture surges seem less likely to generate dusty outflows as compared to thunderstorms associated with air masses arriving from the southeast. Indeed, other analyses have shown an anti-correlation between particulate matter concentrations and moisture levels in El Paso (Wise and Comrie, 2005) and an anti-correlation between dust concentrations in El Paso and precipitation from Gulf of California monsoon moisture surges during 1998- 2006 (Lozano *et al.*, 2007).

Conditional probabilities for convective dust days (Figure 10) are most positively associated with 24-hour trajectory endpoints >600 km south and east of El Paso. These fastest-moving (farthest-distance) trajectories bringing convectively-driven dust to El Paso would be consistent with maritime tropical air mass surges from the direction of the Gulf of Mexico.

4. SUMMARY

Although 24-hour air mass back trajectories into El Paso, Texas during 2001-2005 were overall relatively symmetrically distributed around the city, for days in which dust was observed (about 12% of all days) the trajectories were most associated with southwesterly flow from an area of known dust sources in the Chihuahuan Desert. An area with source contribution function >1 (a high likelihood for air residence) during dust days existed in northwest Mexico near the eastern slope of the Sierra Madre Occidental.

Convectively-driven dust events (haboobs), most frequent during the summer monsoon, were most prevalent with airflow from the south and east, as opposed to Gulf of California moisture surges.

The fastest- moving trajectories during days with dust in El Paso advected a distance of >600 km in 24-hours, consistent with air parcels moving toward lee cyclones over the southwestern Great Plains or (for convectively-driven dust events) moisture surges from the Gulf of Mexico region.

The recognition of these characteristic air mass trajectories can aid in forecasting dust storms in the Paso del Norte metropolitan area.

5. ACKNOWLEDGEMENTS

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