**Texas Commission on Environmental Quality**

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## GLOSSARY

Aerosol – A suspension of particulate matter in the air
AQS – Air Quality System
BIBE – Abbreviation for Big Bend National Park
$b_{PM}$ – The light extinction due to particles
$b_{sp}$ – The light extinction due to light scattering by particles
$b_{scat}$ – The light extinction due to all scattering phenomena
$b_{total}$ – The total extinction from both gaseous and particulate components
CAMS – Continuous Air Monitoring Station
CDT or CST – Central Daylight Time, Central Standard Time
CFR– Code of Federal Regulations
DS – Dust storm
dv – Deciview, a unit of haze intensity
EPA – United States Environmental Protection Agency
Extinction – The loss of clarity of the image due to haze
FRM – Federal Reference Method
GUMO – Abbreviation for Guadalupe Mountains National Park
km – Kilometer
mph – Miles per hour
IMPROVE – Interagency Monitoring of Protected Visual Environment
MDT – Mountain Daylight Time
NASA – United States National Aeronautics and Space Administration
NEPA – National Environmental Policy Act
NOAA – United States National Oceanic and Atmospheric Administration
NPS – United States National Park Service
$PM_{10}$ – Particulate Matter with a diameter of 10 microns or less
$PM_{2.5}$ – Particulate Matter with a diameter of 2.5 microns or less
$PM_{coarse}$ – Particulate Matter with a diameter less than 10 microns and greater than 2.5 microns
RH – Relative humidity
SIP – State Implementation Plan
TCEQ – Texas Commission on Environmental Quality
$\mu g/m^3$ – Micrograms per cubic meter

## EXECUTIVE SUMMARY

Dust storm events are recurring natural air pollution episodes that are not controllable by the State of Texas. Further, dust storms contribute to some of the highest regional haze and particulate matter (PM) events measured in West Texas. West Texas is one of the areas of the continental United States (U.S.) with a high probability of dust storms due to the combination of eroded soils and high wind speeds in the Chihuahuan Desert. The number of dust storms in this region varies from year to year from approximately 5 to 25 per year. These natural dust events will continue in northern Mexico and the southwest U.S. desert. Texas cannot control these natural events, and consequently these events should be considered part of the natural conditions in developing a Regional Haze State Implementation Plan (SIP).

This document proposes the use of a set of explicit scientific criteria to identify individual dust storms. These criteria use a wide variety of publicly available air quality data, satellite images, photographic images, and meteorological measurements. Full documentation of a single episode day demonstrates that these criteria re-enforce one another. Using these criteria, an estimate can be made of all major dust storm days. These criteria more accurately identify dust storms than those proposed by U.S. Environmental Protection Agency (EPA) rules for wind events as Exceptional Particulate Matter Events.

Because dust storms are the major natural events contributing to haze in West Texas, an estimate was made of the natural events for the two Texas Class I areas. Wind climatology and characteristics of the top layer of the soil are considered as constants during the period of 2000 to 2004 for the purposes of this analysis. The TCEQ estimates of natural conditions at Guadalupe Mountains National Park for the worst 20 percent days show a reasonable range of 10.6 to 14 deciviews (dv) compared with the U.S. federal Interagency Monitoring of Protected Visual Environments (IMPROVE) estimate of 7 deciviews. The higher deciview value resulting from TCEQ estimates more accurately reflects the numerous dust storms that will occur naturally at Guadalupe Mountains.

Fewer dust storms occur at Big Bend than at Guadalupe Mountains. Further, recent studies of the conditions at Big Bend have indicated that international transport of air pollutants is a major source of total extinction values for the haze in this area. These factors prevent the determination of an accurate estimate of natural conditions for Big Bend using the methodology in this report. Other approaches will be needed to estimate Big Bend's natural conditions deciview value accurately .

## NATURAL EVENTS: DUST STORMS

Dust storm events are recurring natural air pollution episodes. A dust storm is defined in this document as a natural high-wind event with a spatial scale greater than 10 kilometers (km) and is differentiated from local anthropogenic dust events. The frequency and intensity of a dust storm depend on the weather, the moisture content of the soils, and other physical properties of the soil particles. In West Texas, dust storms occur 5 to 25 times per year and have caused some of the densest hazes in the area. This is one of the areas of the continental United States with a high probability of dust storms due to the combination of eroded soils and high wind speeds (Washington et. al. 2003). These desert particulate matter sources will continue to occur in the future.

West Texas is part of the Chihuahuan Desert, which extends from the Mexican state of Chihuahua into Arizona, New Mexico, and Texas. Figure 1: *Location of the Chihuahuan Desert* shows the extent of the Chihuahuan Desert, represented in light pink (or light gray if the image is in black and white). Both of Texas' Class I areas, Guadalupe Mountains National Park and Big Bend National Park, are within this desert. The area has very limited rainfall, less than 250 millimeters per year, and sparse vegetation. It contains many dried lakebeds and playas with loose fine soils, which can easily be picked up into the air by moderate to high wind gusts (30 mph or greater). For purposes of this document, West Texas is defined as that portion of Texas west of the 103$^{rd}$ meridian. This meridian is the border between Texas and New Mexico.

The calendar years 2000 to 2004 were analyzed to meet the EPA requirement of establishing a baseline period and to estimate the natural conditions. This period determines the starting point of the "glide slope" used to represent the uniform rate of progress towards reaching natural conditions by 2064.

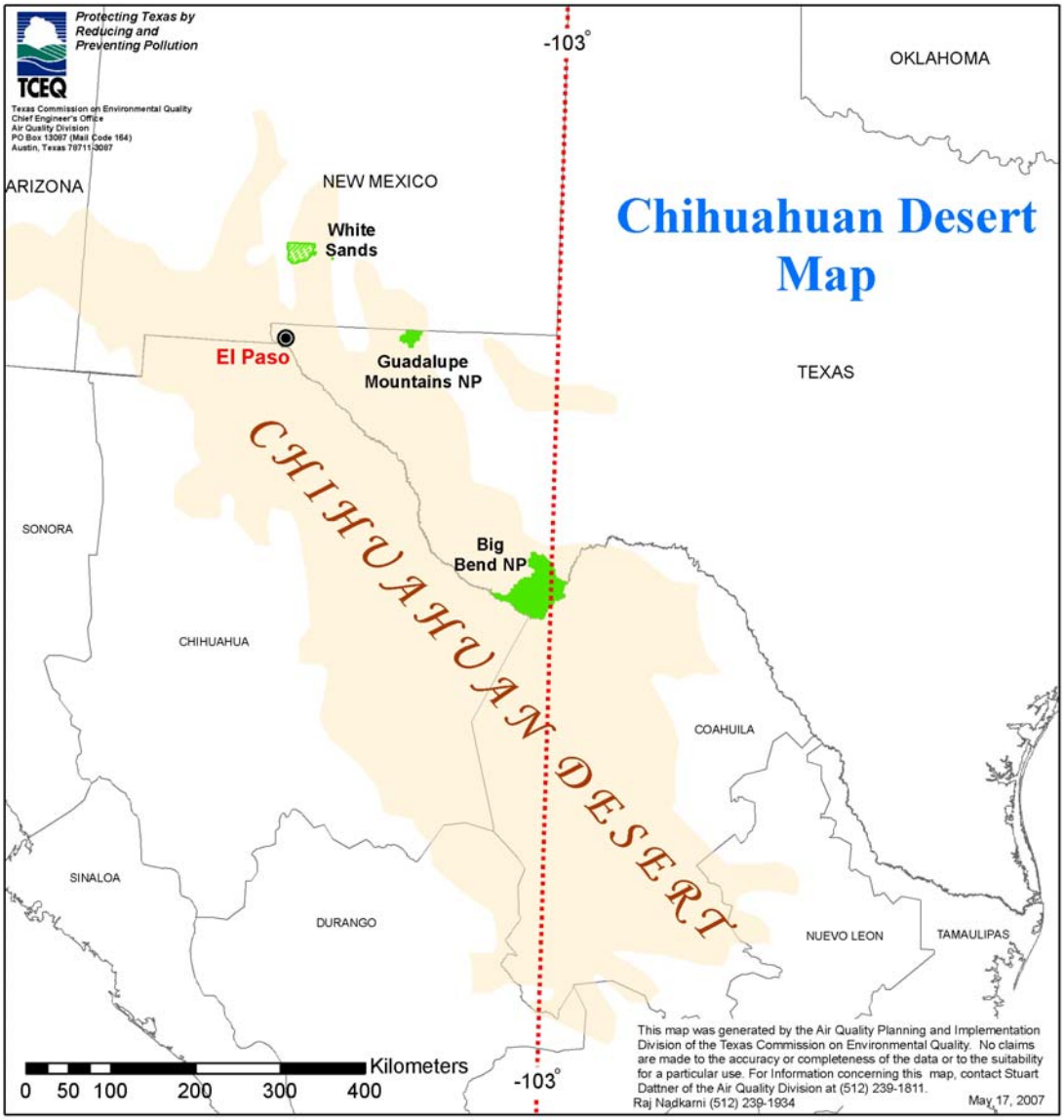


**Figure 1: Location of the Chihuahuan Desert**

**Section 1. Data Used to Document Dust Storms**

Determining a dust storm occurrence depends upon the analysis of many different observations and various measuring sources. They include:

1. Air Quality Data Collected by Texas

The TCEQ and local air pollution control agencies operate a network of $PM_{2.5}$ continuous monitors, $PM_{2.5}$ Federal Reference Method (FRM) or equivalent monitors, and $PM_{2.5}$ and $PM_{10}$ chemical speciation instruments in El Paso and other areas of West Texas. These instruments are operated under EPA operating protocols. The continuous $PM_{2.5}$ and $PM_{10}$ instruments report raw results near real-time as they are taken. The $PM_{2.5}$ FRM and the speciated $PM_{2.5}$ monitors collect samples which have to be sent to a laboratory for analysis. The laboratory reports the data to the TCEQ and the EPA three months after the end of each calendar quarter. This data is available to the public through the EPA Air Quality System (AQS) database on air quality. Meteorological measurements are also available for most of these sites.

2. Air Quality Data Collected by the Federal Government

A federal project called the Interagency Monitoring of Protected Visual Environments (IMPROVE) collects haze-related measurements in most Class I areas, which include National Parks, National Forests, and wildlife management areas. These monitoring sites measure optical properties and meteorological parameters on a continuous basis. The IMPROVE speciated $PM_{2.5}$ and $PM_{10}$ instruments collect a 24-hour sample every third day. The data are reported on a public IMPROVE web site, but it can take more than one year from the date the sample was collected for the validated measurements to be posted on the web site.

3. Data Collected by the National Weather Service (NWS)

The NWS and the Federal Aviation Administration operate a network of automated stations that measure meteorology and visibility at most airports in the United States. These data include ground-based measurements and long range radar.

4. Satellite Data

The NWS, the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA) operate a variety of satellites that measure many meteorological, optical, and related parameters. The TCEQ operates a downlink for the data from the NOAA Geostationary Operational Environmental Satellites.

5. Photographic Visibility Data

The TCEQ and the National Park Service (NPS) operate digital cameras that take images of landscapes to document visual air pollution. These images are sent to a central repository within one hour of the image being recorded. The TCEQ operates three cameras in West Texas, with one each at Big Bend National Park, Guadalupe Mountains National Park, and McDonald Observatory. The TCEQ cameras take an image every 15 minutes. The NPS also operates a camera at Big Bend National Park that takes images every 15 minutes, and they post the observations daily on a public web site, http://www2.nature.nps.gov/air/WebCams/parks/bibecam/bibecam.cfm.

**Section 2. Criteria for a Documenting a Dust Storm**

**In this analysis** dust storm is defined as an event that meets three or more of the following criteria:

1. Meteorological evaluation shows these conditions: uniform haze, high wind speeds at the source of the dust, dry conditions in the source areas prior to the dust storm. The meteorological evaluation may also include evaluation of radar images and back trajectory analysis.;
2. Continuous PM (and visibility) instruments show a rapid rise in concentrations associated with a change in the weather (convective modification of the boundary layer, thunderstorm outflows, passage of cold fronts, etc.). Only dry events with the relative humidity below 50 percent are considered to be dust storms. The thresholds for one hour are: $PM_{2.5}$ >40 µg/m$^3$; $PM_{10}$ > 150 µg/m$^3$ ; $b_{scat}$ >60 m$^{-6}$, or visual range<10 km (6 statute miles);
3. The 24-hour average PM light extinction exceeds 33 inverse mega meters (15 deciviews). In addition, the crustal material (fine soil and coarse PM) must make up at least 50 percent of the 24-hour particulate light extinction estimated from ambient measurements using the IMPROVE data and the new IMPROVE Reconstruction Equation.
4. The 24-hour average $PM_{2.5}$ mass is greater than 20 µg/m$^3$ and more than 50 percent of its mass is crustal based on the chemical speciation data;
5. The 24-hour average $PM_{10}$ mass is greater than 150 µg/m$^3$ and more than 50 percent of its mass is crustal based on the chemical speciation data;
6. The sampling instrument(s) fails due to filter clogging or reads full scale and other observations strongly suggest that a dust storm has occurred;
7. Satellite information indicates dust events with spatial scales greater than 10 km;
8. Photographic information shows a large scale uniformity of the haze associated with the change in the weather event; and
9. Airport or other observers report “dust storms,” “blown dust,” “haze” or visibility reduced below 10 km at sites greater than 10 km from the monitoring site under consideration.

**Section 3. Documentation of the Example Dust Storm of April 15, 2003**

Documentation of a typical intense dust storm at Guadalupe Mountains National Park and Big Bend National Park is below. The quoted text is from the main page of the TCEQ public web site for April 15, 2003, which can be accessed at the web address below. Not all of the data listed in the description of the dust storm on the web site were included in this report. The web site information for this day includes over 60 images, most of them associated with the animations or the effects of the dust storm on El Paso. Only selected images were used to determine the occurrence of a dust storm related to visibility in the two Texas Class I areas. For more information, please refer to the TCEQ public web site at http://www.tceq.state.tx.us/compliance/monitoring/air/monops/sigevents03.html.

**Report on the TCEQ Public Web Site for Dust Storm Day April 15, 2003**

"West Texas Dust Storm April 15, 2003

**Images**
Satellite Animation
True-Color Satellite
True-Color Satellite Comparison 4/15/2003 vs 4/16/2003
Web Cam Animation from Chelsea Street
Web Cam Animation from the McDonald Observatory
Surface Weather Analysis 1:00 p.m. MDT
C12/C37 PM10
C12/C40 PM2.5
West Texas PM2.5
C37 PM10 and Visibility
C12 PM10 and Wind Gusts
C37 PM10 and Wind Gusts
C40 PM2.5 and Wind Gusts
C12 PM10 and PM2.5
C12 Temperature and Humidity
C12 Wind

**Description**
The worst dust storm since April of 2001 swept across West Texas on Tuesday, April 15, 2003. High winds associated with a strong low pressure system centered in Colorado kicked up large plumes of dust from parts of northern Mexico, southern New Mexico, and West Texas.

The University of Texas at El Paso (UTEP) Continuous Air Monitoring Station (CAMS) 12 recorded a peak one-hour $PM_{10}$ average of 4,724 micrograms per cubic meter ($\mu g/m^3$) for the hour from 1:00 to 2:00 p.m. Mountain Daylight Time (MDT) and had a 24-hour average of 718 $\mu g/m^3$. The Ascarate Park CAMS 37 had a peak one-hour $PM_{10}$ average of 4,710 $\mu g/m^3$ for the hour from 1:00 to 2:00 p.m. MDT and a 24-hour average of 715$\mu g/m^3$. The daily average $PM_{10}$ at both sites rated as Hazardous on the EPA Air Quality Index (AQI) scale.

The satellite animation shows dust originating in northern Mexico blowing across much of West Texas and parts of southern New Mexico. The largest dust plume originates on the north side of a large dry lake bed about 50 miles west-southwest of El Paso as shown in the true-color satellite image (courtesy of the National Aeronautic and Space Administration).

The El Paso Airport reported visibility as low as to 1/8 mile with blowing dust at 1:03 p.m. MDT and a peak wind gust of 66 miles per hour (mph) at 1:09 p.m. MDT. The Guadalupe Pass automatic weather station reported a minimum visibility of 1/2 mile at 3:29 p.m. MDT and a peak wind gust of 98 mph at 1:54 p.m. MDT.

The highest peak wind gust measured in the El Paso air monitoring network was 68 mph at Lower Valley CAMS 36 at 1:35 p.m. MDT. Two additional sites measured wind gusts above 60 mph. McDonald Observatory CAMS 317 to the east of El Paso measured a maximum wind gust of 61 mph at 6:05 p.m. Central Daylight Time (CDT). Ascarate Park CAMS 37 reported visibilities less than 5 miles from 10:10 a.m. to 4:35 p.m. MDT with a minimum visibility of 0.4 mile at 12:40 p.m. and 1:05 p.m. MDT."

The description below has sufficient information to show that the event meets dust storm Criterion 1.

> "The worst dust storm since April of 2001 swept across West Texas on Tuesday, April 15, 2003. High winds associated with a strong low pressure system centered in Colorado kicked up large plumes of dust from parts of northern Mexico, southern New Mexico, and West Texas."

The description below has sufficient information to show that the event meets dust storm Criteria 2 and 9.

> "The El Paso Airport reported visibility as low as to 1/8 mile with blowing dust at 1:03 p.m. MDT and a peak wind gust of 66 miles per hour (mph) at 1:09 p.m. MDT. The Guadalupe Pass automatic weather station reported a minimum visibility of 1/2 mile at 3:29 p.m. MDT and a peak wind gust of 98 mph at 1:54 p.m. MDT."

**Satellite Image, April 15, 2003**

Figures 2 through 7 demonstrate that this dust storm event meets the other criteria. Figure 2: *CST Visual/Infrared Satellite Image for 5:30 pm, April 15, 2003,* shows an intensive area of dust originating in southern New Mexico and northern Chihuahua, Mexico and being blown into West Texas. The dust is the light brown area seen in the center of this image (in black and white, the area may appear medium gray). The arrows identify the locations where the dust was entrained into the air. The bright white objects are clouds. The dust storm area includes El Paso, Guadalupe Mountains National Park (GUMO), and McDonald Observatory (McDO). At Big Bend National Park (BIBE), the dust seems to be coming from different sources farther south than at GUMO, but it is still part of the same weather event. Figure 2: *CST Visual/Infrared Satellite Image for 5:30 pm, April 15, 2003,* documents that the event in both national parks meets dust storm Criterion 7 (satellite image).

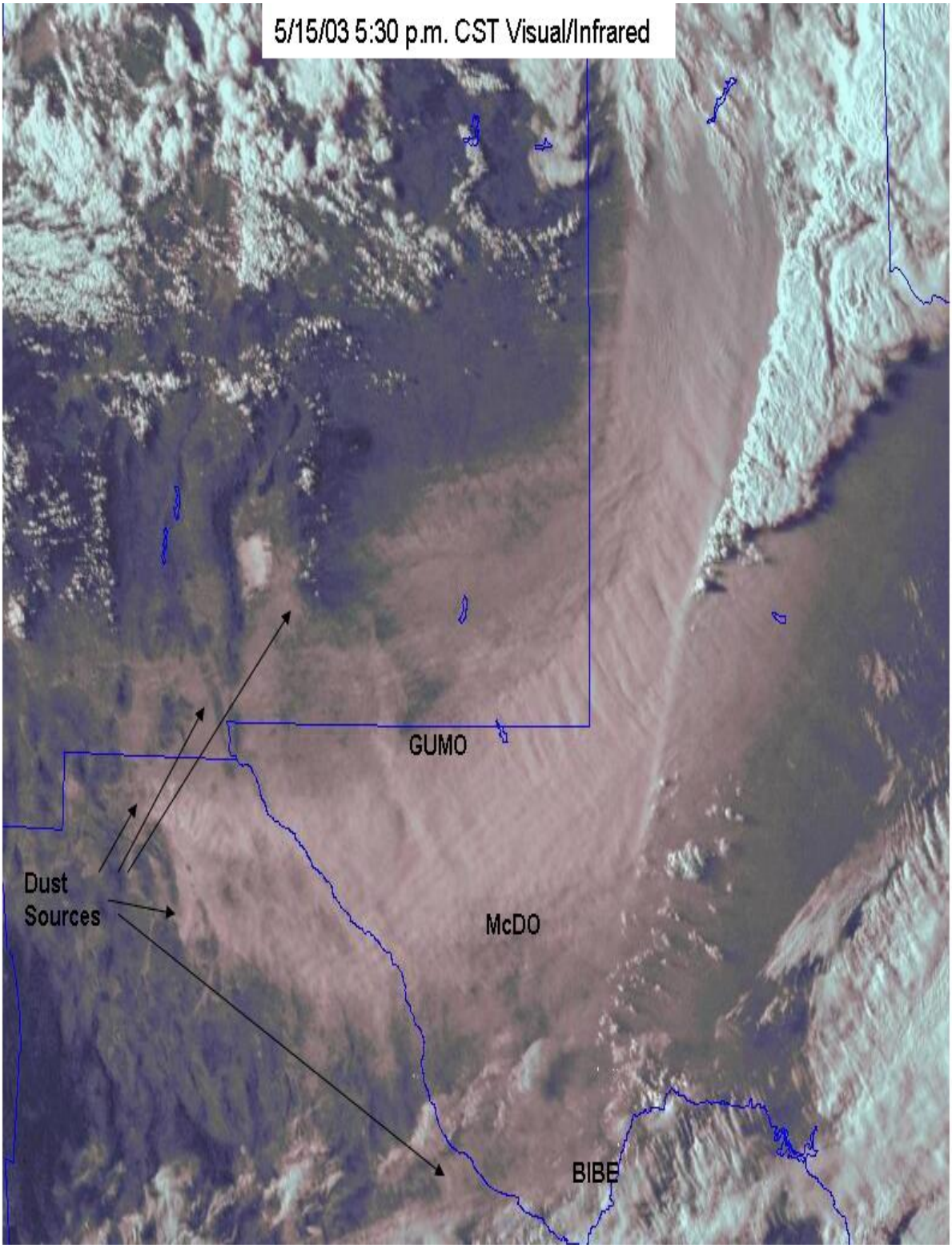


**Figure 2: CST Visual/Infrared Satellite Image for 5:30 pm, April 15, 2003**
The white areas are clouds. The light brown areas are blown dust.

**Continuous Monitoring Data During the Dust Storm Event**

Analyzing the IMPROVE continuous monitoring data recorded at the time of the possible dust storm helps re-enforce the finding that April 15, 2003, was a dust storm day meeting criterion 2. Figures 3 and 4 show a rapid rising of light extinction while the relative humidity stays below 50 percent.

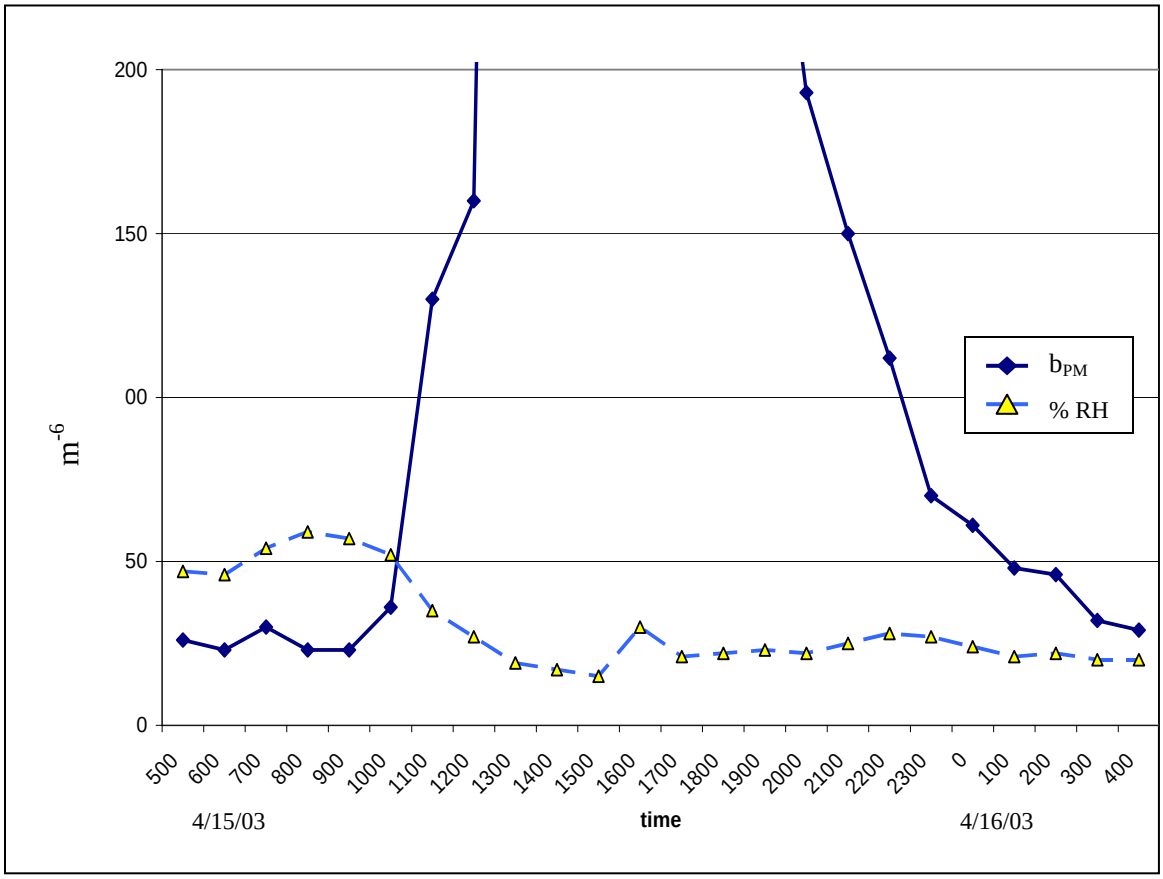


**Figure 3: Comparison of Light Extinction ($b_{sp}$) from Aerosols and Relative Humidity (RH) during a Major Dust Storm in the Guadalupe Mountains National Park on April 15, 2003**

Figure 3 shows that a peak in the light extinction plot occurs from 11:00 am to midnight on April 15, 2003. The transmissometer value, $b_{PM}$, is at its maximum instrumental value of 815 $m^{-6}$ for much of this spike period. The scale was truncated so that the relative humidity changes can also be seen. The relative humidity drops from a value of about 50 percent before the dust storm to about 25 percent during the dust storm, which indicates the dry nature of the air associated with the dust storm. This day is considered to be a dry peak event documented by transmissometer data. Figure 1-3 documents that the GUMO event meets dust storm Criterion 2. At GUMO on April 15, 2003, the $PM_{10}$ concentration was 173 µg/$m^3$, the $PM_{2.5}$ concentration was 40 µg/$m^3$, and the 24-hour average light extinction was 138 $m^{-6}$ (26 dv).

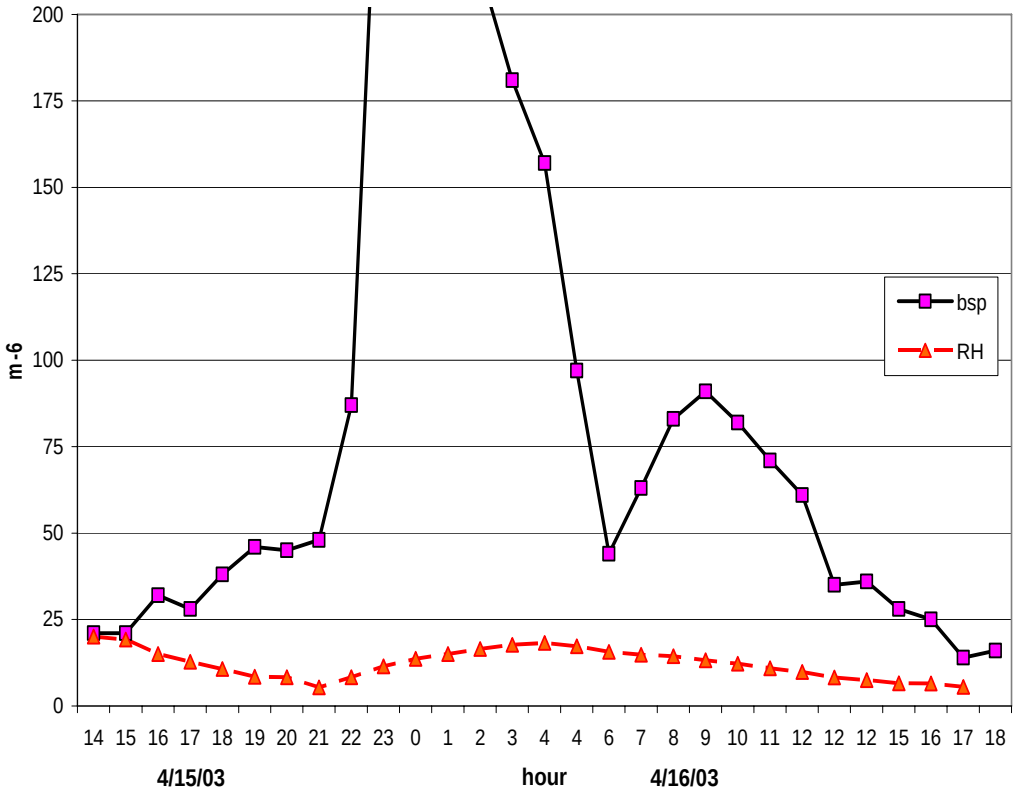


**Figure 4: Comparison of Light Extinction ($b_{sp}$) from Aerosols and Relative Humidity (RH) during a Major Dust Storm in Big Bend National Park on April 15, 2003**

Figure 4 is similar to Figure 3, with a spike in light extinction indicating that a dust storm also occurred at Big Bend National Park (BIBE) on this same day. The dust storm started later at BIBE (10:00 pm CST) than at GUMO (11:00 am MST). The maximum peak of $b_{sp}$ in BIBE was only 316 $m^{-6}$, compared to over 800 $m^{-6}$ in GUMO. The daily averaged $b_{PM}$ at BIBE was 47 $m^{-6}$ (17 dv). Although the PM concentrations and light extinction at BIBE were about one-third of those for GUMO on this day, these figures show that Criteria 2 and 9 are further supported at both sites.

**Photographic Documentation During the Dust Storm Event**

Figures 5, 6, and 7 show a progression of images from the McDonald Observatory camera that document that dust storm criterion 8 was met on April 15, 2003. The McDonald Observatory was the site with the best documentation of the dust storm, and since this was a dust storm of regional scale, these images are representative of both Class I areas in Texas. Figure 5: *View from McDonald Observatory on a Clear Day* is included as a reference to show how much the visibility was reduced as compared to an average, clear day.

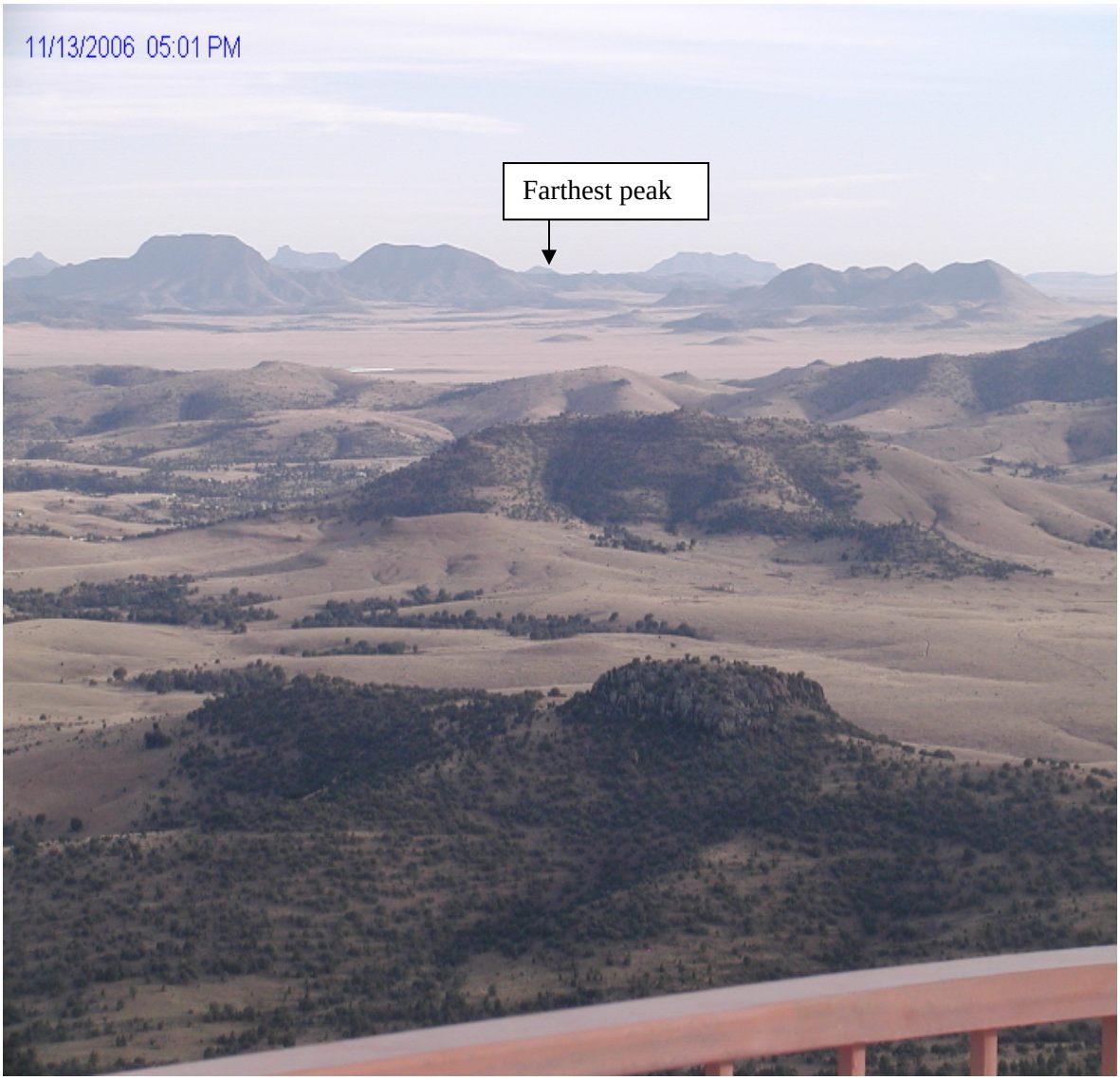


**Figure 5: View from McDonald Observatory on a Clear Day**

Figure 5 shows a very clear view from the McDonald Observatory looking south towards Big Bend National Park. The McDonald Observatory is located between Big Bend and Guadalupe Mountains National Parks. This view is typical for West Texas on a clear day. The twin peaks in the left side of the image are about 30 km from the camera, and Big Bend National Park is about 80 km beyond these twin peaks. The farthest peak, just below the arrow, is about 160 km south of the camera. The range of 160 km limits the minimum deciview value based on image analysis to about 8 dv.

**Figure 6: View from McDonald Observatory at the Start of the Dust Storm on April 15, 2003**

Figure 6 shows the beginning of the dust storm near the McDonald Observatory in the early afternoon. The uniform haze obscures most details behind the twin peaks, which are about 30 km from the camera. Therefore, the visual range was somewhat greater than 30 km at 1:31 pm, and the deciview value at this time was about 25 dv.

**Figure 7: View from McDonald Observatory during the Worst of the Dust Storm on April 15, 2003**

Figure 7 shows that most of the image is obscured by the dust storm. The density of the haze in this image is uniform. The only distant object barely visible is the closest ridge, which is several hundred meters from the camera. The brown wood railing, a few meters from the camera, is the only object in Figure 7 that is clearly visible. The visual range at this time was less than 1 km, and the deciview value was approximately 50 dv or greater. Most PM and optical instruments do not accurately measure the high concentrations associated with a dust storm of this intensity.

Figures 5, 6, and 7 show the visibility degradation due to the dust storm on April 15, 2003. These degradation images document that the event at both GUMO and BIBE meet dust storm Criterion 8. April 15, 2003, has now been shown to meet dust storm criteria 1, 2, 7, 8, and 9. This documentation is more than sufficient to qualify this day as a natural event for blowing dust.

Analysis of particulate matter chemical speciation data for this date shows that the event also meets Criteria 3 and 5.

**Section 4. Documentation of Dust Storm Natural Events Using IMPROVE Speciated Data**

IMPROVE samplers collect 24-hour $PM_{2.5}$ samples every third day at both Big Bend and Guadalupe Mountains National Parks. With the data from chemical speciation analysis of these samples, the IMPROVE program estimates the 24-hour average visibility from the concentrations using the updated IMPROVE equation. The IMPROVE equation computes the total aerosol light extinction by adding the individual PM light extinction components from seven measured species. These are:

- Mass associated with sulfate;
- Mass associated with nitrate;
- Mass associated with organic carbon;
- Mass associated with elemental carbon;
- Mass associated with sea salt based on chlorine concentrations;
- Mass associated with fine soil ; and
- Coarse mass.

Table 1: *Probable Dust Storm Days at Big Bend and Guadalupe Mountains National Parks 2000-2004* shows days where more than half the aerosol light extinction came from crustal materials based on the speciated IMPROVE data using the new IMPROVE reconstruction formula. Analysis of the IMPROVE data shows that this ratio is a good discriminator of dust storm events even though the IMPROVE formula does not include all portions of the crustal material. Water of hydration, organic material, and sodium compounds in the soil are not included in the IMPROVE equation's definition of crustal materials. In addition, since dust storms usually occur for less time than the 24-hour IMPROVE speciation data are measured, other events are included in the daily averages. The documentation in Table 1: *Probable Dust Storm Days at Big Bend and Guadalupe Mountains National Parks 2000-2004* is based on data from the IMPROVE web site, http:// www.vista.cira.colostate.edu/improve/. This data was retrieved on October 30, 2006 and contains complete data for all five years.

In 2000, 2001, and early 2002 there was less available documentation of weather, photographic images, and satellite images than the remainder of the time. During the first half of 2002 the TCEQ air pollution meteorology staff increased the amount of documentation collected and archived for dust storm events.

Table 1: *Probable Dust Storm Days at Big Bend and Guadalupe Mountains National Parks 2000-2004* includes:

- The site and date of the measurements;
- The total light extinction by particles for the 24-hour sampling period ($b_{PM}$);
- The deciview value for the 24-hour sampling period (dv);
- An x indicating that the deciview was in the worst 20 percent of all days (Top 20 percent);
- The maximum one-hour extinction (Max ext);
- The maximum one-hour relative humidity (Max RH percent);
- The fraction of the $b_{PM}$ attributed by soil materials (Crustal fraction);
- Brief comments describing whether the event was initially identified as a dust storm day by an observer and the nature of the peak in $b_{PM}$ at that site. The transmissometer is identified as trans and the nephelometer is identified as neph; and
- A list of which of the nine dust storm criteria were met on each specific day (Criteria met).

Days in plain type are those with events that meet sufficient criteria to be defined as natural dust storm events. Days in ***bold italics*** are those when the relative humidity was greater than 50 percent during the period of maximum light extinction and are excluded from being considered as dust storm days.

**Table 1: Probable Dust Storm Days at Big Bend and Guadalupe Mountains National Parks 2000-2004**

| Site | Date | 24 hour $b_{PM}$ | **dv** | Top 20 percent | Max hourly ext | Max RH percent | Crustal fraction | Comments, other verification | Criteria met |
|---|---|---|---|---|---|---|---|---|---|
| BIBE | 3/22/00 | 67 | **20** | x | 131 | 25 | 0.57 | neph dry peak 3/22/00 | 1, 2, 3 |
| GUMO | 4/15/00 | 31 | **14** | | 100 | 25 | 0.69 | trans dry peak 4/15/00 | 1, 2, 3 |
| GUMO | 4/22/00 | 61 | **20** | x | 186 | 20 | 0.71 | trans dry peak 4/22/00 | 1, 2, 3, 4, 6 |
| GUMO | 4/29/00 | 47 | **17** | x | 19 | 12 | 0.62 | trans dry peak 4/29/00 | 1, 2, 3 |
| GUMO | 5/13/00 | 41 | **16** | x | 68 | 30 | 0.58 | trans dry peak 5/13/00 | 1, 2, 3 |
| GUMO | 5/17/00 | 55 | **19** | x | 108 | 20 | 0.59 | trans dry peak 5/17/00 | 1, 2, 3 |
| GUMO | 10/3/00 | 44 | **17** | x | 137 | 33 | 0.52 | trans dry peak 10/3/00 | 1, 2, 3 |
| BIBE | 2/9/01 | 74 | **21** | x | 434 | 27 | 0.90 | neph dry peak 2/9/01 | 1, 2, 3, 5 |
| BIBE | 4/10/01 | 44 | **17** | x | 282 | 10 | 0.60 | neph dry peak 4/10/01 | 2, 3, 6, 9 |
| GUMO | 4/10/01 | 243 | **32** | x | 805 | 48 | | trans dry peak 4/10/01 | 2, 4, 5, 6, 9 |
| GUMO | 4/22/01 | 79 | **22** | x | 193 | 45 | 0.87 | trans dry peak 4/22/01 | 1, 2, 3, 5, 6 |
| ***GUMO*** | ***5/19/01*** | ***38*** | ***15*** | ***x*** | | ***80*** | ***0.66*** | ***trans missing, humid day*** | ***3*** |
| ***GUMO*** | ***5/31/01*** | ***46*** | ***17*** | ***x*** | | ***79*** | ***0.57*** | ***trans missing, humid day*** | ***3*** |
| GUMO | 6/3/01 | 56 | **19** | x | 173 | 26 | 0.71 | dry trans peak 6/3/01 | 1, 2, 3 |
| GUMO | 6/24/01 | 43 | **17** | x | 181 | 45 | 0.64 | trans dry peak 6/24/01 | 1, 2, 3 |
| BIBE | 6/27/01 | 47 | **17** | x | 65 | 50 | 0.57 | neph dry peak 6/26-27/01 | 1, 2, 3 |
| GUMO | 9/7/01 | 50 | **18** | x | 109 | 46 | 0.68 | dry trans peak 6/3/01 | 1, 2, 3 |
| BIBE | 10/13/01 | 23 | **12** | | 1193 | 54 | 0.80 | neph dry peak 10/12-13/01 | 1, 2, 3 |
| BIBE | 10/16/01 | 30 | **14** | | 38 | 49 | 0.72 | neph dry peak 10/15-16/01 | 1, 2, 8 |
| BIBE | 11/24/01 | 37 | **15** | x | 117 | 40 | 0.80 | neph dry peak 10/23-24/01 | 1, 2, 3 |
| GUMO | 1/20/02 | 41 | **16** | x | 439 | 28 | 0.69 | El Paso DS 1/20/02, trans dry peak 1/20/02 | 1, 2, 3 |
| BIBE | 2/10/02 | 32 | **14** | | 54 | 34 | 0.79 | neph dry peak 2/10/02 | 1, 2, 3 |
| GUMO | 2/25/02 | 36 | **15** | x | 281 | 28 | 0.73 | DS from West Texas 2/26/02, noisy data with several full scale spikes | 1,3, 6 |
| BIBE | 3/9/02 | 34 | **15** | | 41 | 25 | 0.79 | West Texas DS 3/8/02, neph dry peak 3/9/02 | 1, 2, 3, 7, 8, 9 |
| GUMO | 3/9/02 | 35 | **15** | | 74 | 47 | 0.72 | West Texas DS 3/8/02, dry trans peak 3/8-9/02 | 1, 2, 3, 7, 9 |
| BIBE | 3/12/02 | 60 | **19** | x | 91 | 28 | 0.85 | West Texas DS 3/11/02, neph dry peak 3/12/02 | 1, 2, 3, 7, 8, 9 |

| Site | Date | 24 hour $b_{PM}$ | **dv** | Top 20 percent | Max hourly ext | Max RH percent | Crustal fraction | Comments, other verification | Criteria met |
|---|---|---|---|---|---|---|---|---|---|
| GUMO | 3/12/02 | 18 | **10** | | 48 | 36 | 0.62 | West Texas DS 3/11/02, dry trans peak 3/11/02 | 1, 2, 7, 9 |
| GUMO | 3/15/02 | 45 | **17** | x | 84 | 34 | 0.65 | El Paso DS 3/14-16/02, dry trans peak 3/14-15/02 | 1, 2, 3, 4, 7, 9 |
| GUMO | 3/24/02 | 84 | **22** | x | 280 | 36 | 0.76 | El Paso DS 3/23-24/02, dry trans peak 3/24/02 | 1, 2, 3, 4, 7, 9 |
| BIBE | 3/30/02 | 37 | **15** | | 148 | 25 | 0.77 | neph dry peak 3/29-30/02 | 1, 2, 3 |
| BIBE | 4/2/02 | 45 | **17** | x | 70 | 39 | 0.59 | neph dry peak 4/2/02 | 1, 2, 3, 8, 9 |
| GUMO | 4/2/02 | 48 | **17** | x | 182 | 43 | 0.72 | dry trans peak 4/2/02 | 1, 2, 3, 9 |
| GUMO | 4/20/02 | 37 | **15** | | 328 | 18 | 0.79 | El Paso DS 4/20/02, dry trans peak 4/20/02 | 1, 2, 3 |
| GUMO | 5/2/02 | 43 | **17** | x | 298 | 32 | 0.70 | El Paso DS 5/2/02, dry trans peak 5/2/02 | 1, 2, 3 |
| GUMO | 5/8/02 | 31 | **14** | | 65 | 10 | 0.73 | hump trans 5/8/02 | 1, 2, 5 |
| GUMO | 5/14/02 | 30 | **14** | | 138 | 47 | 0.64 | El Paso DS 5/13/02, dry trans peak 5/14/02 | 1, 2, 9 |
| GUMO | 5/26/02 | 50 | **18** | x | 141 | 30 | 0.58 | dry trans peak 5/26/02 | 1, 2, 3 |
| GUMO | 6/4/02 | 34 | **15** | | 125 | 20 | 0.57 | dry trans peak 6/3-4/02 | 1, 2, 3 |
| GUMO | 6/13/02 | 45 | **17** | x | 161 | 44 | 0.67 | dry trans early 6/13/02 | 1, 2, 3 |
| BIBE | 6/16/02 | 45 | **17** | x | 72 | 31 | 0.59 | neph dry peak 6/16/02 | 1, 2, 3, 8 |
| GUMO | 6/19/02 | 45 | **17** | x | | 42 | 0.58 | missing trans | 2, 3 |
| GUMO | 7/16/02 | 36 | **15** | x | 52 | 51 | 0.65 | borderline case, hump not peak | 2, 3, 7, 8 |
| BIBE | 11/10/02 | 32 | **14** | | 120 | | 0.81 | neph dry peak 11/10/02 | 1, 2, 7 |
| BIBE | 12/16/02 | 8 | **6** | | | 41 | 0.51 | El Paso DS 12/17/02, neph missing | 2, 6, 9 |
| GUMO | 12/16/02 | 25 | **12** | | 43 | 30 | 0.54 | El Paso DS 12/17/02, dry trans peak 12/17/02 | 1, 2, 7, 9 |
| GUMO | 2/2/03 | 92 | **23** | x | 562 | 34 | 0.78 | El Paso DS 2/2/02, dry trans peak | 1, 2, 3, 5, 7, 9 |
| GUMO | 3/4/03 | 78 | **22** | x | | 55 | 0.85 | West Texas DS 3/4/03, missing trans | 3, 5, 7, 9 |
| GUMO | 3/16/03 | 31 | **14** | | 161 | 39 | 0.76 | dry trans peak 3/16/03 | 1, 2, 3 |
| BIBE | 3/19/03 | 14 | **9** | | 24 | 31 | 0.69 | West Texas DS 3/18/03, neph dry peak 3/18/03 | 1, 2, 7, 9 |
| ***GUMO*** | ***3/19/03*** | ***20*** | ***11*** | | ***307*** | ***87*** | ***0.72*** | ***West Texas DS 3/18/03, moist late in 3/19/03*** | ***1, 2, 9*** |
| BIBE | 3/28/03 | 39 | **16** | x | | 59 | 0.76 | West Texas DS 3/27/03, neph missing | 1, 2, 3, 6, 7, 8, 9 |
| GUMO | 3/28/03 | 14 | **8** | | 80 | 20 | 0.30 | West Texas DS 3/27/03, trans dry peak | 1, 2, 7, 9 |
| BIBE | 4/6/03 | 33 | **15** | | | 7 | 0.79 | West Texas DS 4/5-6/03, neph missing | 3, 7, 8, 9 |

| Site | Date | 24 hour $b_{PM}$ | **dv** | Top 20 percent | Max hourly ext | Max RH percent | Crustal fraction | Comments, other verification | Criteria met |
|---|---|---|---|---|---|---|---|---|---|
| GUMO | 4/6/03 | 15 | **9** | | 45 | | 0.60 | West Texas DS 4/5/03, trans peak 4/5-6/03 | 1, 2, 7, 9 |
| BIBE | 4/15/03 | 47 | **17** | x | 316 | 25 | 0.45 | West Texas DS 4/15/03 neph dry peak 4/15/03 | 1, 2, 7, 8, 9 |
| GUMO | 4/15/03 | 129 | **26** | x | 815 | 35 | 0.79 | West Texas DS 4/15/03, dry trans peak 4/15/03 | 1, 2, 3, 4, 5, 7, 8, 9 |
| BIBE | 4/18/03 | 15 | **9** | | 24 | 23 | 0.66 | El Paso DS 4/17/03 neph dry peak 4/17/03 | 1, 2, 9 |
| GUMO | 4/18/03 | 49 | **18** | x | 636 | | 0.84 | El Paso DS 4/17/03, dry trans peak 4/17-18/03 | 1, 2, 3, 7, 9 |
| BIBE | 4/24/03 | 27 | **13** | | 67 | 12 | 0.63 | dry neph peak 4/23-24/03 | 1, 2, 8, 9 |
| GUMO | 4/24/03 | 30 | **14** | | 60 | 28 | 0.72 | dry trans peak 4/23-24/03 | 1, 2, 9 |
| BIBE | 4/30/03 | 14 | **9** | | 33 | 51 | 0.27 | dry neph peak 4/29-30/03 | 1, 2, 9 |
| GUMO | 4/30/03 | 34 | **15** | x | 93 | 29 | 0.68 | dry trans peak 4/29-30/03 | 1, 2, 3, 9 |
| GUMO | 5/9/03 | 40 | **16** | x | 94 | 12 | 0.62 | dry trans peak 5/9/03 | 1, 2, 3 |
| GUMO | 5/15/03 | 109 | **25** | x | | 14 | 0.76 | El Paso DS 5/15/03, missing trans | 3, 4, 5, 7, 9 |
| GUMO | 6/2/03 | 32 | **14** | | 94 | 51 | 0.59 | partial data | 2, 3, 6 |
| GUMO | 7/23/03 | 96 | **23** | x | 88 | 27 | 0.73 | dry trans peak 7/23/03 | 1, 2, 3, 4 |
| GUMO | 8/4/03 | 49 | **18** | x | 256 | 52 | 0.64 | dry trans peak 8/4/03 | 1, 2, 3 |
| GUMO | 10/24/03 | 21 | **11** | | 104 | 41 | 0.50 | West Texas DS 10/25/03 dry trans peak 10/24-25/03 | 1, 2, 9 |
| GUMO | 11/23/03 | 16 | **9** | | 49 | 29 | 0.62 | El Paso DS 11/22/03, dry trans peak 11/23/03 | 1, 2, 9 |
| GUMO | 12/8/03 | 86 | **23** | x | 332 | 43 | 0.77 | El Paso DS 12/8/03, dry trans peak | 1, 2, 3, 8, 9 |
| BIBE | 12/23/03 | 10 | **7** | | 66 | 48 | 0.60 | West Texas DS 12/22/03 neph dry peak 12/22-23/03 | 1, 2, 8, 9 |
| GUMO | 12/26/03 | 85 | **22** | x | 718 | 40 | 0.89 | West Texas DS 12/26/03, dry trans peak 12/26/03 | 1, 2, 3, 4, 9 |
| GUMO | 1/31/04 | 54 | **19** | x | 401 | 37 | 0.81 | El Paso DS 1/31/04, dry trans peak 1/31/04 | 1, 2, 3, 9 |
| GUMO | 4/21/04 | 31 | **14** | | 112 | 11 | 0.61 | El Paso DS 4/22/04, dry trans peak 4/21/04 | 1, 2, 9 |
| GUMO | 6/8/04 | 68 | **20** | x | | | 0.79 | El Paso DS 6/8-9/04, missing trans & RH | 3, 4, 7, 9 |
| BIBE | 6/20/04 | 44 | **17** | x | 81 | 49 | 0.62 | El Paso DS 6/21/04 neph dry peak 6/20/04 Saharan Dust | 1, 2, 3, 8, 9 |

Table 1: *Probable Dust Storm Days at Big Bend and Guadalupe Mountains National Parks 2000-2004*, shows that of the 74 proposed dust storm events, 70 meet at least 3 of the dust storm criteria. On one day at GUMO, June 19, 2002, the transmissometer data and meteorological data are missing, and the documentation for this day is incomplete. Three other days had higher relative humidity than 50 percent during the spike, so these days did not qualify as dust storm days.

On April 10, 2001, GUMO was missing part of the speciated data due to instrument failure. It had low concentrations of sulfate, nitrate, and carbon, but the soil measurements were missing. This day had the largest $b_{PM}$ (243 $m^{-6}$) and the largest $PM_{10}$ (341 $\mu g/m^3$) of any day during the five-year period and would have likely met enough dust storm criteria if the measurements were complete.

Criterion 3 alone, based on the 50 percent crustal material light extinction ratio, accurately identifies dust storms about 95 percent of the time. It misses approximately 5 percent of the dust storms which have a lower crustal extinction ratio or have no readings of the speciated data. The EPA requirement that PM in blowing dust must be at least 85 percent crustal material was found to identify only 4 of the dust storms in 2000-2004. Analysis of Table 1: *Probable Dust Storm Days at Big Bend and Guadalupe Mountains National Parks 2000-2004* strongly suggests that the threshold of the crustal to total extinction ratio should be about 50 percent to be used as documentation of a dust storm event. Only one dust storm was missed by the ratio criteria, and that was at BIBE on April 15, 2003, because the crustal to total extinction ratio was only 0.45.

Many of these events are also in the worst 20 percent of haze days measured at the Class I monitoring site. Seventy out of 74 events meet more than 3 criteria. The dust storm at GUMO on April 15, 2003, meets eight out of the nine criteria. All of these dust storms should be considered when estimating the natural conditions for the Regional Haze Rule.

Dust storms are most numerous in the winter and early spring of each year but are not uniformly distributed over time. In 2003, the highest number of dust storms were observed in the five-year period - 27 events. In 2004, the least number of dust storms were observed - only four events. The GUMO site has the majority of the dust storms during this period, with 50 events. The frequency of yearly occurrence of dust storms seems to be random in these five years.

The number of dust storms at BIBE and GUMO do not correlate with each other. This suggests that different parts of the Chihuahuan Desert are contributing dust to the events or different source areas were contributing to the concentrations at each site. For example, on March 28, 2003, BIBE's $b_{PM}$ is more than twice the value measured at GUMO. Then on April 15, 2003, BIBE's $b_{PM}$ is about one third the value at GUMO. Figure 2: *CST Satellite Image for April 15, 2003*, shows that BIBE is affected by a dust source from a different location than the one affecting GUMO. This strongly suggests that dust from different areas of the Chihuahuan Desert affects the two sites. In addition, GUMO appears to have more events associated with northerly winds than BIBE does. Because of these differences, the natural conditions for these two sites should be evaluated individually.

**Section 5. Calculation of Natural Conditions**

The objective of identifying the natural conditions for a given site is critical in producing estimates of progress. These estimates are part of the glide path method of tracking progress in regional haze.

The natural conditions can be estimated using the following assumptions:

- For the upper bound, all of the light extinction on dust storm days is due to the dust storm;
- Anthropogenic sources are the major sources of haze when a dust storm is not present in the 20 percent worst days; and
- In 2064 all of the 20 percent worst days will be caused by dust storm events assuming that the anthropogenic contribution to haze will be zero by then.

In this work the calculations followed this procedure:

- Sequentially remove anthropogenic haze days from the 2000-2004 daily haze measurements in descending haze index (deciview) order of ;
- When the number of dust storm days equals 10 percent of all days with measurements, stop; and
- The value associated with the 90$^{th}$ percentile day is equal to natural conditions for the worst 20 percent of days with measurements.

This technique works well for Guadalupe Mountains National Park, which has many dust storm days. The estimated value using the methods described above is 14 dv, and this gives the upper bound for the estimate of natural conditions. The lower bound was calculated in a similar manner except that only the IMPROVE crustal extinction is used, resulting in 10.6 dv.

Figure 8: *Comparison of Predicted Deciviews and Glide Slope by EPA and TCEQ at Guadalupe Mountains for 2000 to 2064* shows the differences in the glide slopes using the upper and lower bounds resulting from the TCEQ proposed methods as compared to the EPA default method.

Big Bend National Park has significantly fewer dust storms than Guadalupe Mountains National Park. It also has more complex sources of regional haze. They include Mexican anthropogenic sources that frequently affect the park. In addition, smoke from agricultural burning wild fires in Mexico and Central American produces some hazy days at Big Bend. Qualitatively, the EPA default natural conditions of 7 dv for the worst 20 percent of days is likely lower than the actual value for this Class I area. The last major scientific study of haze at Big Bend conducted in 1999 did not explicitly address quantification of natural conditions.[4]

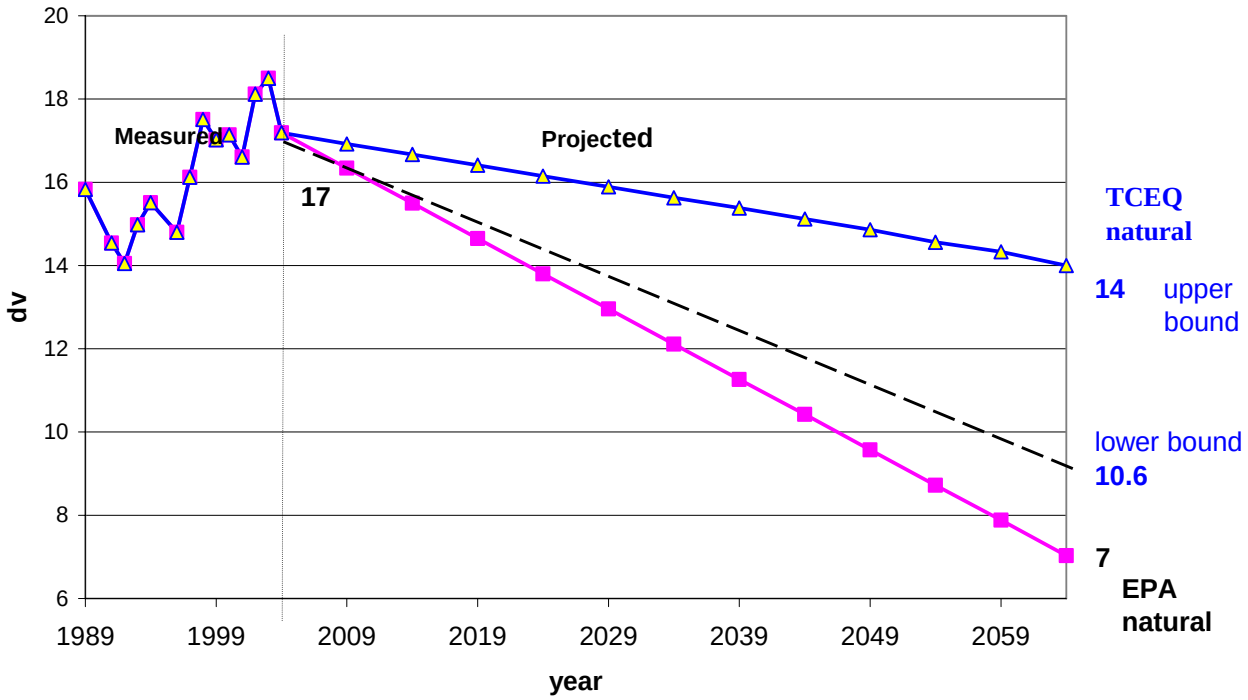


**Figure 8: Comparisons of Predicted dv and Glide Slope by EPA and TCEQ at Guadalupe Mountains 2000 to 2064**

## Section 6. International Dust Transport

International transport of dust appears to not be a source of any of the worst 20 percent visibility impairment days in Big Bend and Guadalupe National Parks in 2000-2004. The intercontinental dust transport from Africa and East Asia do not appear as clearly in satellite images over land as do the West Texas dust storms, making them more difficult to track. The haze densities of these intercontinental dust transport events entering West Texas were usually less than the criteria used in this document to determine a dust storm event.

Analysis of the ratios of the crustal elements suggests that the June 20, 2004, event originated outside the Chihuahuan Desert since it had different elemental ratios than the other dust storms at Big Bend. An African dust event was observed in eastern portions of Texas from June 17, 2004 to June 20, 2004, confirming this finding. This dust may have also reached as far inland as Guadalupe Mountains, but a particulate matter sample is not available for this period at that site. The intercontinental dust transport has contributed some indeterminate amounts of natural haze in West Texas but it appears not to be a significant cause of haze on any of the worst 20 percent days.

## Section 7. Recommendations Regarding Dust Storms

This analysis describes a method for determining accurately when naturally occurring dust storms impact West Texas. The method uses public sources of information and applies a set of criteria. Based on detailed analysis of the data for the years 2000-2004, the TCEQ recommends that:

1. The criteria described above be used for documenting dust storms in West Texas and at other Class I sites located in or near the Chihuahuan Desert or impacted by dust from the Chihuahuan Desert.

2. The visibility impairment caused by coarse mass and fine soil on all dust storm days documented in the above manner be considered part of the natural visibility conditions at these Class I areas.

If these recommendations are followed, the deciview value for natural conditions will significantly increase above EPA's default values. This change will then affect the glide slope used in calculating progress in reducing anthropogenic impacts on regional haze at the Class I areas affected by dust storms.

## References

Washington, R. et. al., "Dust-Storm Source Areas Determined by the Total Ozone Monitoring Spectrometer and Surface Observations," Annals of the Association of American Geographers, volume 93, pp 297-313, 2003, Blackwell Publishing, Malden, MA.