Climatology of Spring 2009/2010 Dust Storm Events Across the Little Colorado River Valley of Northeastern Arizona

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Abstract

High impact blowing dust events frequent the Little Colorado River Valley (LCR) in northeast Arizona during periods of high winds often observed during the spring months. This study examined several cases of observed blowing dust while comparing them against each other, in addition to evaluating the peak wind speeds observed for each event. Further analysis into both short and long term drought conditions and their influence on dust severity was considered as well. The study found that wind advisory criteria being met across the LCR usually led to minimal disruptions to travel with limited blowing dust observed, while high wind warnings often led to significant travel disruptions and areas of widespread blowing dust. Drought severity appeared to play a role in blowing dust, though a conclusive relationship is difficult to attain given lack of dust storm history in this area. The approximate threshold for dust suspension is presented which will aid forecasters in anticipating future high impact dust events in northeast Arizona.

Introduction

During the spring months of 2009 and 2010, numerous significant wind storms impacted parts of northern Arizona, but the largest impact was not from the wind itself, but rather from dust being blown by the wind. The blowing dust lead to localized, but significant reductions in visibility, enough to close sections of Interstate 40 numerous times over the course of the spring. Additionally, some of these dust events were extended in nature, one closing the interstate for two days, all due to a limited sector of roadway being impacted by heavy blowing dust.

Given the fact that these storms usually occur in advance of a large scale synoptic system, they are extremely predictable when strong winds are forecast in this region. Proper forecasting of future dust episodes is essential to improve our decision support efforts during these high impact weather events.

This study aims to improve prediction of future dust storms in the Little Colorado River Valley and greater northeast Arizona by examining the source region of the dust, the geographic area affected; wind speed thresholds necessary to create blowing and suspended dust, as well as the synoptic conditions associated with the dust storm events. The study also considers how short and long term precipitation deficits may have contributed to the severity of the dust storms.

Background

The Little Colorado River Valley (LCR) is a sparsely populated region which covers a broad section of northeastern Arizona (Appendix 1, Figure A-1). This region features arid to semi-arid climatology with the elevations ranging from 4,000 to 6,000 feet, and a vegetation type consisting of sparse vegetation with dry and loose soils. Most susceptible to dust suspension are dry river and lake beds frequently present in the Little Colorado River drainage region, which may act as source region for significant blowing dust (ADEQ, 2009).When winds become strong, this loose soil can be easily blown by the wind and suspended through a deep layer of the lower troposphere as was the case on numerous dust events during the 2009/2010 spring seasons. Additionally, Interstate 40 runs from east to west along the center portion of the LCR, making it highly susceptible to blowing dust.

During the spring months of 2009, and especially 2010, drought conditions expanded across the already dry LCR, with the US Drought monitor expanding D1/D2 (Moderate/Severe) drought status into parts of northeastern Arizona. This may have compounded with the frequent wind events in the spring to intensify the severity of blowing dust. A study from the National Weather Service (NWS) El Paso Weather Forecast Office (WFO) found a 95% correlation with severe blowing dust days and years with below normal precipitation (Novlan et. al, 2006), further supporting the likely role ongoing drought plays on regional dust events. The springs of 2009 and 2010 were also the first in recent memory of any interstate closures being caused by blowing dust, leading to questions of changes in land use in addition to the ongoing drought.

The Arizona Department of Transportation (ADOT) has examined the soil types and biomes from which the blowing dust has originated. Figure 1 illustrates the blowing dust areas overlaid with specific land types from which the dust is originating. The biome type is considered Great Basin desert scrub within the semi-arid land type, which tends to accumulate dust and salts, and is mostly devoid of heavy land cover or grasses (ADOT 2009). The greatest dust suspension is located immediately downwind of the Little Colorado River drainage, where dry river and lake beds create an optimal environment for dust lofting due to the presence of fine soils. This land type, especially after a period of dryness or when the riverbed dries out, favors blowing dust when winds become strong enough to suspend the dust particles.

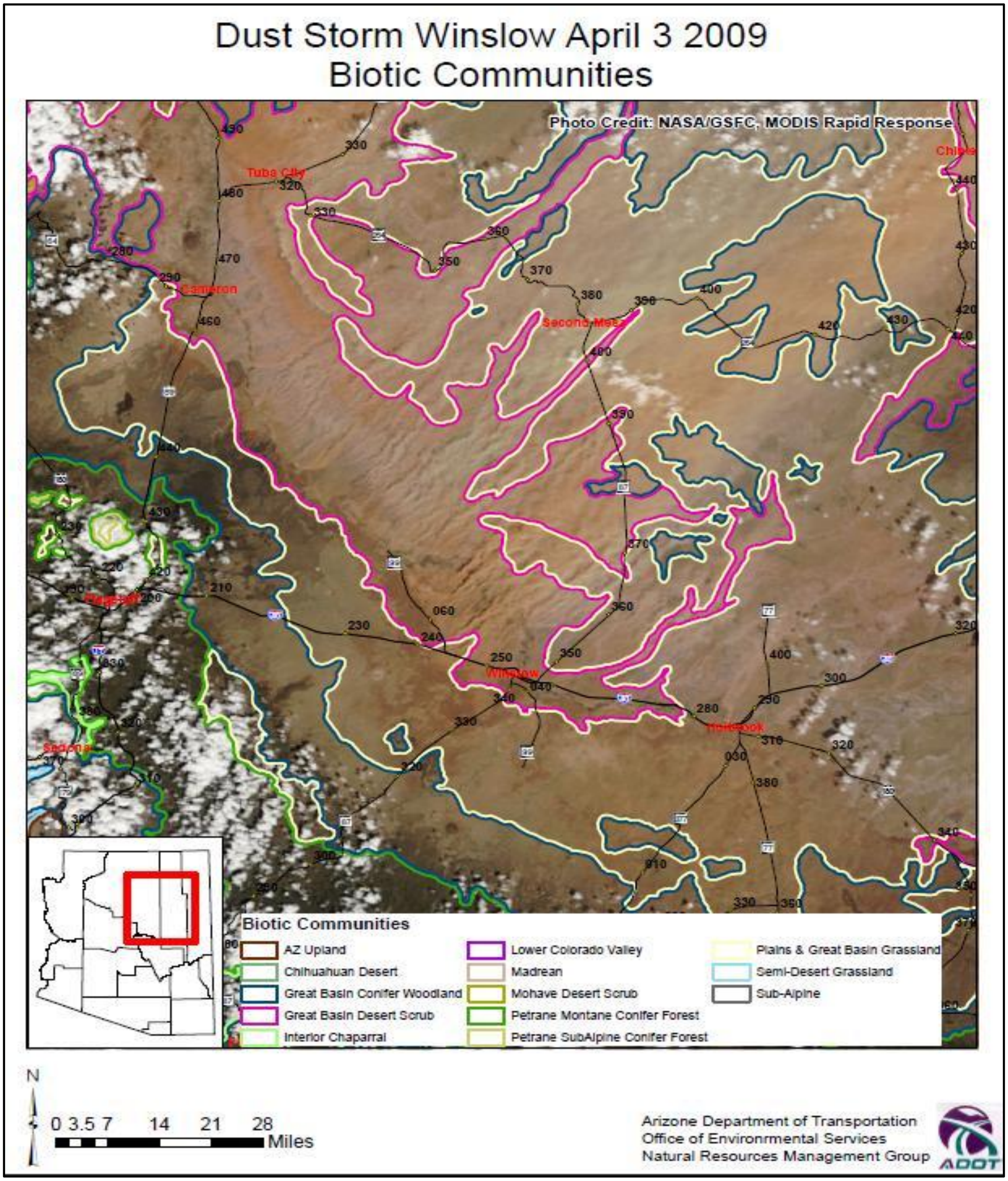

Figure 1 Biotic communities overlaid with blowing dust from April 3rd, 2009 dust event.

As is typical in high impact weather events, the dust storms caught a fair amount of local media attention, listed below are a few excerpts from local newspapers about the storms:

“A blizzard of dust powered by 74 mph wind gusts resulted in zero visibility and forced the closure of an 8-mile section of Interstate 40 west of Winslow for about 12 hours Wednesday. Conditions were severe over a 30-mile stretch of highway -- four times the usual area affected.” (Arizona Daily Sun 4/29/10)

“Strong winds and blowing dust have closed stretch the stretch of Interstate 40 between Meteor Crater rest area and Winslow for the second time in less than a week.” (Arizona Daily Sun 4/12/10)

“The fourth dust storm in a month stopped Interstate 40 traffic east of Flagstaff for more than six hours Wednesday.” (Arizona Daily Sun 4/15/09)

The impacts of the dust storms were not limited to motorists on I-40. At least one storm led to the early dismissal of a school in Leupp, located in the Navajo Nation, because driving winds and blowing dust created “red-out” conditions.

Methodology

The study began by examining archives of NWS text products, primarily wind advisories and high wind warnings that were issued during March, April, and May from 2009 through 2011. These products provided a foundation for the dates which needed to be examined more closely as possible dust event cases. A search was also performed of archived newspaper articles relating to highway closures during the same time frame. The majority of newspaper articles came from the Arizona Daily Sun, a major Flagstaff newspaper. A detailed listing of specific mileposts and times of the regional closures was also provided by ADOT, which significantly aided in knowledge of specific location and timing of the worst visibility reductions (Appendix 1, Table A-1).

Once the dates of the dust storms had been determined, archived surface observations were obtained through MesoWest. The surface observations provided information on wind speed, winds gusts, wind direction, and visibility. Statistical relationships between wind speeds and visibility reduction were also examined using weather data from the ADOT sensor at Two Guns, and the Winslow, AZ Automatic Surface Observing System (ASOS). Unfortunately, observing sites are quite sparse in the LCR, so the satellite information was a necessity to have a complete set of data.

Visible satellite imagery, obtained through National Oceanic and Atmospheric Administration (NOAA) archives, was then examined to determine what time and location the dust began and detailed which areas were affected by the dust. The satellite imagery from all of the dust events was then compiled to depict which areas are most prone to the dust events. With the dust prone areas outlined by the satellite composite overlay, the relationship between wind speed and visibility can be determined.

Analysis

This section highlights a few select cases in which the dust was especially prolific across northeast Arizona, to better highlight the significance and location of the problem spots. Thereafter, the statistical relationships between wind speeds, drought conditions, and blowing dust are discussed.

April 3rd, 2009

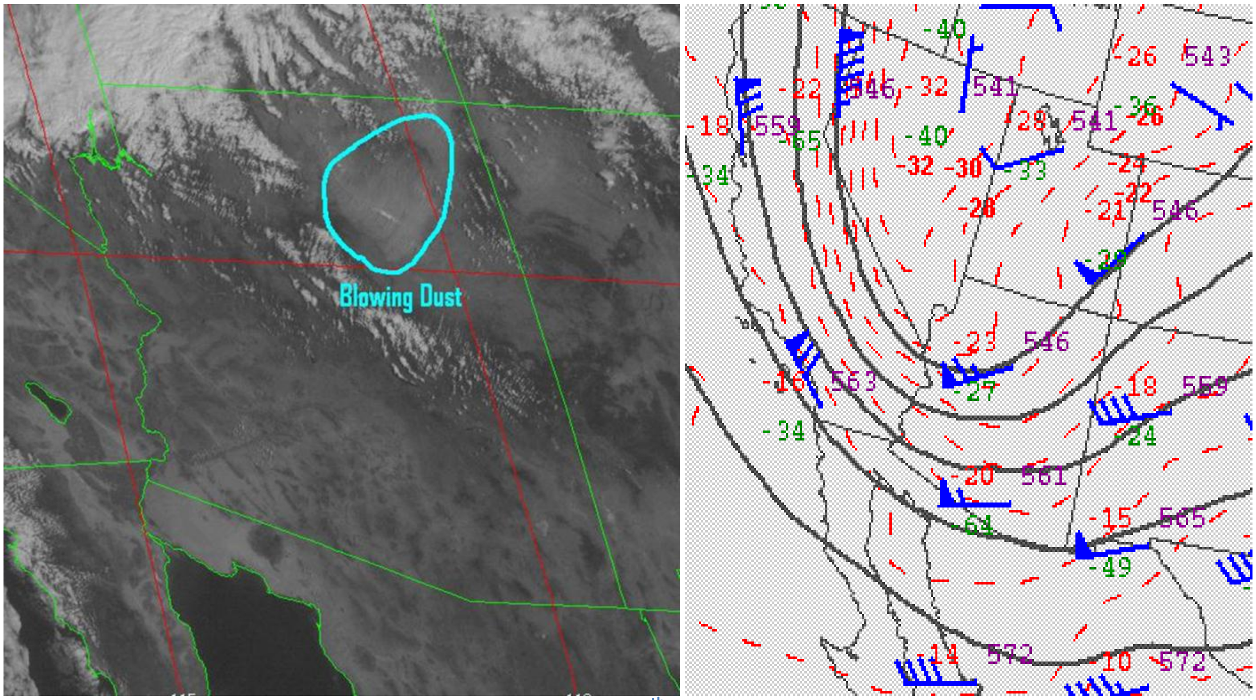

Figure 2- 1715 UTC visible satellite imagery (left), and 00Z April 4th 500 mb analysis (right) depicting strong southwest flow ahead of approaching shortwave trough.

On April 3rd, 2009 a strong trough of low pressure was digging south across the southwestern deserts. This induced a tight pressure gradient across the state of Arizona with a strong southwesterly flow observed across the LCR. The visible satellite image shown in Figure 2, valid at 1715 UTC, indicated a large area of blowing dust across the region downstream of the Mogollon Rim, impacting a broad stretch of the LCR as well as much of Interstate 40. The 500mb analysis for the same day (upper right), indicates a strong shortwave trough approaching northern Arizona. Strong jet stream winds in excess of 60 kts near 500 mb mixed down to the surface in advance of sharp height falls. On this day, peak winds observed in Winslow and Two Guns, both locations frequently impacted by strong winds and blowing dust, were 66 mph and 69 mph respectively. Interstate 40s closure was forced on this day by both the high winds and blowing dust.

April 15th, 2009

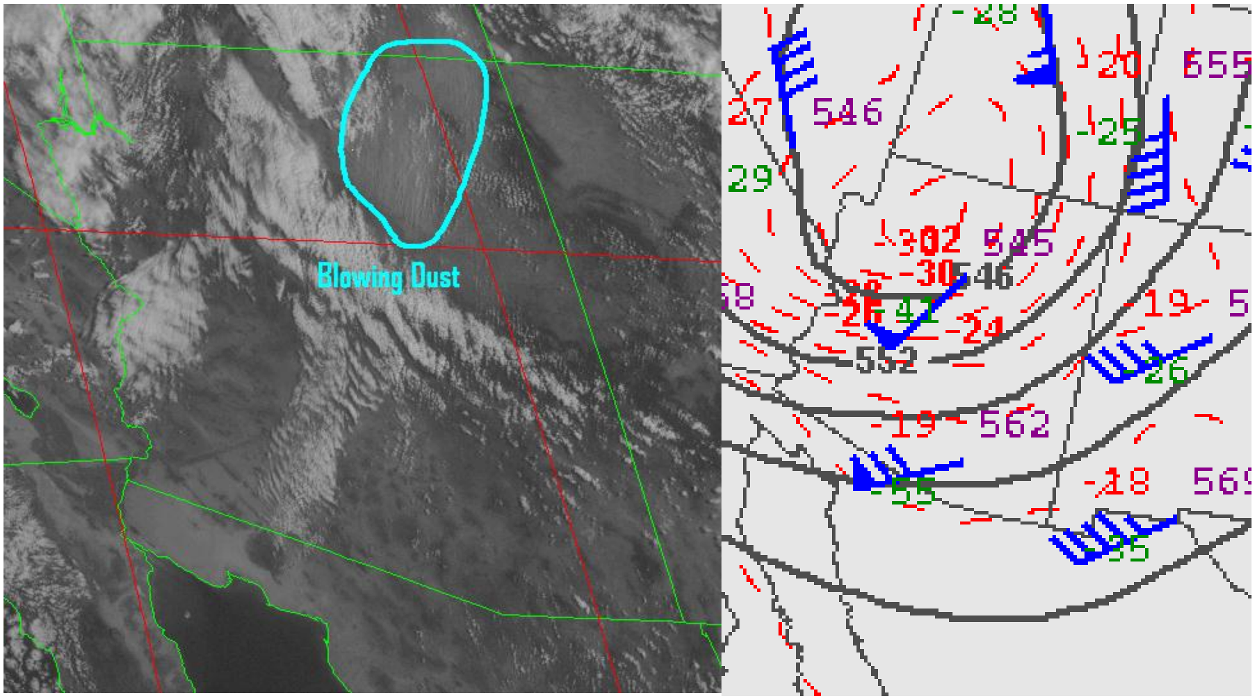

Figure 3 – 1900 UTC visible satellite imagery (left), and 500 mb analysis for 00Z April 16th.

Figure 3 shows that a closed low was lifting across southern Nevada with significant height falls moving across northeast Arizona. Though the setup was different than the week prior, the result was the same. Strong winds stretched across a broad region of the LCR inducing blowing dust from the northern edge of the Mogollon Rim all the way to the four corners. Peak wind speeds of 60 to 70 mph easily suspended dust across the region and reduced visibilities enough to force the closure of Interstate 40 once again.

May 29, 2010

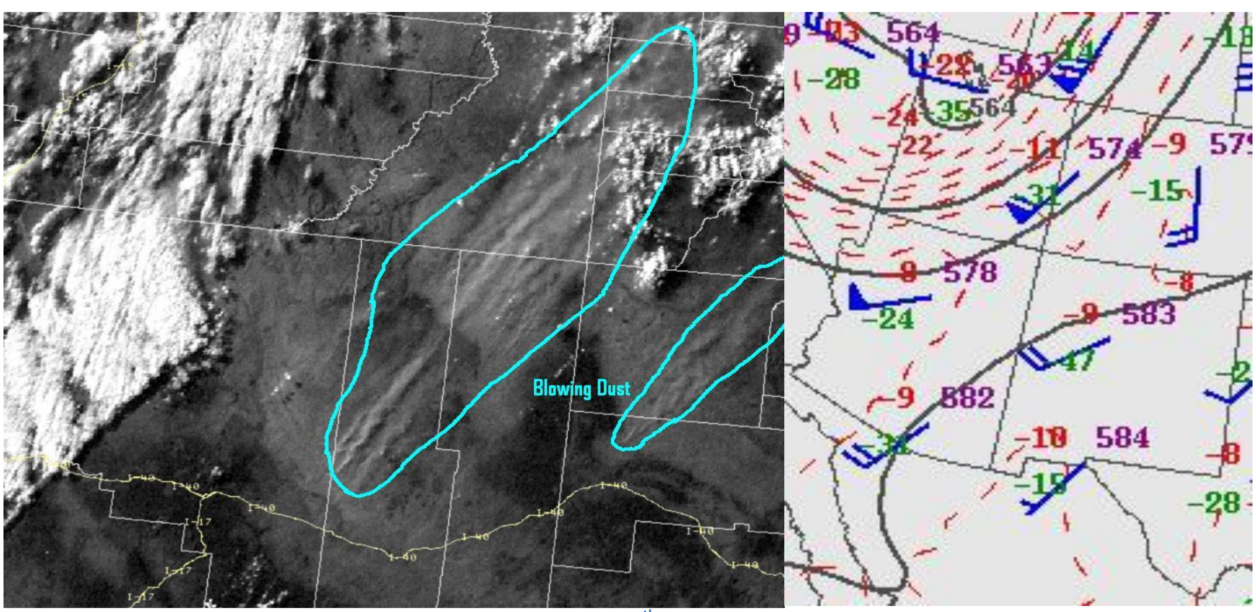

Figure 4 – Visible satellite imagery from 00Z May 30th (left) and corresponding 500mb analysis (right)

Figure 4 shows that on May 29th, 2010, a shortwave trough was lifting across the Intermountain West while dragging a cold front across northwest Arizona. In advance of this front, strong winds impacted much of the LCR and four corners region. One notable difference in this case is that the primary dust plumes are concentrated further north, and also north of Interstate 40, closer to the location of the stronger winds with this more northerly shortwave, as illustrated in figure 4. Winds were strong across the southern half of the LCR as well but perhaps not enough to cause windspread dust concerns, as Winslow's peak wind gust was only 38 mph. The interstate was able to maintain functionality for the duration of the event.

A statistical review of the wind speeds observed in all the dust cases revealed that the average peak wind speed in Winslow and Two Guns was 49 mph, while the average peak wind observed during strictly interstate closing events was 60 mph. More generally, most sub freeway closing wind events consisted of peak winds in the 35-55 mph range, while most freeway closing events consisted of winds gusts of 55mph and above. This relationship indicates most wind advisory days will not observe significant visibility reductions, while interstate closures become more likely once high wind warning criteria is met (Appendix 1, Table A-2).

A composite image of the location and trajectories of the dust plumes was created by overlaying some of the dust plume imagery available (for clear days only), which resulted in the image shown in Figure 5. Table 1 shows the average wind direction and peak wind speed in miles per hour on the days included in the composite shown in Figure 5.

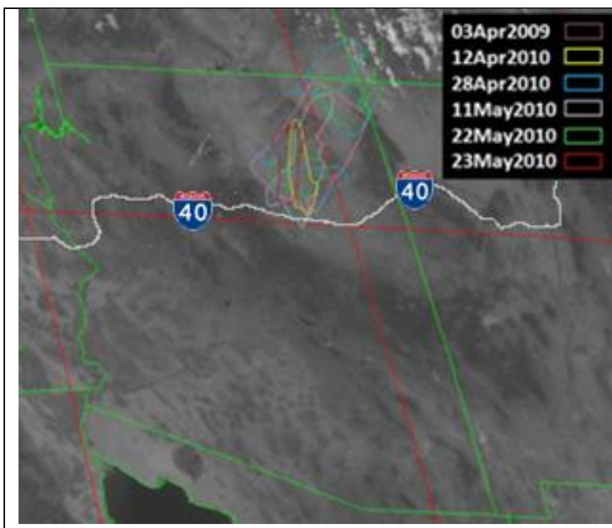

Figure 5

Peak Wind Direction and Gust at KIWN and Two Guns For days outlined in Figure 5 (KINW/TwoGuns)

Date	Wind Direction	Peak Wind - MPH (KINW/Two Guns)
03April 2009	240	69/65
12April 2010	190	55/51
28April 2010	220	70/73
11May 2010	230	58/77
22May 2010	210	47/56
23May2010	190	60/60

Table 1

As depicted in Figure 5, blowing dust most frequently develops in the LCR near Winslow while being blown northeastward towards the four corners. There is also a remarkable relationship between the location of the Little Colorado riverbed and the downstream dust plume, signaling the likelihood of the dry river and lakebeds of the Little Colorado as a significant source region for dust suspension. The sparse nature of the data network in far northeast Arizona prevents better observations from being recorded. However, it's likely that areas downstream of the dust plume origin northeast of Winslow, extending all the way to the four corners region, experience even worse reductions in visibility with a greater frequency than what is observed in Winslow and along Interstate 40.

For the six days included in Figure 5, it is noted that on four of the days the primary wind direction was from 210-240 degrees and consequently the dust plume traveled to the northeast and likely impacted the communities of Second Mesa, Keams Canyon, Dilkon, Ganado, Chinle, Many Farms, Canyon De Chelly, Tsaile, and Teec Nos Pos. The wind speed on the two remaining days was lighter and the primary direction was from 190 degrees. Consequently the dust plume traveled toward the north-northeast, with impacts likely limited to the communities of Second Mesa, Keams Canyon, Dilkon, and Pinon. Perhaps the most significant impact was to travel, because Interstate 40 was closed on all six of these days from approximately 17 miles west of Winslow (near the Meteor Crater exit) to Winslow.

Figure 5 also suggests that a relationship exists between wind speed and the distance that the plume travels from its point of origin. This relationship was calculated based distance measurements from the composite image in Figure 5 for each of the six dates shown. It should be no surprise that the stronger the wind was, the farther the dust traveled, as shown in Figure 6. Keep in mind we are limited to 6 cases due to cloud cover obscuring the dust plume during other events. As future events occur, more cases can be added to increase the accuracy of the regression analysis.

A positive correlation of wind speed to distance was determined to be 0.88. Given the relatively strong dependence of distance to wind speed, the authors feel confident that wind speed can be used as a good predictor of how far dust will travel during future wind events. Thus, forecasters can better predict which locations will be impacted by dust based on predicted wind speed and direction, assuming that the future dust point of origin is also known.

Forecast Wind Speed (MPH)	Distance Dust May Travel (Miles)
40	25
50	70
60	110
70	155
80	200

Table 2

To that end, a simple linear regression equation was developed based on the events highlighted in Figure 5 (distance being the dependent variable and wind speed the independent variable). The regression yielded the following equation:

$$\text{Distance in miles} = -146.742 + 4.3 \text{ (wind speed in MPH)}$$

The values in Table 2 were calculated based on the preceding regression equation, and can be used as forecast guidance in advance of future high wind events.

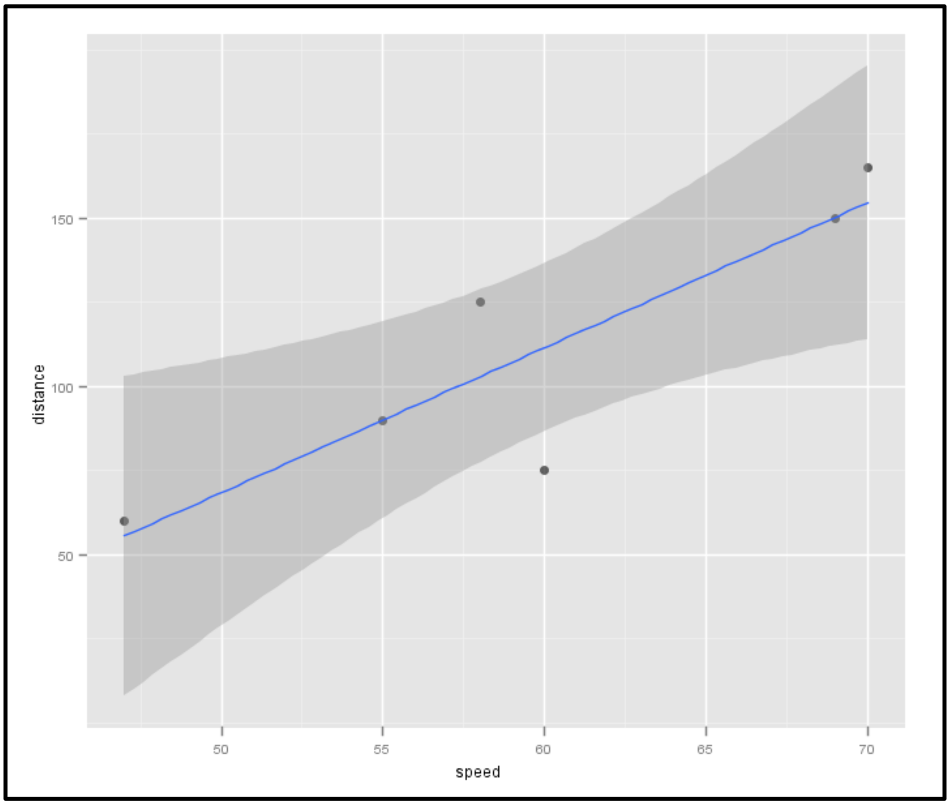

Figure 6 Wind speed (MPH) vs. distance (Miles) that the dust traveled based on the 6 events shown in Figure 5

Using these approximations, operational forecasters may be able to better determine which communities will be impacted by dust during an impending high wind event based on wind speed and direction.

Another interesting finding was that 27% of the cases involving severe blowing dust were followed by light precipitation. This makes meteorological sense given a stronger synoptic system will likely consist of stronger surface wind speeds, and often in advance of an eastward progressing cold front, high winds will be observed prior to precipitation onset with the frontal passage.

Additionally, a significant contributing factor to the frequency of the dust events, especially in 2010, may have been the ongoing drought conditions. This study revealed 55% of all severe blowing dust cases were preceded by moderate to severe drought conditions as reported by the U.S. drought monitor. Other research studies have shown a correlation with ongoing drought conditions with synoptically driven dust events (Rivera, 2006) , and this may be a contributing reason as to why 2009 and 2010 featured such an increase in dust events as opposed to prior years.

Forecast Tools

The Global Ensemble Forecast System (GEFS) can provide support in anticipating the magnitude of an incoming wind event and assessing the potential for dust. Figure 7 depicts the standardized anomalies forecast by the GEFS from its 00z Mar 21st, 2011 run; valid for 12z March 21st. This event produced 59 mph winds in Winslow, and 67 mph winds at Two Guns; however, no freeway closures occurred with this system. Anomalies across northern Arizona ran between three and four standard deviations above the normal, highlighting the strength of the incoming wind gradient.

The GEFS 700mb wind anomalies provide a great supplement to anticipate high wind potential, but further consideration of precipitation, cloud cover, and soil moisture may also influence the likelihood of blowing dust. On this day, despite high wind warning criteria being bet across much of northern Arizona, blowing dust was very minimal due to the presence of light rain across the LCR and cloud cover limiting diurnal mixing. High wind events may occur under much less anomalous thresholds if mixing is more favorable and the strongest 700mb winds are juxtaposed with the midafternoon hours.

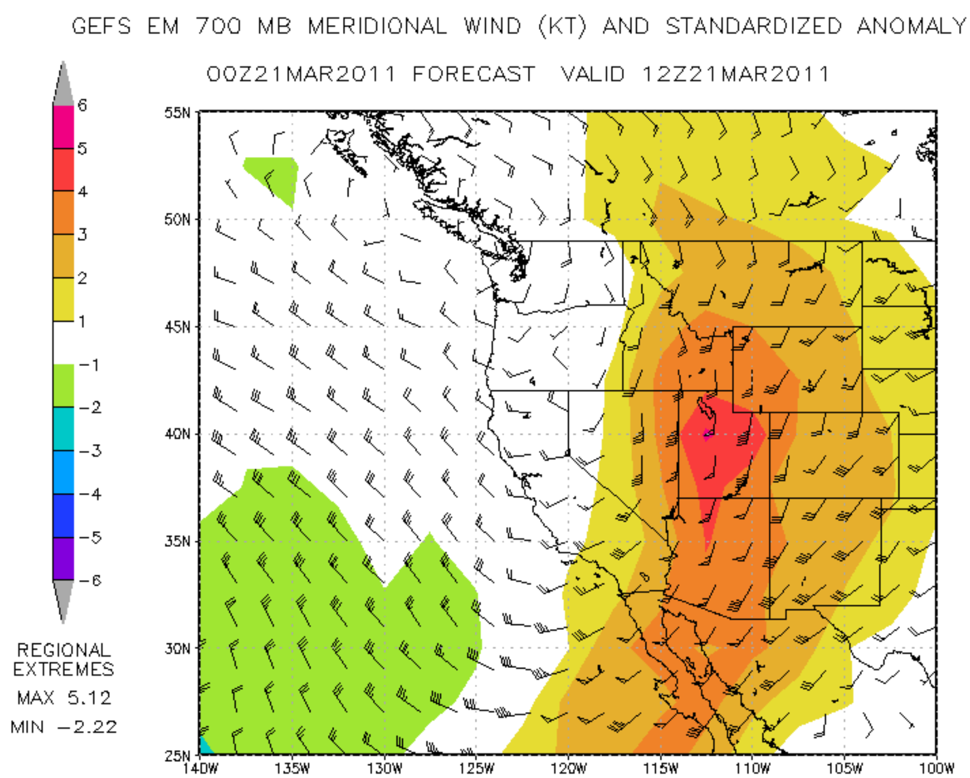

Figure 7 – GEFS 700mb standardized anomalies

2011 Events

Despite having numerous high wind events, the spring of 2011 featured very little in the way of significant blowing dust and no interstate or highway closures. While this may seem counterintuitive to the research presented thus far, it actually supports the theory that high wind warning criteria winds are more conducive to severe blowing dust. While numerous wind events plagued the LCR over the course of the spring, the magnitude of the wind was much less than observed the previous two years. The table below shows the number of wind advisory and high wind warning days impacting the LCR for the spring months (Mar-Jun). Note that despite the high number of wind advisory days, the number of high wind warnings was less in 2011 than in 2010 and 2009, supporting the conclusion that a greater magnitude of wind is required for significant lofting of blowing dust.

Year	Wind Advisories	High Wind Warnings	I-40 Closures
2011	27	2	0
2010	15	6	7
2009	12	5	5

Furthermore, table A-2 (Appendix) shows a sampling of the wind storms between 2009 and 2011. Notice that despite the high number of wind events occurring in the spring of 2011, majority of them were wind advisory level wind, and none created blowing dust significant enough to cause interstate closures.

Conclusions

The 2009 and 2010 dust storms proved how vulnerable the LCR can be to synoptically forced dust events, but while they can develop suddenly and become high impact, they are highly predictable as well. Anytime a wind event is forecast across northeast Arizona, potential for blowing dust must be a consideration, and whenever a high-end wind event is anticipated, blowing dust becomes quite likely. One of the key findings indicated that most wind advisory days will not observe visibility reductions due to dust that will close the interstate. However, high wind warning days are much more likely to produce widespread blowing dust, which may result in interstate closures.

The lack of observation points was most definitely a limitation to this study, as Winslow and Two Guns represent a rather small sample size for winds across the LCR, but prove sufficient to gain insight into the wind magnitudes required for blowing dust. Further research into changes in land use across northeast Arizona and the associated role it may be playing in these dust storms would be beneficial, but it appears the Little Colorado riverbed is the primary source for much of the blowing dust across the LCR. Other tributaries and watersheds across the LCR may be secondary source regions influencing blowing dust across the Winslow and Two Guns regions. Ongoing drought conditions may have aided the severity of blowing dust, but wind speed is the primary determining factor when anticipating severe dust storm events.

Appendix 1

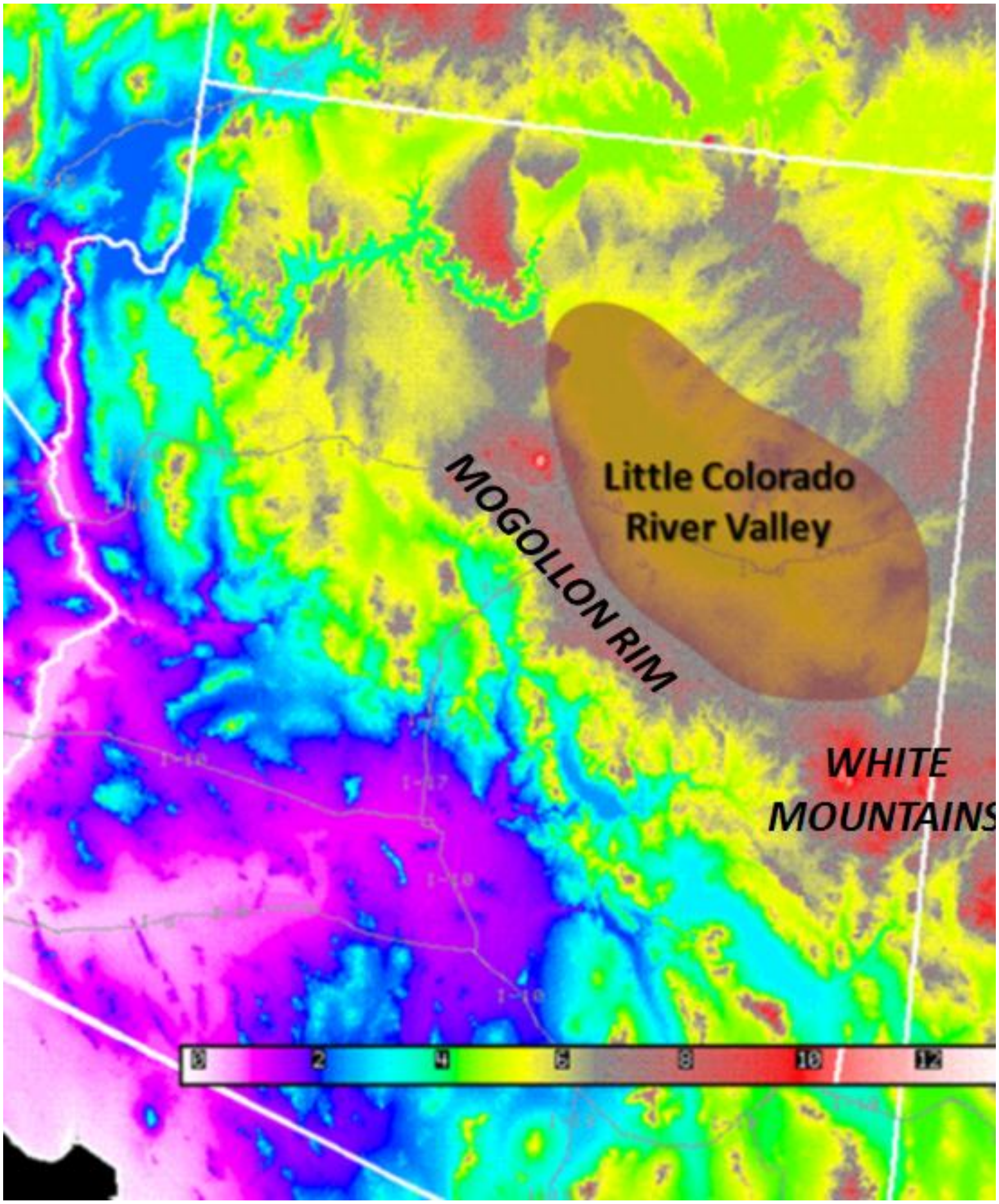

Figure A-1. Northern Arizona topography and location of Little Colorado River Valley

Interstate 40 closures Due to Dust

Date	Highway Segment Affected (Mile Markers and Length)	Other Roads Closed
March 26, 2009	235-252 / 17 miles	SR 77 North of Holbrook
April 3, 2009	235-252 / 17 miles	
April 8, 2009	235-252 / 17 miles	
April 14-15, 2009	235-252 / 17 miles	
April 25, 2009	235-252 / 17 miles	
April 5, 2010	235-252 / 17 miles	Coconino Co Rd 505 to Luepp
April 12, 2010	235-252 / 17 miles	Coconino Co Rd 505 to Luepp
April 21, 2010	235-252 / 17 miles	Coconino Co Rd 505 to Luepp
April 28-29, 2010	230-252 / 22 miles	Coconino Co Rd 505 to Luepp
May 9, 2010	230-252 / 22 miles	
May 11, 2010	219-252 / 33 miles	Coconino Co Rd 505 to Luepp
May 22-23, 2010	219-252 / 33 miles	Coconino Co Rd 505 to Luepp

Table A-1

Dust Event Wind Statistics

Date	I-40 Closure	Primary Wind Direction at KINW	Peak Wind Speed at KINW / Two Guns (MPH)
March 4, 2009	No	220	48/53
March 9, 2009	No	210	43/58
March 22, 2009	No	200	62/65
March 26, 2009	**Yes**	**300**	**61/48**
March 29, 2009	No	230	56/63
April 3, 2009	**Yes**	**240**	**69/65**
April 8, 2009	**Yes**	**210**	**58/58**
April 14, 2009	**Yes**	**210**	**39/M**
April 15, 2009	**Yes**	**190**	**59/M**
April 25, 2009	**Yes**	**210**	**58/60**
April 28, 2009	No	210	39/35
May 2, 2009	No	250	40/47
March 4, 2010	No	200	38/45
March 25, 2010	No	220	35/37
March 26, 2010	No	250	49/55
March 30, 2010	No	220	41/45
March 31, 2010	No	210	55/62
April 5, 2010	**Yes**	**210**	**63/71**
April 12, 2010	**Yes**	**190**	**55/51**
April 21, 2010	**Yes**	**190**	**53/60**
April 28-29, 2010	**Yes**	**220**	**70/73**
May 5, 2010	No	230	40/45
May 6, 2010	No	230	40/45
May 9, 2010	**Yes**	**210**	**47/48**
May 11, 2010	**Yes**	**230**	**58/77**
May 18, 2010	No	230	29/45
May 22, 2010	**Yes**	**210**	**47/56**
May 23, 2010	**Yes**	**190**	**60/60**
May 27, 2010	No	200	40/39
Mar 7th, 2011	No	210	58/54
Mar 17th, 2011	No	210	37/42
Mar 21st, 2011	No	190	59/67
Apr 3, 2011	No	220	56/57
Apr 8, 2011	No	190	58/65
Apr 13, 2011	No	220	35/42
Apr 18, 2011	No	220	50/47
Apr 23, 2011	No	220	39/41
Apr 24, 2011	No	230	47/49
Apr 29, 2011	No	230	48/45
May 8, 2011	No	200	41/47
May 9, 2011	No	210	44/42
May 15, 2011	No	200	40/45

May 18, 2011	No	210	54/49
May 26. 2011	No	220	40/44
May 28, 2011	No	210	52/49
May 29, 2011	No	210	56/68
June 6, 2011	No	200	45/50
June 16, 2011	No	220	40/42

Table A-2

References:

Arizona Department of Transportation (ADOT). Biotic Communities [Image]. 2010.

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