

## **Grand Junction, Colorado, Blowing Dust Climatology January 24, 2012**

There can be significant transport of regional blowing dust into Grand Junction from source regions in Utah and Arizona. While there are sources for wind-blown dust within the Grand Valley and Grand Junction itself, there is evidence from the analysis of soil features, wind and precipitation climatology, and statistical analyses of Grand Junction exceedances of the PM10 standard that regional sources often play a significant role during these blowing dust events. This document provides a weight of evidence analysis for dust transport into Colorado.

Grand Junction, Colorado, is located in a part of the country that is largely arid to semi-arid. Figure 1 through 3 show the annual average precipitation for Colorado, Arizona, and Utah, respectively. Grand Junction is in the Grand Valley of Western Colorado where the annual precipitation is typically less than 10 inches. Northeastern Arizona, which is frequently upwind of Grand Junction during blowing dust events, receives between 5 and 15 inches of precipitation each year. The Colorado River Basin in eastern and southeastern Utah, which is also frequently upwind of Grand Junction during blowing dust events, also receives 5 to 10 inches per year.

Figure 4 shows the 1971-2000 monthly normal precipitation amounts for Grand Junction, Colorado. The annual average for this time period is 8.99 inches. The wettest months are March through May and August through October. The driest months are January, February, June, July, November, and December. These months receive an average of 0.57 inches per month. The annual monthly average precipitation is 0.75 inches.

Arid to semi-arid soils make much of the region susceptible to blowing dust. The map in Figure 5 shows that portion of the Colorado Plateau (circled in red) where modern wind erosion features are common and clearly visible in Google Earth images. These features include longitudinal dunes and other sand or soil erosion structures with a predominant southwest to northeast orientation. This orientation is the result of the predominant southwesterly flow that occurs during high wind and blowing dust events in the region. Figures 6 through 12 present aerial views of ubiquitous erosion features in northeastern Arizona and southeastern Utah. The Painted Desert of northeastern Arizona is frequently the source for much of the blowing dust in the Four Corners region. Figure 13 provides a particularly good satellite image of a blowing dust event originating in the Painted Desert and extending northeastward across the junction of the Four Corners (source: NASA Tera satellite, <http://earthobservatory.nasa.gov/IOTD/view.php?id=37791>). Strong southwesterly winds caused this blowing dust event.

The text that accompanies this image on NASA's Earth Observatory 10<sup>th</sup> Anniversary page follows below:

“A dust storm struck northeastern Arizona on April 3, 2009. With winds over 145 kilometers (90 miles) per hour reported near Meteor Crater, east of Flagstaff, the storm reduced visibility and forced the temporary closure of part of Interstate 40, according to *The Arizona Republic*.

The Moderate Resolution Imaging Spectroradiometer ([MODIS](#)) on NASA's [Terra](#) satellite captured this image on April 3, 2009. Clear skies allow a view of multiple source points of this dust storm. The source points occur along an arc that runs from northwest to southeast.

This dust storm occurred in the area known as Arizona's Painted Desert, and the dust plumes show why. Whereas many dust plumes are [uniform in color](#), these plumes resemble a band of multicolored ribbons, ranging from pale beige to red-brown, reflecting the varied soils from which the plumes arise. The landscapes of the Painted Desert are comprised mostly of Chinle Formation rocks—remains of sediments laid down during the time of the first dinosaurs, over 200 million years ago.”

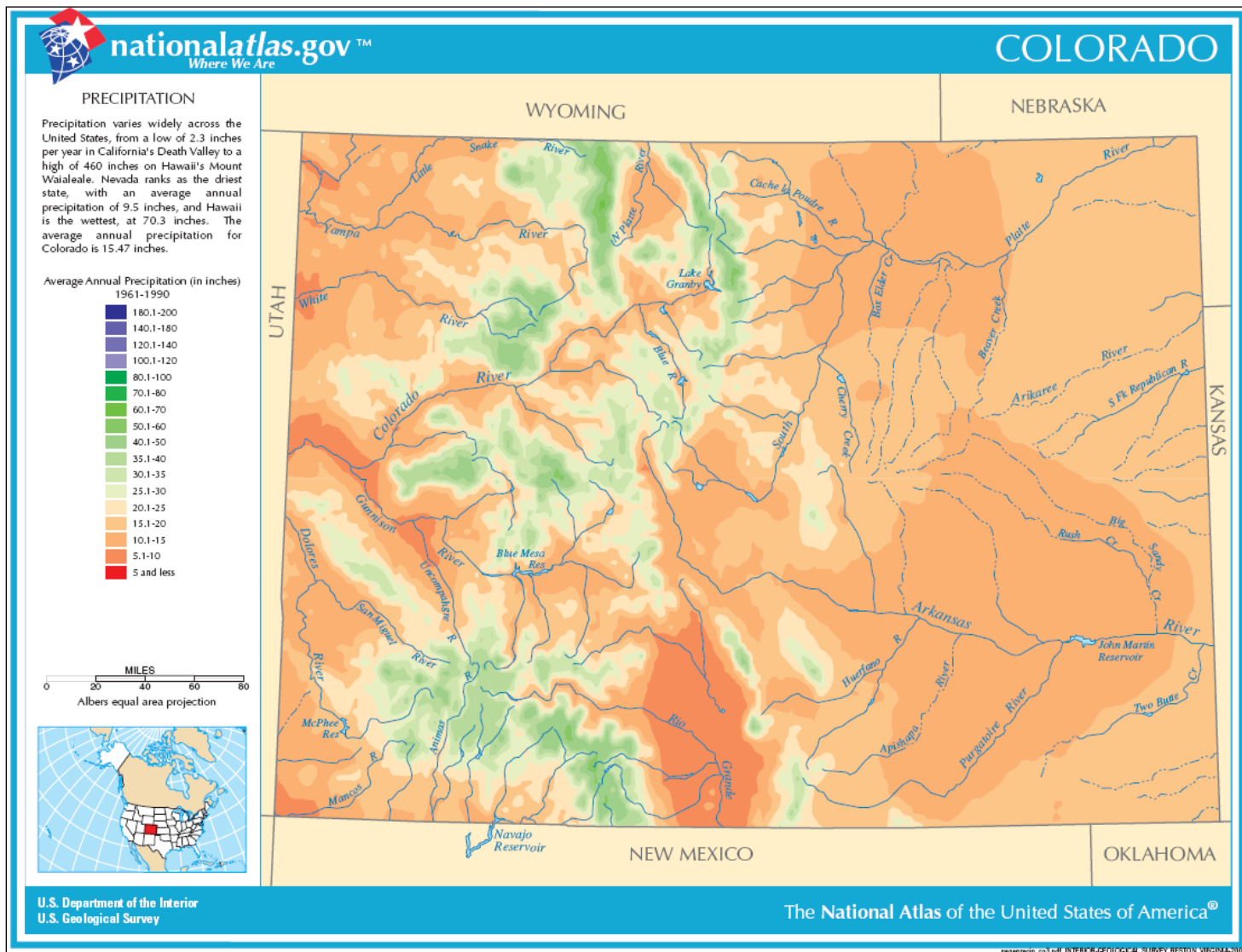


Figure 1. Average annual precipitation in Colorado based on 1961-1990 normals.

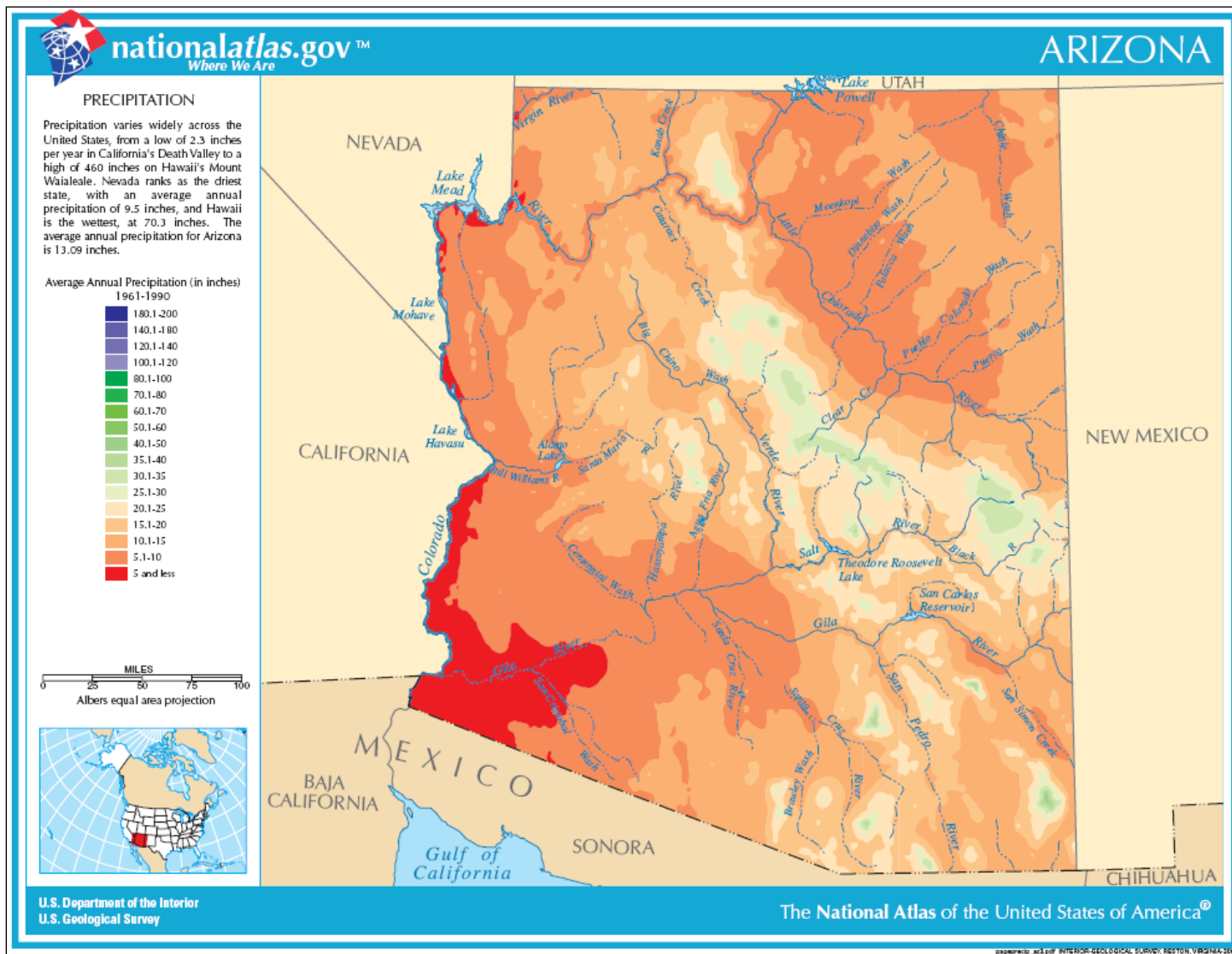


Figure 2. Average annual precipitation in Arizona based on 1961-1990 normals.

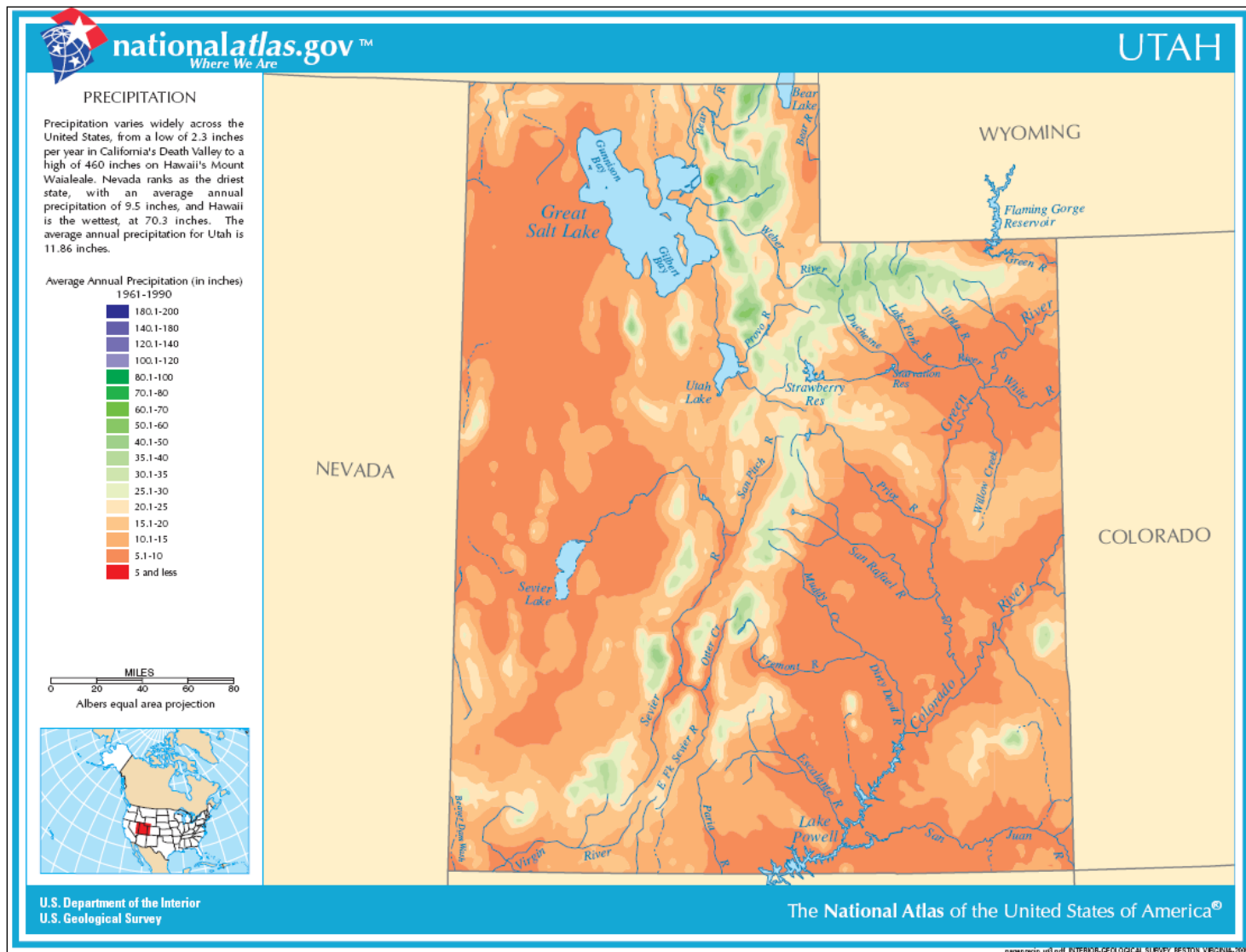


Figure 3. Average annual precipitation in Utah based on 1961-1990 normals.

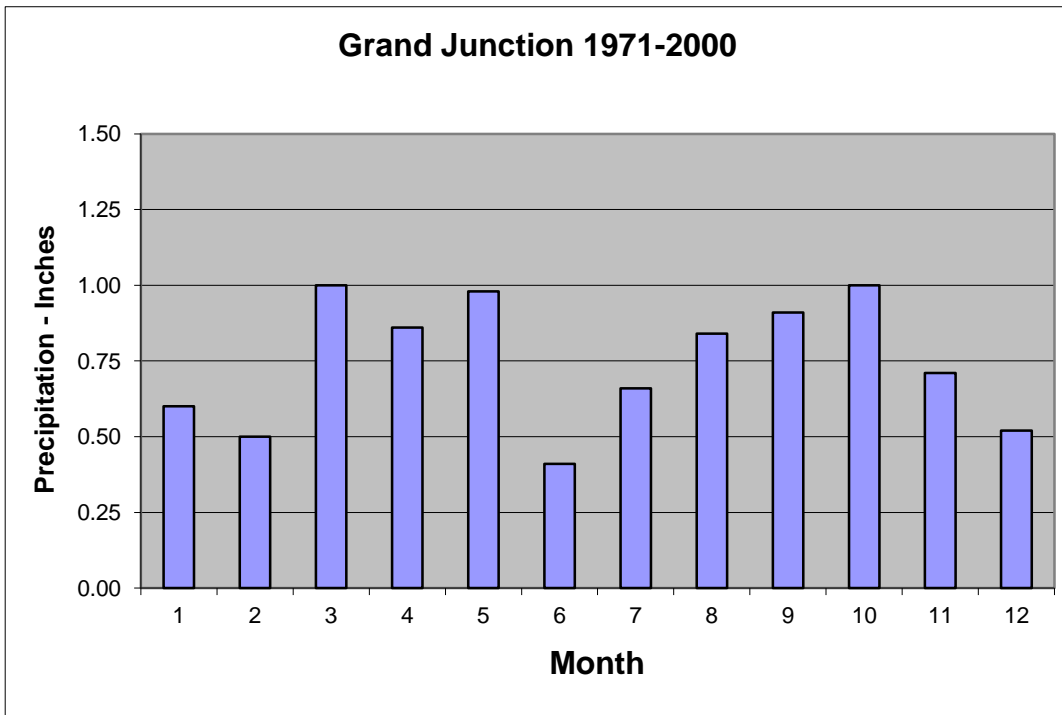


Figure 4. 1971-2000 monthly normal precipitation in Grand Junction Colorado.

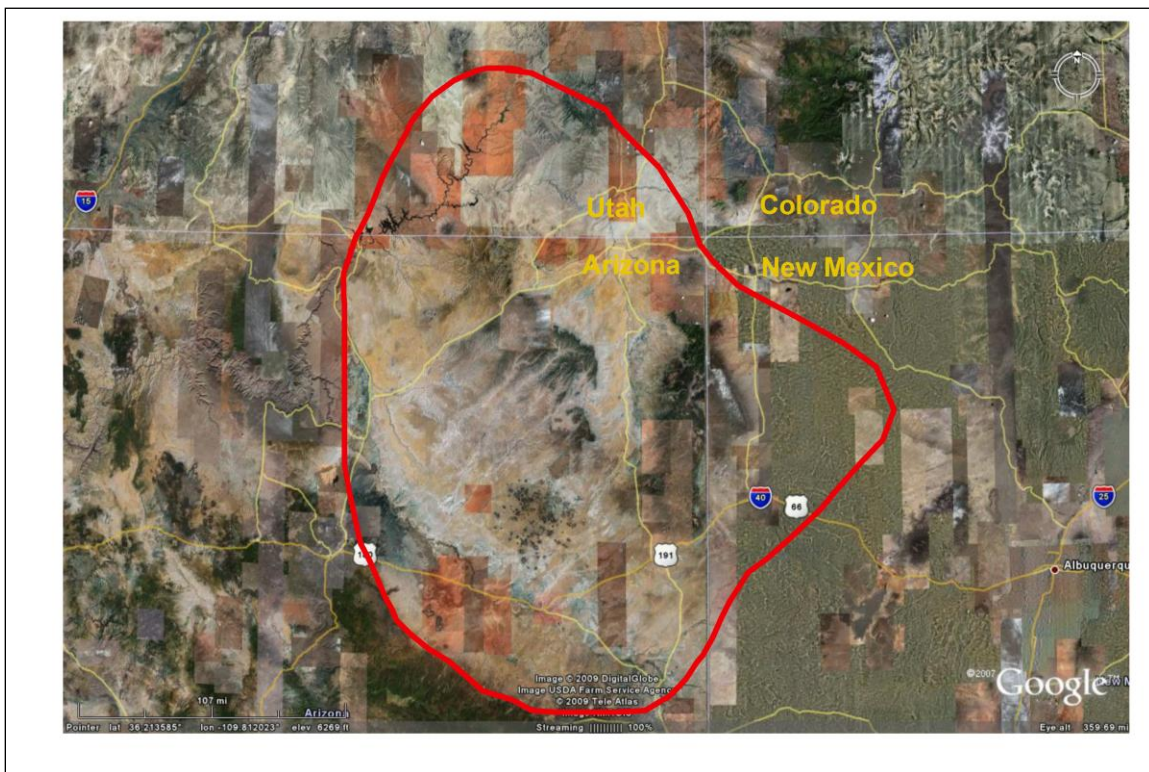


Figure 5. The portion of the Colorado Plateau in Utah, Arizona, and New Mexico that exhibits widespread surface soil and sand erosion features in Google Earth imagery. Much of the highlighted area within Arizona is within the Painted Desert.

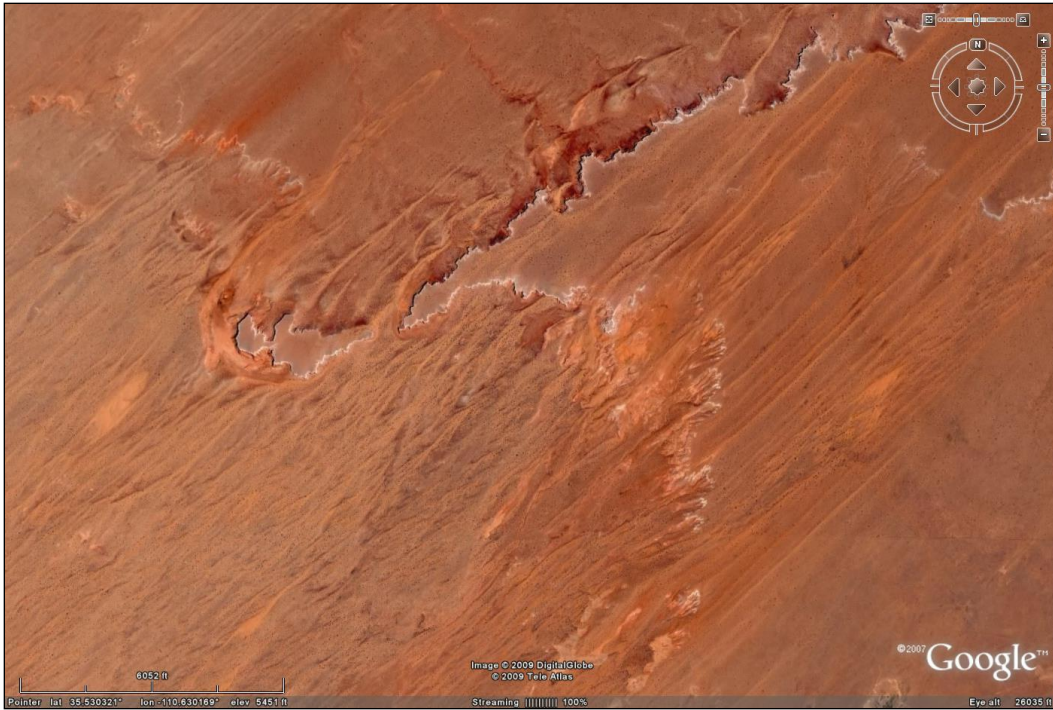


Figure 6. Southwest to northeast soil and sand erosion structures in southeastern Utah.

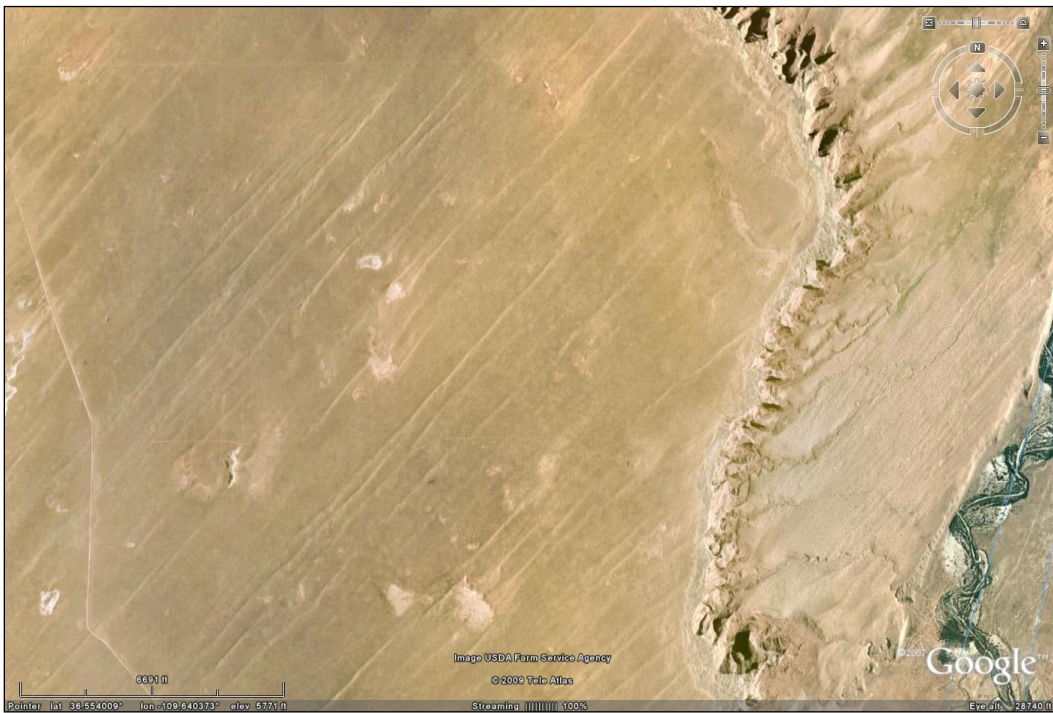


Figure 7. Southwest to northeast soil and sand erosion structures in northeastern Arizona (Painted Desert).



Figure 8. Southwest to northeast soil and sand erosion structures in southeastern Utah.

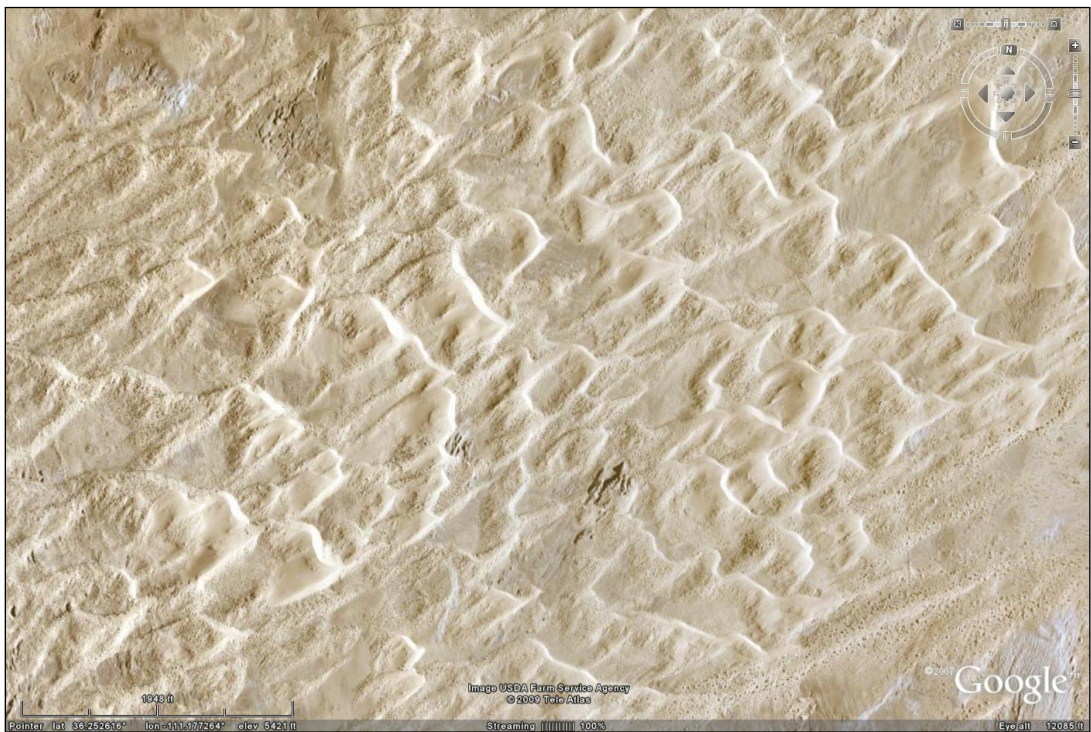


Figure 9. Southwest to northeast soil and sand erosion structures in northeastern Arizona (Painted Desert). The slip faces of dunes (lighter bands) face in the direction of wind flow – toward the northeast.



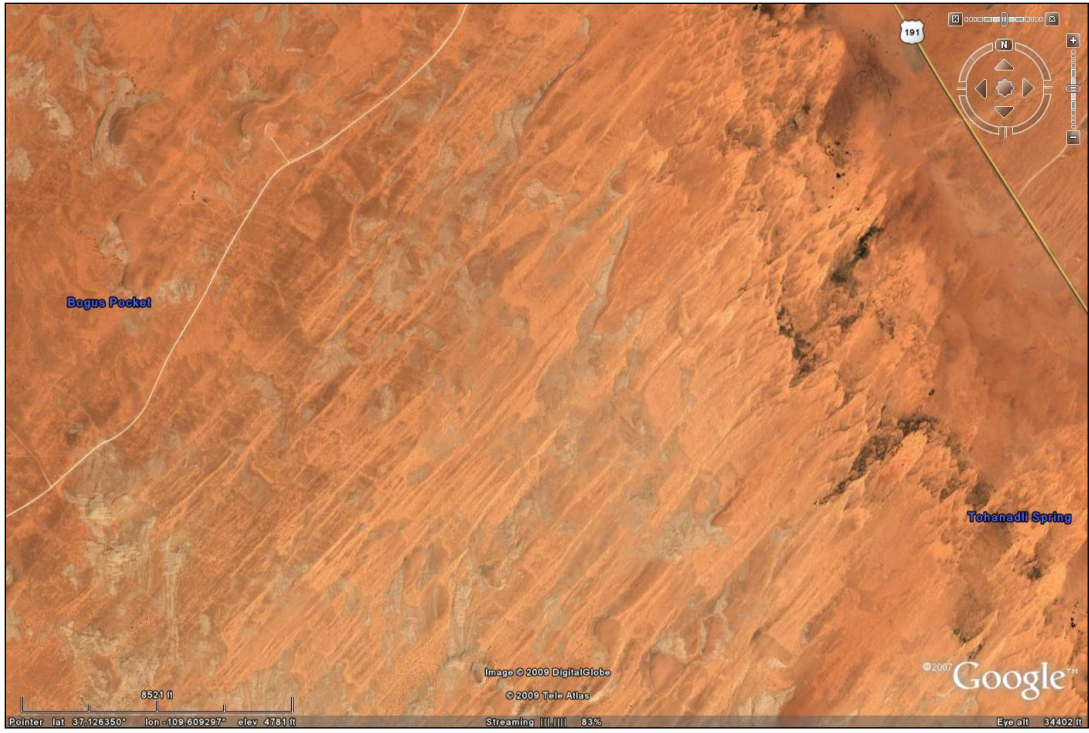


Figure 10. Southwest to northeast soil and sand erosion structures in southeastern Utah.

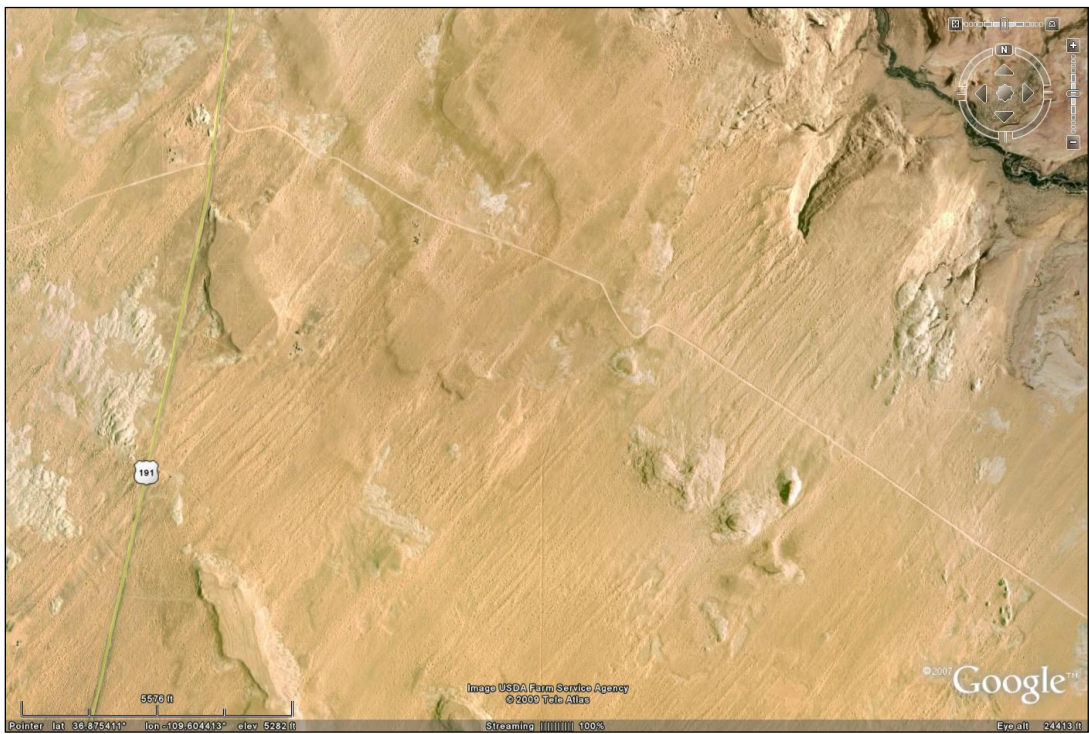


Figure 11. Southwest to northeast soil and sand erosion structures in northeastern Arizona (Painted Desert).



Figure 12. Southwest to northeast soil and sand erosion structures in northeastern Arizona (Painted Desert).

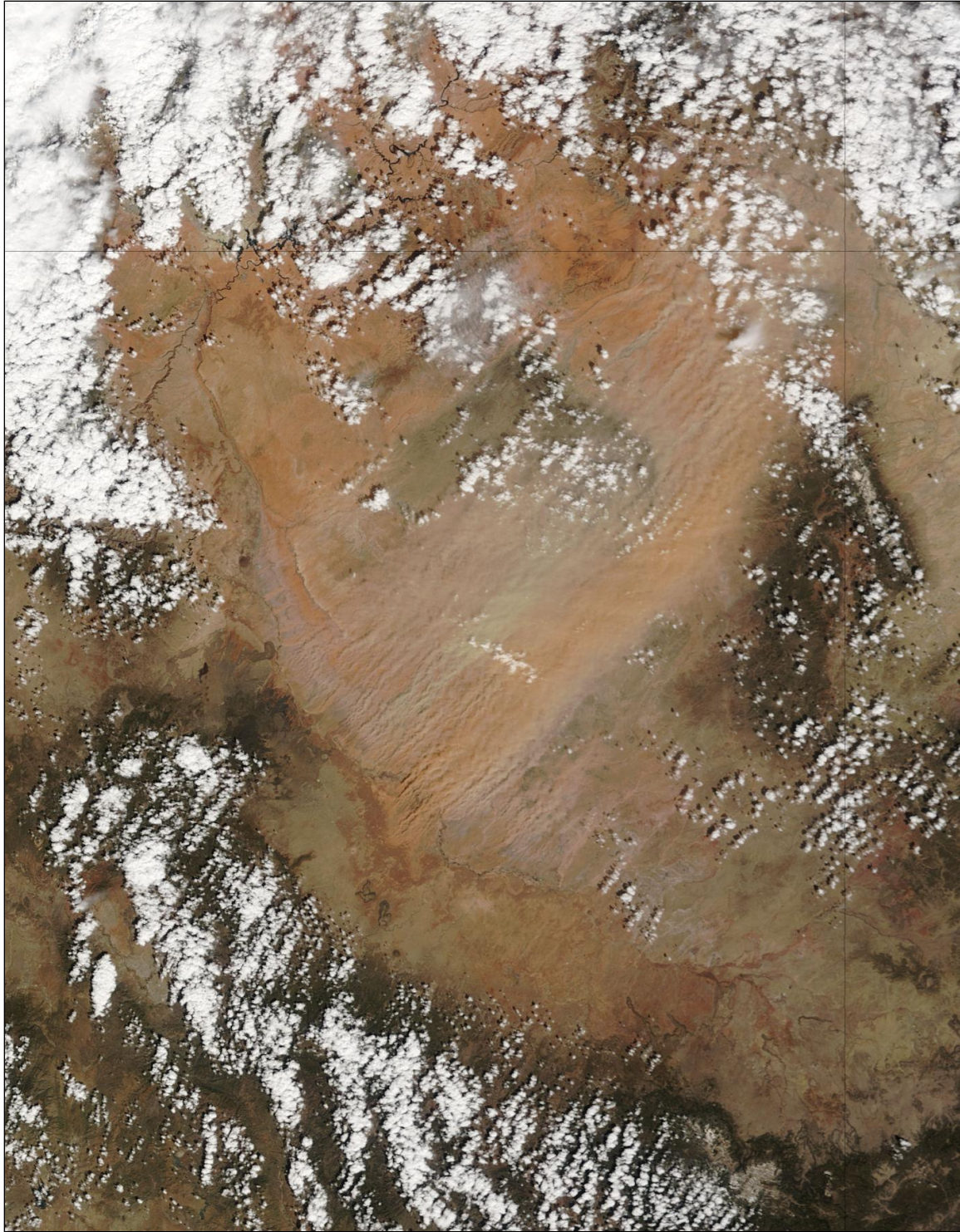


Figure 13. NASA Tera satellite image of a dust storm on April 3, 2009, in southwesterly flow over the Painted Desert of northeastern Arizona (<http://earthobservatory.nasa.gov/IOTD/view.php?id=37791>).

Figure 14 displays the surface weather map for this event (00Z April 4, 2009, or 5 PM MST April 3, 2009). A strong low pressure system in southern Colorado, strong southwesterly winds in the Four Corners area, and the blowing dust symbol (infinity sign) at Farmington (New Mexico) and Cortez (Colorado) are evident in this map. Blowing dust in this region is frequently associated with southwesterly flow.

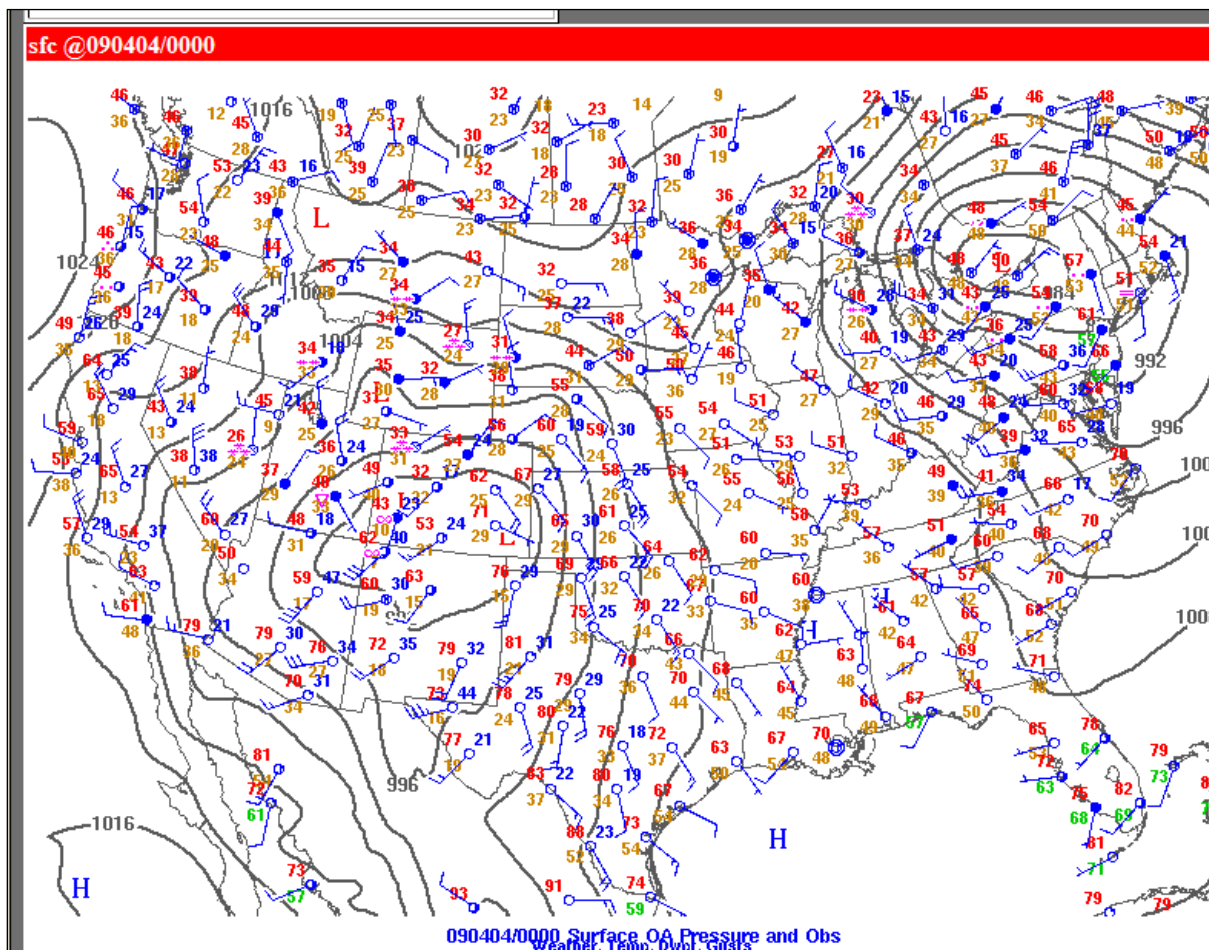


Figure 14. Surface weather map for 00Z April 4, 2009, (5 PM MST April 3, 2009), showing a strong low pressure system in southern Colorado, strong southwesterly winds in the Four Corners area and the blowing dust symbol (infinity sign) at Farmington (New Mexico) and Cortez (Colorado).

A USGS map of the Colorado Plateau in Figure 15 shows the prevalence of eolian or wind-blown sand deposits in southeastern Utah and northeastern Arizona. An analysis of the annual frequency of dust storms (Orgill and Sehmel, 1976) in the western half of the U.S. suggests that portions of eastern and western Utah and northeastern Arizona are source regions for blowing dust (see Figure 16). Soil and sand structures point to the prevalence of southwesterly flow during blowing dust events, and precipitation climatology highlights the potential for blowing dust across much of the region. In addition, an analysis of back trajectories associated with high PM10 concentration events

in Grand Junction discussed in the next section of this document supports the conclusion that soils in Arizona and Utah are likely significant contributors to PM10 measured during many dust storms affecting Grand Junction.

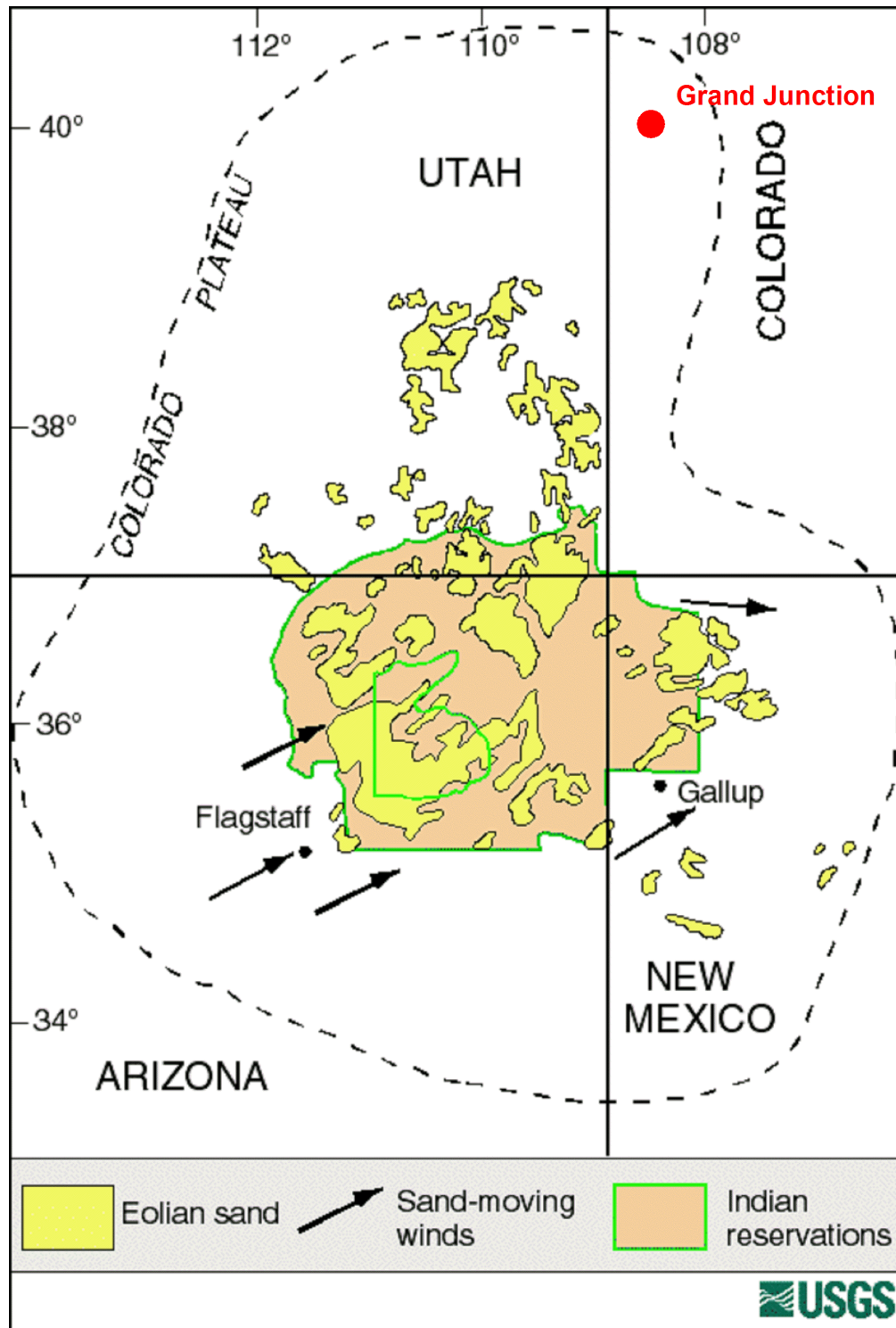


Figure 15. USGS map of eolian sand features on the Colorado Plateau (<http://geochange.er.usgs.gov/sw/impacts/geology/sand/>).

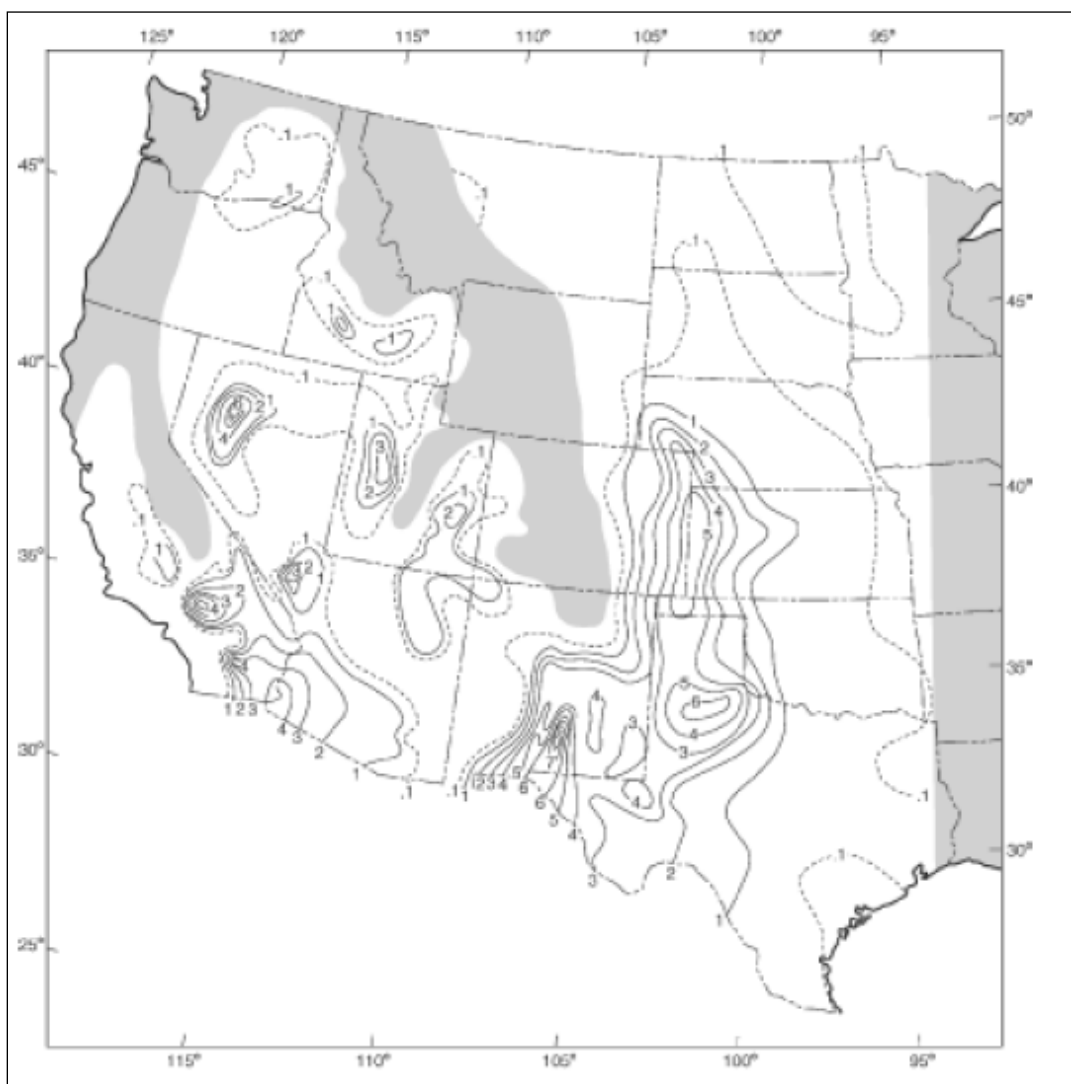


Figure 16. Number of dust storms per year from: Orgill, M.M., Sehmel, G.A., 1976. Frequency and diurnal variation of dust storms in the contiguous USA. *Atmospheric Environment* 10, 813-825.

NOAA HYSPLIT 36-hour back trajectories were calculated for Grand Junction for the eight 24-hour periods from 2004 through early 2009 with the Powell monitor PM<sub>10</sub> concentrations in excess of 75  $\mu\text{g}/\text{m}^3$ , strong regional winds, and dry soils. Trajectories were modeled every 4 hours for each day. Data presented later in this document provides evidence that the moderate to high PM<sub>10</sub> levels on these days were from blowing dust. The 6 back trajectories for each day were calculated for an arrival height of 500 meters using EDAS40 data and model vertical velocities (see: <http://www.arl.noaa.gov/HYSPLIT.php>). The eight days used in the analysis and the Powell monitor concentrations measured on these days are presented in Table 1.

The back trajectories for these high-concentration days are shown in Figure 17. Transport was generally from the west through southwest. A high density of trajectory points is

found in northeast Arizona and southeast Utah. Most of these trajectories in Figure 17 are also consistent with transport from or across suspected or known blowing dust source regions highlighted in Figures 5, 13, 15, and 16.

Table 1. Grand Junction Powell monitor days with concentrations in excess of 75 ug/m3 and blowing dust conditions (from 2004 through early 2009).

Year	Month	Day	Powell 24-hour PM10 concentration in ug/m3
2005	4	19	197.8
2008	4	15	116.1
2008	4	21	103.6
2004	9	3	102
2006	3	3	98.3
2008	5	21	86.7
2008	4	30	83.5
2006	6	7	77.9

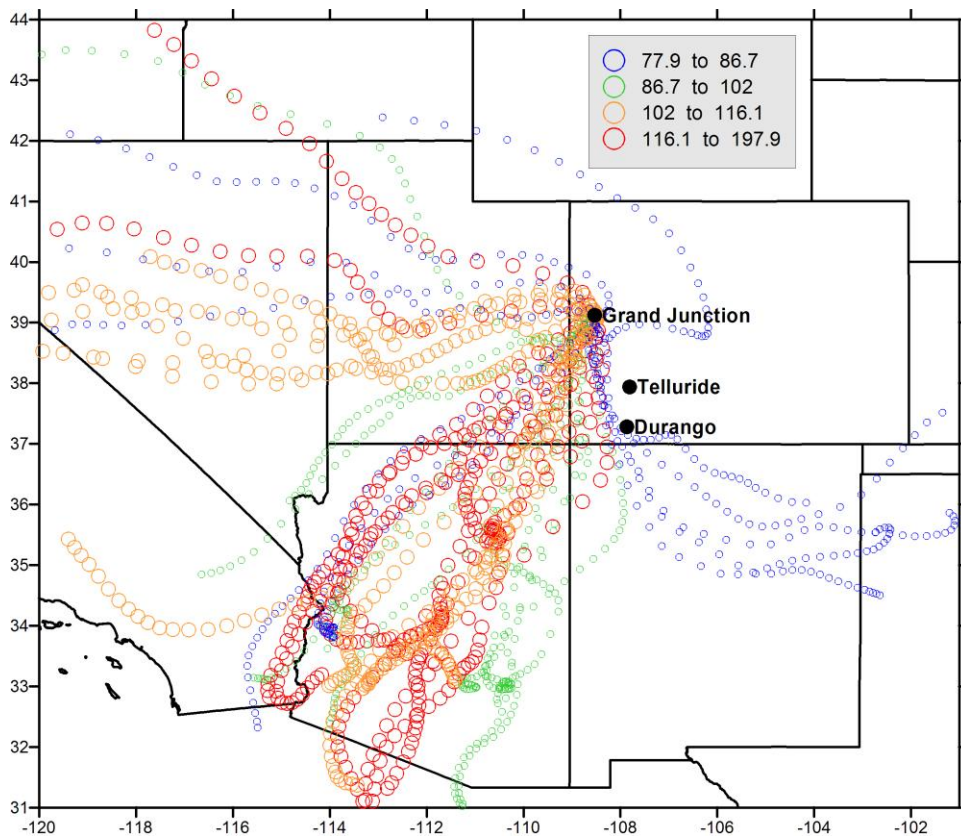


Figure 17. NOAA HYSPLIT 36-hour back trajectories for Grand Junction for those eight 24-hour periods from 2004 through early 2009 with the Powell monitor PM10 concentrations in excess of 75 ug/m3, strong regional winds, and dry soils. Trajectory points are sized and color-coded to reflect 24-hour PM10 concentrations in ug/m3. Trajectories were calculated every 4 hours for each day.

The trajectories in Figure 17 point to the possibility that, at times, dust from Utah and Arizona can have a major impact on Grand Junction and less of an impact elsewhere in western Colorado. This non-homogeneity is possible given the fact that dust storms are frequently organized into discreet plumes from discreet areas that maintain their integrity for long distances. An example of this can be seen in Figure 18 that shows plumes of dust in New Mexico during a windstorm on May 20, 2008.

Figure 19 shows the NOAA HYSPLIT back trajectories for the highest concentration day during the 2004 through early 2009 period: April 19, 2005. Twenty-four hour back trajectories for each hour during the period with high winds (using EDAS40 data and 500-meter arrival heights) show that the back trajectories for Grand Junction were more likely to have crossed the Painted Desert and southeastern Utah than those for Telluride and Durango, which measured lower PM10 concentrations on this day.

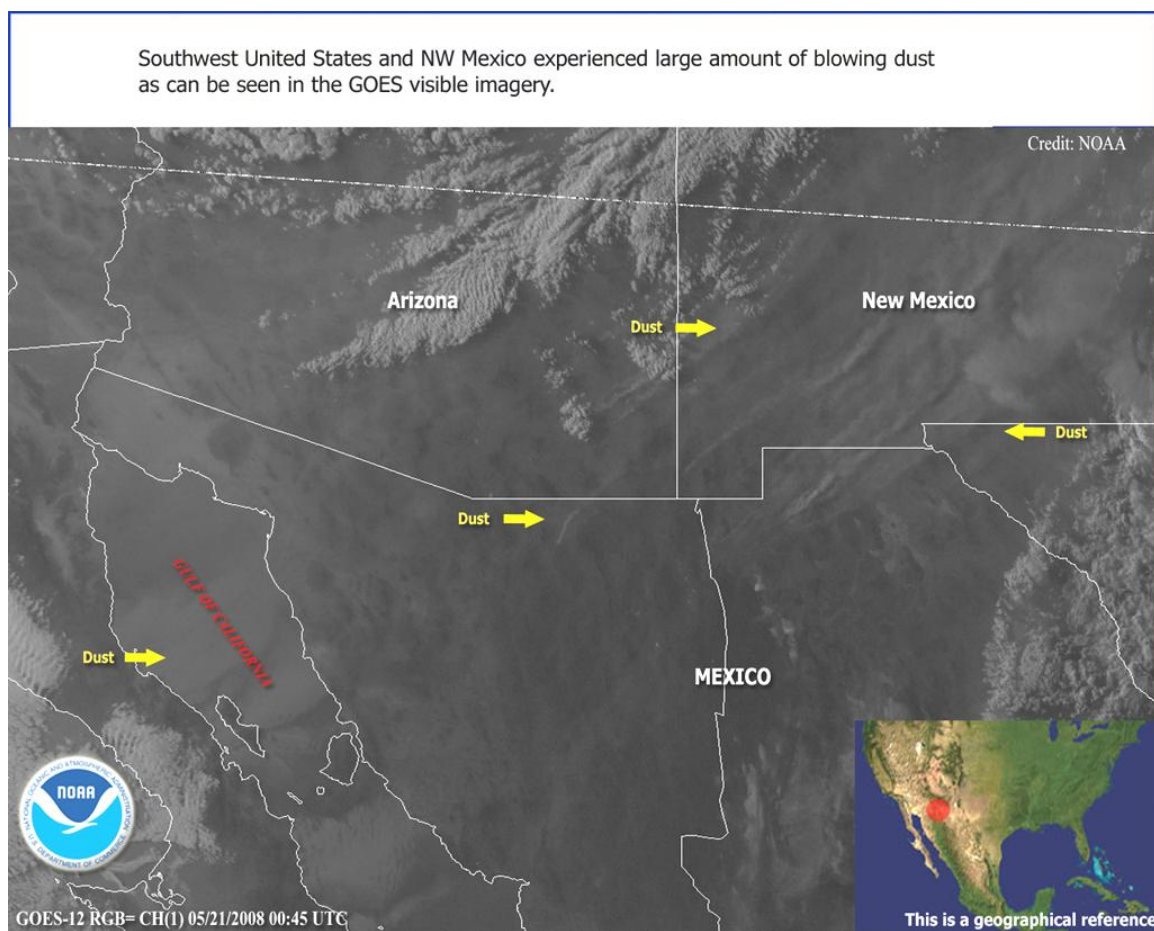


Figure 18. Discreet plumes of blowing dust in New Mexico, Mexico, and Arizona visible in GOES satellite imagery for May 20, 2008 ([http://www.osei.noaa.gov/Events/Dust/US\\_Southwest/2008/DSTusmx142\\_G12.jpg](http://www.osei.noaa.gov/Events/Dust/US_Southwest/2008/DSTusmx142_G12.jpg)).

K-means cluster analysis has been applied to Grand Junction Powell PM10 concentrations, Grand Junction and Painted Desert 30-day total precipitation for each PM10 monitoring day, and Grand Junction and Painted Desert daily maximum wind gust speeds for each monitoring day. K-means cluster analysis is a statistical method for identifying clusters or groupings of values for many variables. For environmental variables, these clusters often represent distinct processes,



conditions, or events. In this case, cluster analysis differentiates PM10 concentrations associated with strong winds, low soil moistures, and blowing dust by providing mean values for these 5 variables for 5 distinct categories of PM10 events. The period of record considered was from January 2004 through March 2009. The Hopi weather station located in the central portion of the Painted Desert was used to represent Painted Desert conditions in northeastern Arizona, and the Grand Junction National Weather Service station was used to represent Grand Junction conditions. The 30-day total precipitation values appear to be a better metric for blowing dust conditions than shorter-term totals.

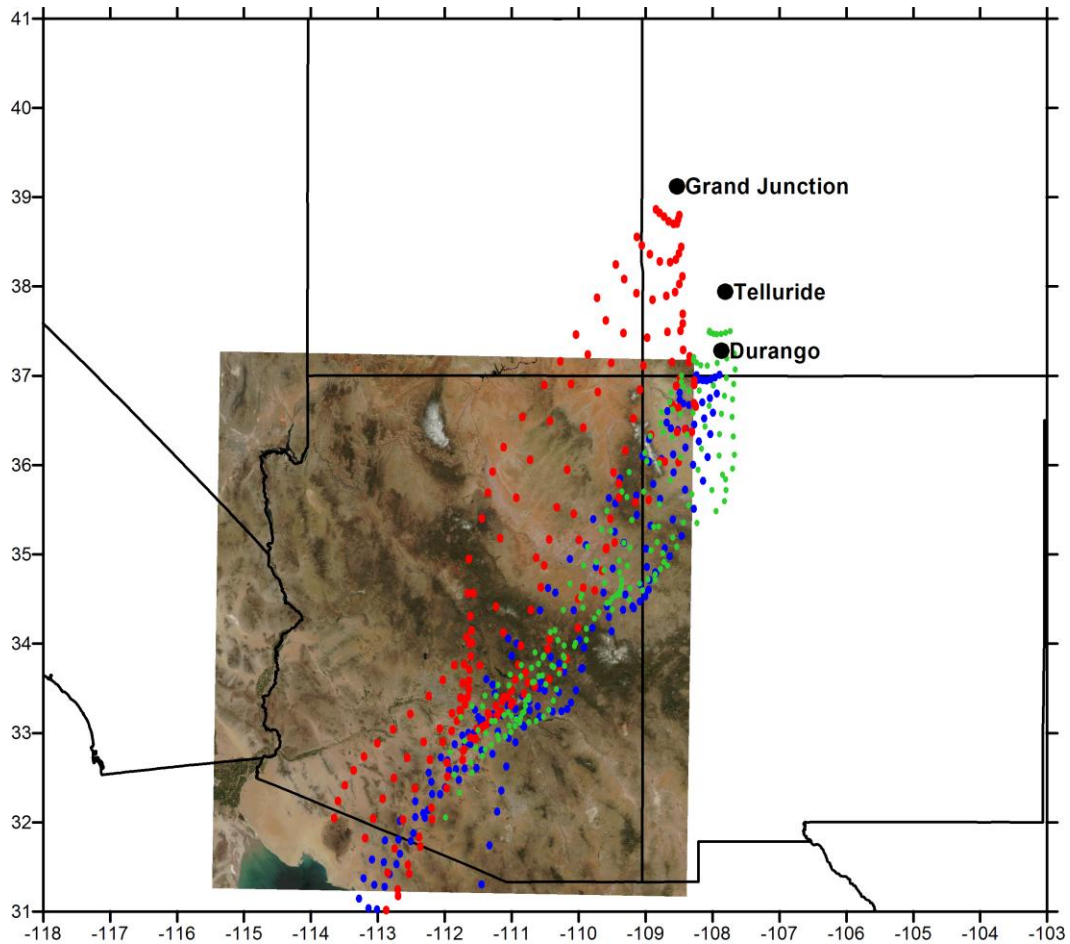


Figure 19. 24-hour NOAA HYSPLIT back trajectories for every hour from 1500 MST to 2200 MST for Grand Junction (red), Telluride (green), and Durango (blue) for the dust storm of April 19, 2005.

The results of the cluster analysis are presented in Table 2 below. Cluster 1 represents high soil moisture conditions, moderate gust speeds, and low PM10 concentrations. Cluster 2 represents very low soil moisture, moderate PM10, and low gust speeds. Cluster 3 represents low soil moisture, moderate gusts, and low PM10. Cluster 4 represents moderate soil moisture, low gusts, and low PM10. Finally, Cluster 5 represents high PM10, high gusts, and low soil moisture. Cluster numbers, Grand Junction Powell PM10 concentrations, and Grand Junction daily maximum gust speeds are plotted in Figure 20.

The data in Figure 20 clearly show that the highest PM10 concentrations tend to occur in Cluster 5 with gusts above 40 mph. The only exceedance in this period occurred on a day with a peak gust of 43 mph. Cluster 2 is likely to be indicative of wintertime inversion conditions with lighter winds and moderately elevated PM10. Figure 21 shows the concentrations and cluster values associated with Hopi station daily maximum gust speeds. The overall pattern is similar. The highest concentration day is associated with a peak gust of 47 mph at Hopi. All of the days/events presented in Figure 17, 19, and Table 1 were classified as Cluster 5.

Table 2. K-means cluster analysis means for Grand Junction PM10 and meteorological variables.

Cluster Variables	Cluster 1 Means	Cluster 2 Means	Cluster 3 Means	Cluster 4 Means	Cluster 5 Means
Powell 24-hour PM10 in ug/m3	24.5	37.3	24.3	21.8	74.9
Hopi Wind Gust in mph	20.8	18.0	32.5	20.7	40.5
Grand Junction Wind Gust in mph	20.4	16.5	31.8	19.6	43.1
Grand Junction 30-day Precipitation	1.7	0.4	0.5	0.8	0.6
Hopi 30-day Precipitation	1.8	0.2	0.5	0.7	0.3
Count	85	120	170	147	24

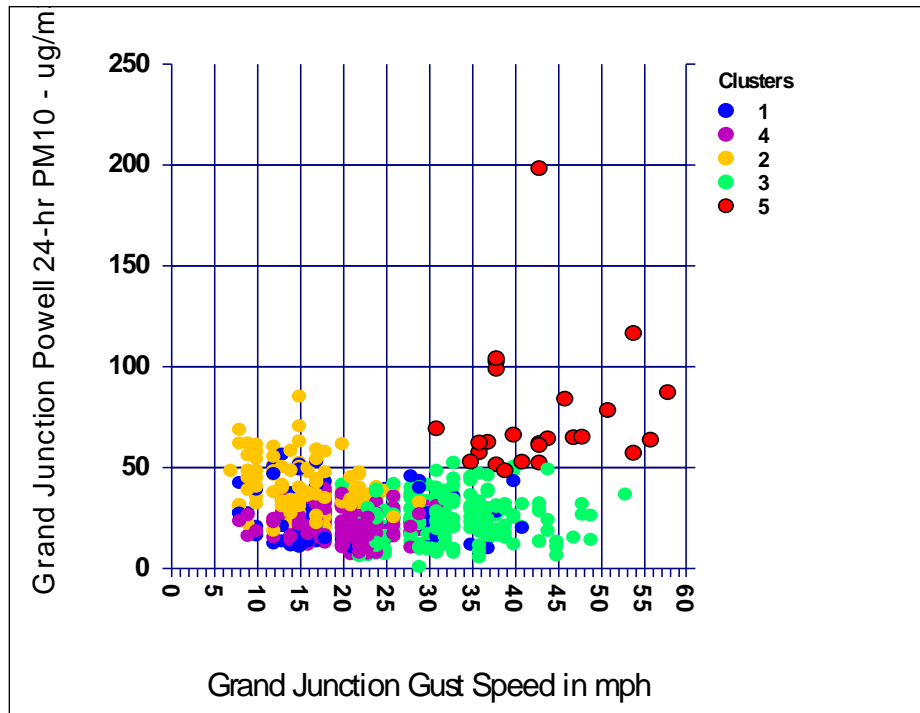


Figure 20. Grand Junction Powell 24-hour PM10 concentrations versus Grand Junction gust speed by cluster.

Figures 22 and 23 show Powell PM10 concentrations versus Grand Junction and Hopi 30-day precipitation totals, respectively, by cluster. The blowing dust group, Cluster 5, is generally associated with 30-day precipitation totals of less than 1.00 inches at Grand

Junction and less than 0.50 inches at Hopi. While this is not proof that the measured dust in Grand Junction is from Arizona, it adds to the weight of evidence that the Painted Desert makes a significant contribution to PM10 concentrations in Grand Junction during many blowing dust events. Of interest in this regard are the two high concentrations (greater than 100 ug/m3) that occurred when Grand Junction 30-day precipitation totals were greater than an inch (see Figure 22). One of these occurred when transport was from the southwest. On this day (April 21, 2008) the NOAA Satellite Smoke Text Archive reported the following (see <http://www.ssd.noaa.gov/PS/FIRE/smoke.html>):

“Blowing dust is seen over most of Utah (and part of western Nevada) and the dust is moving toward the northeast, reaching into northwestern Colorado and southern Wyoming.”

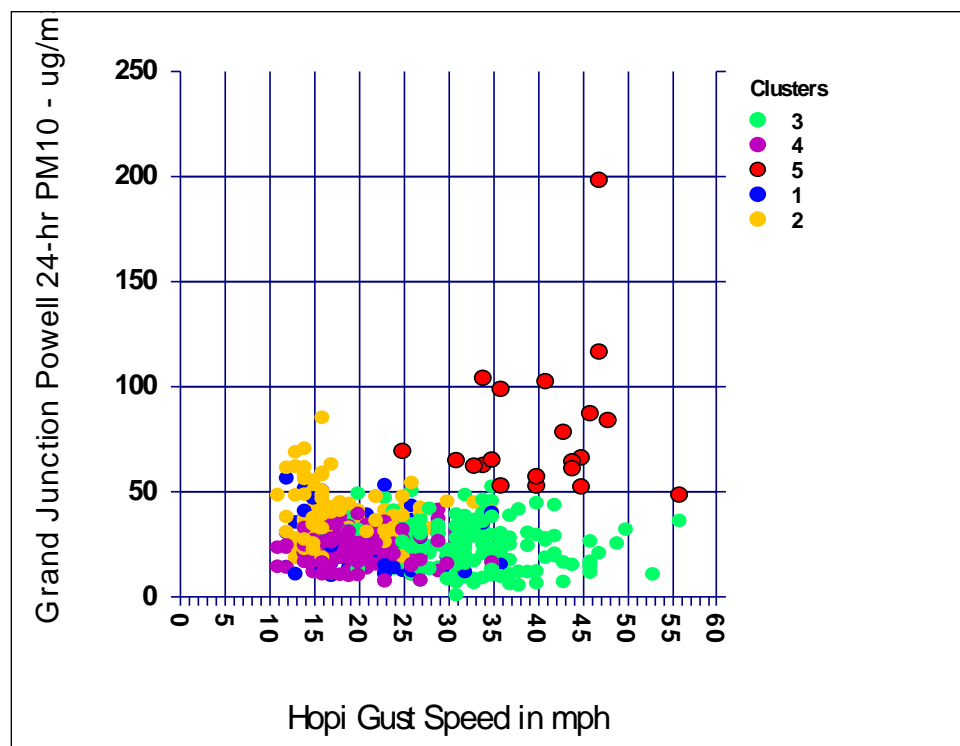


Figure 21. Grand Junction Powell 24-hour PM10 concentrations versus Hopi gust speed by cluster.

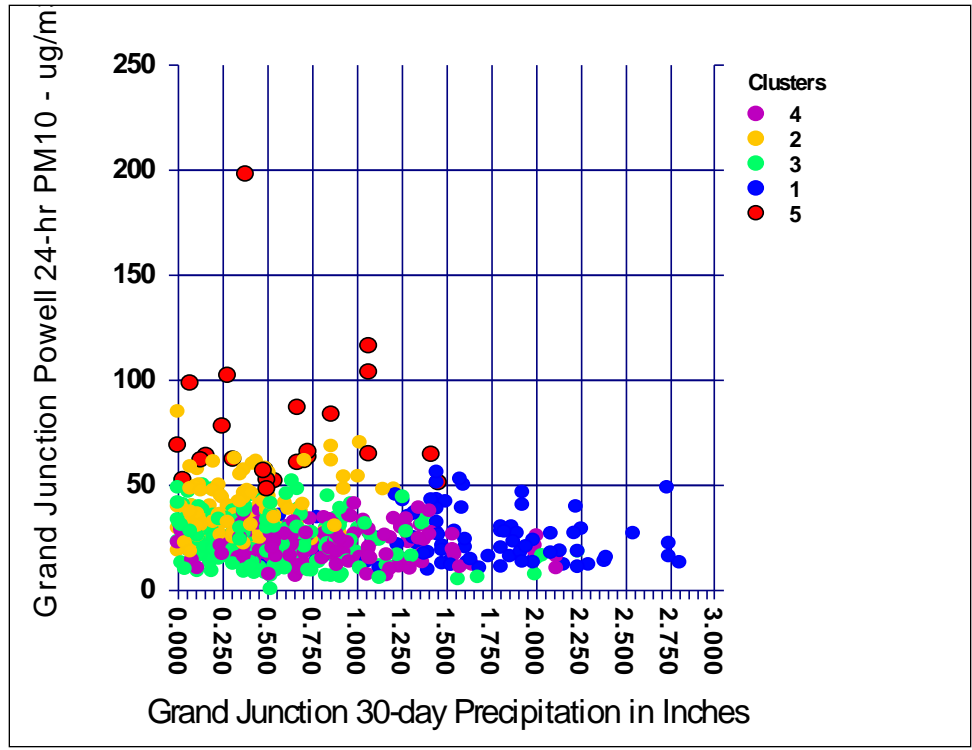


Figure 22. Grand Junction Powell 24-hour PM10 concentrations versus Grand Junction 30-day total precipitation by cluster.

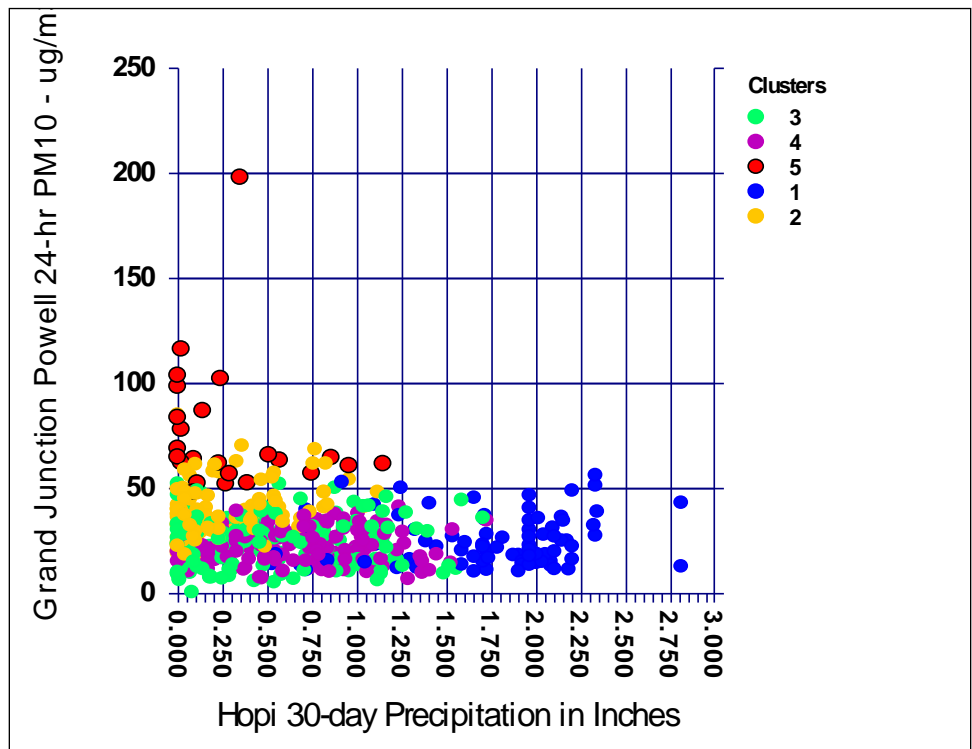


Figure 23. Grand Junction Powell 24-hour PM10 concentrations versus Hopi 30-day total precipitation by cluster.

The other occurred on April 15, 2008, when the flow was from Arizona and southeast Utah. The transport conditions, the discrepancy between high recent precipitation in Grand Junction and low recent precipitation at Hopi for these two days, and, in one case, analyst discussion of what was visible in satellite images suggest that much of the dust might have originated from outside of the Grand Junction environment.

Figure 24 shows Grand Junction Powell 24-hour PM10 concentrations versus peak gust wind directions at the Little Delores RAWs weather station about 25 miles west-southwest of Grand Junction. Grand Junction is situated on the floor of the Grand Valley, a major northwest to southeast trending basin that can force or channel synoptic scale flows. As a result, surface wind directions in Grand Junction may not be useful indicators of the direction of longer-range transport. Little Delores is on the Umcompahgre Plateau, and winds here are more likely to reflect the larger-scale transport directions for the region. This graph indicates that high PM10 at Grand Junction (Cluster 5) is associated with winds from the south-southeast to west-southwest at Little Delores. These directions point to dust sources in southeast Utah and northeastern Arizona. This is further evidence that dust from these areas may make a significant contribution to PM10 measured in Grand Junction during blowing dust events.

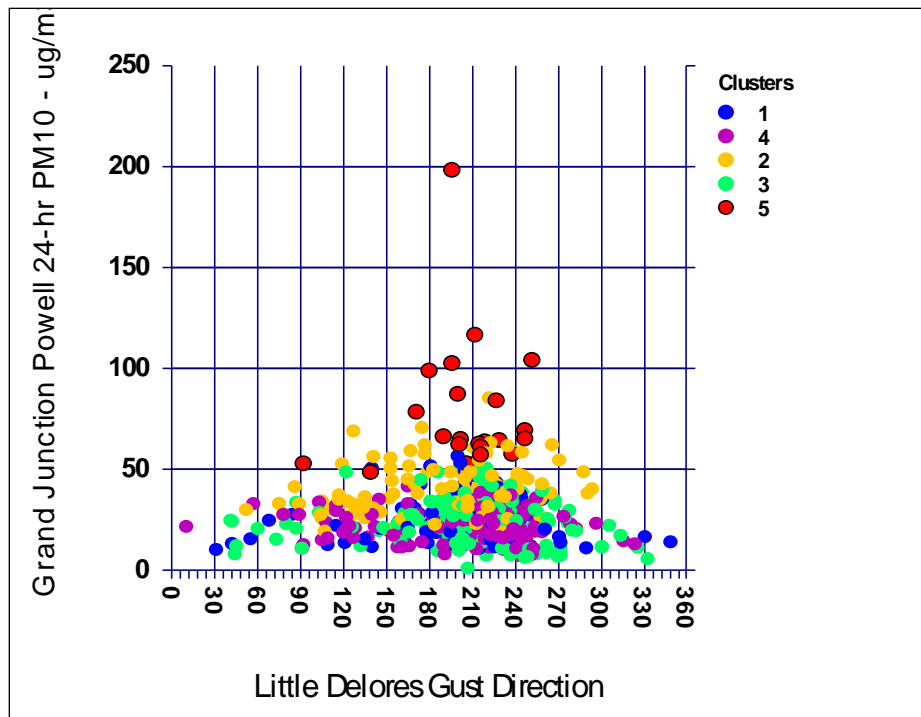


Figure 24. Grand Junction Powell 24-hour PM10 concentrations versus peak gust wind directions at the Little Delores RAWs weather station, by cluster.

Figure 25 presents monthly percentiles for Grand Junction gust speeds. Wind gusts generally considered to be high enough for significant blowing dusts (40 mph or higher) are within the upper 5 to 15 percent during each month of the year. Consequently, these events can be viewed as exceptional rather than normal. Gusts in this category can occur any month of the year, but are most likely in March, April, May and October. Figure 4 shows that in Grand Junction these

are typically among the wettest months of the year. It is in drier years, therefore, that blowing dust may be most prevalent during the spring and fall months. January, February, and June are typically very dry, and might be expected to have a significant proportion of blowing dust events.

Figures 26 and 27 show histograms for Grand Junction and Hopi wind gusts, respectively. The 95<sup>th</sup> percentile gust speed for Grand Junction is 43 mph. For Hopi it is 41 mph. For both sites, it is clear that gusts in the range that is associated with blowing dust are the exception rather than the rule. Cluster analysis also shows that the blowing dust events represent only 4% of the PM10 sample days (from Table 2, Cluster 5 had 24 cases out of a total of 546). The weight of evidence presented in this document clearly suggests that source regions in Arizona and Utah can have a significant impact on PM10 concentrations in Grand Junction during blowing dust events and that these events occur when dry soils are affected by winds of exceptional strength. Control of these sources, which are outside of Colorado, may not be reasonably achievable or possible.

*The precipitation climatology for the Four Corners area indicates that the area can be susceptible to blowing dust when winds are high. Landform imagery shows that northeastern Arizona and southeastern Utah in particular have experienced a long-term pattern of wind erosion and blowing dust when winds have been southwesterly and blowing into western and southern Colorado. Back trajectories, case studies, satellite imagery, and statistical analyses have also shown that northeastern Arizona and southeastern Utah are a significant source for blowing dust transported into Colorado. Elevated PM10 in Grand Junction during windstorms is generally associated with wind gusts of 40 mph or higher at Grand Junction and Hopi in northeastern Arizona and southwesterly flow in Grand Junction. Elevated PM10 in Grand Junction is generally associated with 30-day precipitation totals of less than 1.00 inches at Grand Junction and less than 0.50 inches at Hopi.*

#### **Reference:**

Orgill, M.M., Sehmel, G.A., 1976. Frequency and diurnal variation of dust storms in the contiguous USA. **Atmospheric Environment** 10, 813-825

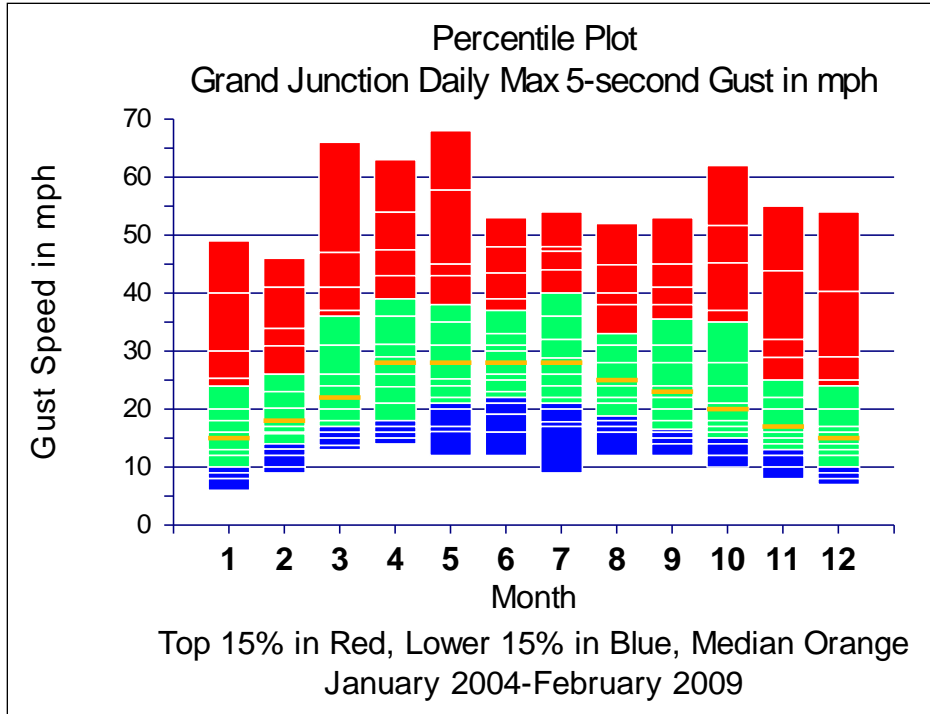


Figure 25. Percentile plot of Grand Junction daily maximum 5-second gust speed in miles per hour showing that gusts of 40 mph or greater always occur within the top 15 percentile speeds for each month of the year.

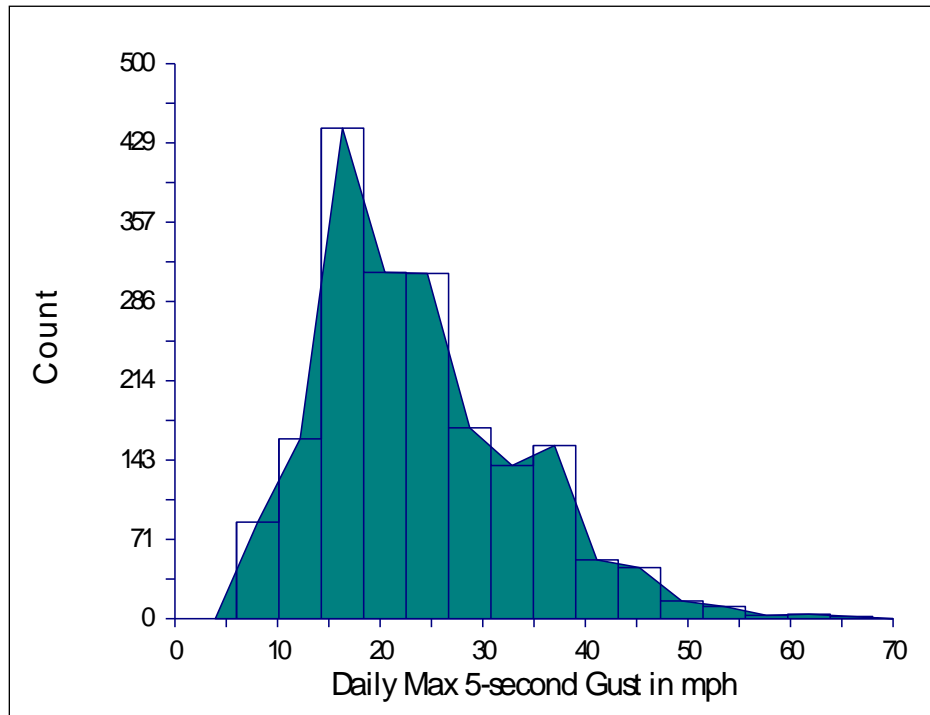


Figure 26. Histogram of daily maximum 5-second wind gusts at Grand Junction based on January 2004 – February 2009.

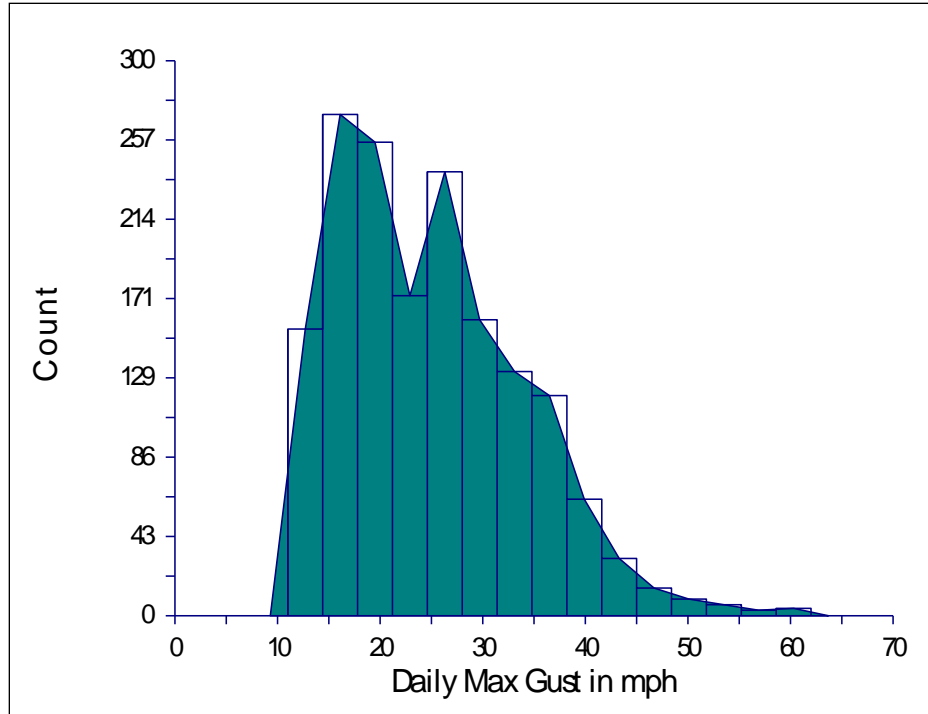


Figure 27. Histogram of daily maximum 5-second wind gusts at Hopi based on January 2004 – February 2009.