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The Spatial and Temporal Impact of the February 26, 2023, Dust Storm on the Meteorological Conditions and Particulate Matter Concentrations Across New Mexico and West Texas

Robinson. C. Mary.[1] Schueth Kaitlin.[2] and Ardon-Dryer Karin.[1]

1 Department of Geosciences, Texas Tech University, Lubbock TX, USA 79409.

2 NOAA/National Weather Service, 2579 S Loop 289, Lubbock, Texas 79423 USA

Correspondence to: Karin Ardon-Dryer (karin.ardon-dryer@ttu.edu)

Abstract. The Southwestern portions of the United States experience dust events frequently due to the arid and semi-arid environments and close proximity to multiple deserts. On February 26, 2023, a dust event was initiated in New Mexico due to strong winds aloft mixing down to the surface. The dust intensified as it moved eastward into West Texas, and turned into a dust storm (visibility < 1 km) in multiple locations. This study examined the meteorological characteristics of this dust storm using 21 meteorological stations and examines the impacts on $PM_{2.5}$ and/or PM_{10} (particulate matter with an aerodynamic diameter < 10 and 2.5 µm) concentrations using 19 air quality stations. The dust event lasted up to 18 hours, and locations experienced dust storm conditions from five minutes up to 65 minutes, with even zero visibility. The highest wind speed and wind gust recorded during the dust were 27.3 m s^{-1} and 37 m s^{-1} respectively. This dust had a strong impact on the air quality in the area, as very high PM values were recorded across the region, and nine of the PM stations exceeded the EPA daily threshold. The maximum hourly $PM_{2.5}$ and PM_{10} concentrations recorded were 518.4 µg m^{-3} and 9,983 µg m^{-3} respectively. For some locations (e.g., Lubbock Texas), these high $PM_{2.5}$ concentrations were the highest ever recorded, highlighting the significance of this dust storm.

1 Introduction

Dust events are a meteorological phenomenon that occurs when dust particles are lifted into the atmosphere by strong winds and reduce visibility. Visibility during dust events range between 1 to 10 km, while dust storms are classified when visibility drops below 1 km (WMO, 2019). Dust events are prominent in arid and semi-arid environments, but can influence other types of environments (Middleton, 2019). The strength of the dust events is dependent on multiple factors. Strong winds are very important for dust initiation, generally caused by a synoptic or convective meteorological disturbance (Kelley and Ardon-Dryer, 2021). Drought conditions (Arcusa et al., 2020) and vegetation cover (Stout, 2001) are also important factors that contribute to dust initiation.

There are multiple hazards associated with dust events. Lower visibility increases the chances of traffic and aviation accidents (Li et al., 2018; Al Kheder and Al Kandari, 2020; Tong et al., 2023). The blowing dust particles can cause abrasions and damage to crops (Middleton, 2019) and health complications for livestock (Mu et al., 2013). High particulate matter (PM)

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concentrations can result in poor air quality (Achakulwisut et al., 2017; Ardon-Dryer and Kelley, 2022; Ardon-Dryer et al., 2023a), leading to different health and wellbeing impacts. Exposure to dust particles during dust events can cause significant health problems such as respiratory issues (Toure et al., 2019; Herrera-Molina et al., 2023), cardiovascular issues (Goudarzi et al., 2017), stroke (Schweitzer et al., 2018), toxemia of pregnancy (Bogan et al., 2021), Valley Fever (Tong et al., 2022; Gorris et al., 2023), and even lead to death (Pérez et al., 2008; Malig and Ostro, 2009). Therefore, the United States Environmental Protection Agency (EPA) and the World Health Organization (WHO) have set standards for PM_{10} and $PM_{2.5}$ (particulate matter with an aerodynamic diameter below 10 and 2.5 µm, respectively) to determine poor air quality conditions. The EPA $PM_{2.5}$ and PM_{10} daily standards are 35 µg m^{-3} and 150 µg m^{-3}, respectively (EPA, 2023), while the WHO updated daily thresholds are 15 µg m^{-3} and 45 µg m^{-3} for $PM_{2.5}$ and PM_{10}, respectively (WHO, 2023).

The southwestern United States is prone to dust events and dust storms. One of the most significant dust storms that have occurred in this region over the last decade occurred on February 26, 2023. This study presents the meteorological conditions that initiated this dust storm and those measured during it, as well as the impact it had on the air quality across New Mexico and West Texas.

2. Methods

2.1 Automatic Surface Observation Station (ASOS)

Automatic surface observation systems (ASOS) are meteorological stations located at most airports that provide meteorological measurements released to the public via Meteorological Aerodrome Reports (METARs). The meteorological measurements include 5-minute to 1-hour measurements of temperature, dew point, relative humidity, wind speed, wind direction, wind gust, pressure, visibility, precipitation, and a Present Weather code. Some stations are continuously monitored by a contracted weather observer while others are mostly automatic (Ardon-Dryer et al., 2023b). The purpose of the weather observer is to back up any instrumentation outages and augment any weather information the ASOS station cannot automatically record. The Present Weather code (entered automatically by the station or manually by the on-duty observer) is an important aspect of the METAR as it provides information on the current weather, such as thunderstorms, fog, hail, and dust events. The classification of the dust event in this study was based on the combination of present weather codes, with the reduction of horizontal visibility (< 10 km) and increase of wind speed (> 6 m s^{-1}), similar to the method used in Kelley and Ardon-Dryer (2021) and Ardon-Dryer et al. (2023b). METAR data from 21 ASOS stations across West Texas and New Mexico were downloaded from the Iowa University Mesonet (Iowa Mesonet, 2023) for February 26-27, 2023, from midnight to 23:59 local time. Table S1 provides information on each of the ASOS stations utilized in this study, while Fig. 1A shows their location.

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2.2 Particulate Matter

Hourly concentrations for PM_{10} and $PM_{2.5}$ from 6 stations across West Texas were taken from the Texas Commission on Environmental Quality (TCEQ, 2023), while hourly PM_{10} and $PM_{2.5}$ concentrations for 13 stations across New Mexico were taken from the New Mexico Environment Department (New Mexico Environmental Department, 2023) or provided by Mr. Patrick Hudson, a Senior Environment Health scientist for the City of Albuquerque. All PM sensors are Federal Equivalent Methods (FEMs). The PM data included hourly measurements for February 26-27, 2023, from midnight to 23:59 local time. Table S2 outlines each of the PM sensors used in this study, while Fig. 1B shows the geographical spread of PM sensors. Six stations only measured $PM_{2.5}$ (5ZS, 6Q, C320, C1025, C1014, and C37) concentrations and four only measured PM_{10} (6ZK, 6ZL, 6ZM, and 6WM) concentrations, while the remaining nine stations had both $PM_{2.5}$ and PM_{10} (6CM, Del Norte HS, Foothills, Jefferson, North Valley, San Jose, South Valley, C49, and C41). The majority of the stations across West Texas contain only $PM_{2.5}$ measurements while other locations including El Paso, Texas, and Albuquerque, New Mexico contain both $PM_{2.5}$ and PM_{10}. Calculations of $PM_{10-2.5}$ and $PM_{2.5}/PM_{10}$ were performed for stations that contained both $PM_{2.5}$ and PM_{10}. Almost all PM sensors had meteorological measurements such as hourly ambient temperature, wind direction, and wind speed. If these variables were not available, meteorological measurements from the nearest ASOS or PM station were used. For example, station 6Q in Las Cruces, New Mexico did not have wind measurements and therefore wind measurements from the closest station (6WM in West Mesa, which is 10.6 km away) were used to supplement the missing data. Additionally, station C320 in Amarillo, Texas did not have wind measurements and therefore wind measurements were taken from the KAMA ASOS station (11.8 km away). Lastly, the San Jose and North Valley (in Albuquerque, New Mexico) stations did not have wind measurements and therefore wind measurements from the South Valley station (5.7 and 5.2 km away, respectively) were used.

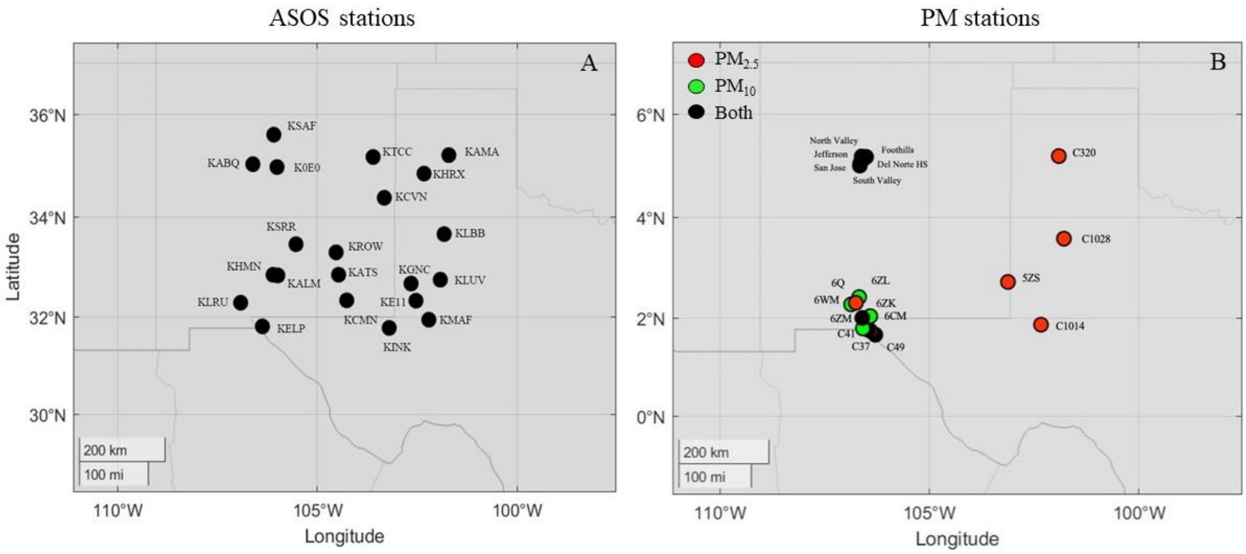

Figure 1. Distribution of ASOS (A) and PM (B) stations spread across New Mexico and West Texas used in this study.

2.3 Meteorology Overview Maps

The synoptic maps were made using the North American Rapid Refresh version 3 (RAPv3) with a horizontal grid spacing of 13 km and 51 vertical levels (Benjamin et al., 2016). The RAPv3 has a one-hour assimilation frequency with only the initialization hours and no forecast hours used in this study. Each synoptic map was made using the Metpy python package (May et al., 2023), with several meteorological variables layered.

The Geostationary Operational Environmental Satellite (GOES) imagery over eastern North America (GOES-East, also known as GOES-16) encompasses the research area and provides 5-minute updates. The satellite data was pulled from Amazon Web Services and plotted with the GOES-2-Go python package (Blaylock, 2022). The Dust RGB derived satellite product was utilized to highlight the progression of the dust throughout the dust event. The Dust RGB, which consists of band differencing and IR thermal channel, allows dust to be observed through satellite imagery during both the day and night. The density of the dust particles was inferred by the range of the magenta/pink color. This method is commonly used to detect and identify dust events (Fuell et al., 2016; Ardon-Dryer et al., 2023b).

Nexrad WSR-88D radars were also used to visualize thunderstorms and mesoscale boundaries. The data from various radars across the Southern Plains (Lubbock, Midland/Odessa, Amarillo, Clovis, San Angelo, Dyess Air Force Base, and Frederick) was retrieved via Amazon Web Services to plot a mosaic radar image using a Pyart python package (Helmus and Collis, 2016).

3. Results

3.1 The Meteorological Conditions Resulted in the Formation of the Dust Storm

During the morning and afternoon hours on February 26, 2023, a robust and slightly negatively tilted 500 mb closed low ejected eastward from Southern California across the Four Corners region of the United States (Fig. 2A). The right exit region (Fig. 2B) of the nearly 51-62 m s^{-1} (100-120 knot) 500 mb jet streak, associated with the upper low, entered the Chihuahuan Desert region of Mexico, Texas, and New Mexico around early to mid-afternoon (18:00 local time; 00:00 UTC). A stacked 700 mb trough axis brought a 31-36 m s^{-1} (60-70 knot) jet axis over the aforementioned area at the same time (data not shown). In conjunction with the approaching upper low, intense surface cyclogenesis developed along the leeward side of the Rockies before sliding eastward across the Oklahoma Panhandle and then pushing farther northeast into Kansas by midnight. Warm air advection from southerly surface winds led to sufficient daytime heating and mixing of the strong winds aloft to the surface. In addition, the south winds advected low level moisture into the Southern Plains with a weak dryline present and near 40-to-

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50-degree dewpoints east of the boundary (Fig. 2C). Instability in the atmosphere combined with this boundary led to thunderstorm development across the far southern Texas Panhandle through the afternoon hours (starting around 17:00 local time; 23:00 UTC). As the upper level closed low continued to swing eastward through the evening, so did the corresponding north-south extending Pacific cold front. The front eventually caught up with the dryline just east of Lubbock where additional storms initiated along the colliding boundaries as shown in the radar reflectivity (Fig. S1), along with both of the boundaries (dryline and Pacific cold front) at 17:00 Central time for Texas (23:00 UTC). These thunderstorms created very strong wind gusts up to 51 m s^{-1} across West Texas (shown in Fig. S2).

The south-southwest winds began to increase through the morning hours and into the afternoon, with several severe wind gusts (> 26 m s^{-1}) reported across eastern New Mexico and West Texas. Multiple National Weather Service (NWS) offices across the Southern High Plains and Southern Great Plains highlighted the wind potential through products such as High Wind Warnings and Wind Advisories. As the south-southwest surface winds increased, dust particles began to be lofted and started to cause a reduction in visibility. When the Pacific front began to move eastward across New Mexico, winds began to shift out of the west and continued to exhibit strong to severe wind speeds. Additional dust particles were lifted along the quick moving boundary. Both satellite imagery (Fig. S3) and radar reflectivity (Fig. S1) reveal the evolution and intensity of the dust along this front during the afternoon hours across West Texas. One of the biggest factors that made this event an anomaly was the already advected dust across a large area (~4×10^5 km^2) prior to the frontal passage due to the strong to severe winds from the south-southwest during the morning hours. Some of the locations mentioned throughout this study (e.g., Lubbock, Texas) may experience both synoptic and convective disturbances, which may assist in the duration of high wind gusts along with the severity of dust in the region.

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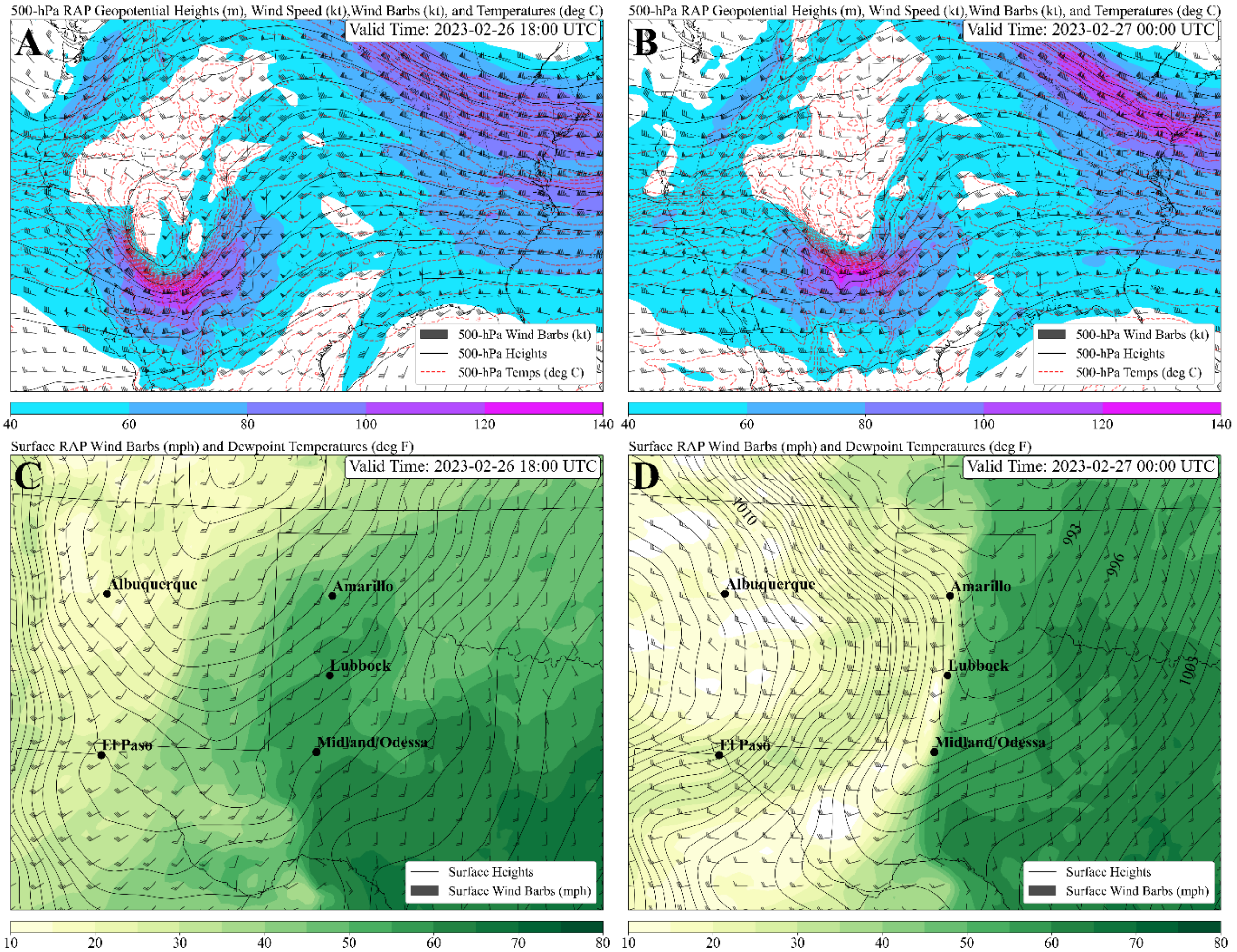

Figure 2. 500 mb geopotential heights (m), wind speed (kt), wind barbs (kt), and temperature (°C) for February 26 at 18:00 UTC, 12:00 central time (A) and 27 at 00:00 UTC, 18:00 central time (B) and surface wind barbs (mph) and dew point temperature (°C) for February 26 at 18:00 UTC, 12:00 central time (C) and 27 at 00:00 UTC, 18:00 central time (D).

3.2 Meteorological Observations During the Dust Storm

Observations of wind speed, wind gust, and visibility were collected from each of the 21 active ASOS units. ASOS units with on-duty observers (such as KLBB for Lubbock, KELP for El Paso, and KABQ for Albuquerque) had present weather codes that represent dust (e.g., blowing dust: BLDU, vicinity blowing dust: VCBLDU, and dust storm: DS), while the remaining automated ASOS units had a present weather code of haze (HZ). Observations of visibility showed that the dust event initiated in New Mexico during the morning hours and was first observed in Texas around noon local time. The first report of dust across New Mexico in the present weather code was in Albuquerque (KABQ) at 10:15 local time, with BLDU reported despite

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visibility being > 10 km. Visibility was reduced to < 10 km at 10:21 local time, making it officially a dust event based on the World Meteorological Organization (WMO, 2019). According to the WMO (2019), dust events should be defined based on visibility < 10 km; although we determined the duration of the dust based on times when dust particles were present in the air, based on duration when visibility was below 16.1 km (maximum visibilities reported in the ASOS; ASOS User's Guide, 1998). Based on this definition the duration of the dust event across New Mexico lasted from 25 minutes (KSAF in Santa Fe) up to eight hours (KALM in Alamogordo-White), while across Texas, it lasted from three hours (KE11 in Andrews) up to 16 hours (KLBB in Lubbock). Calculations of duration based on WMO (2019) criteria when visibility was < 10 km were similar range. Duration ranged from 20 minutes (Santa Fe, New Mexico) up to 13 hours (Lubbock and Lamesa, Texas). The last report of dust was on February 27 at 03:55 local time at the KLBB station in Lubbock, Texas. This dust event lasted much longer than previous dust events reported in the area (Doggett IV et al., 2002; Kelley and Ardon-Dryer, 2021) and also compared to those reported in Arizona (Nicking and Brazel, 1984; Raman et al., 2014).

The wind speed measured during the dust event ranged from 9.7 m s^{-1} (KHMN at Alamogordo, New Mexico) up to 25.2 m s^{-1} (KSRR at Alto, New Mexico) and wind gusts measured from 15.4 m s^{-1} (KLUV at Lamesa, Texas and KMAF at Midland, Texas) up to 34 m s^{-1} (KSRR at Alto, New Mexico). The highest wind speed and wind gust (27.3 m s^{-1} and 37 m s^{-1} respectively) were recorded in New Mexico (KTCC at Tucumcari) at 12:20 local time. Information from each ASOS station including duration, maximum wind speed, and wind gust at the beginning and during the dust event can be found in Table S3. Most of the wind speeds at the beginning of the dust event (>10.5 m s^{-1}) were above the wind speed reported by Stout and Arimoto (2010) as a threshold for dust to be lofted. The wind speeds during this event were in the range of wind speeds reported in Hagen and Woodruff (1973) for dust events that occurred in the Great Plains in the 1950s. All 21 ASOS locations examined, showed wind speed values at the beginning of the dust event that were higher than the wind speed reported by Zobeck and Van Pelt (2006) during the March 2003 dust storms in the region. Similar maximum wind speed values were measured in the area during the December 15, 2003, dust storm (Lee et al., 2009). However, much higher wind speeds were measured in the July 2014 dust storm in Phoenix, Arizona (Eagar et al., 2017), perhaps since the one in Arizona was mainly convective.

Although all the ASOS units in the region experienced dust event conditions, not all experienced conditions of dust storms (visibility < 1 km), as shown in Table S3. A total of eight ASOS stations (five in New Mexico and three in Texas) reported visibility below 1 km and therefore experienced dust storm conditions. The remaining stations had a reduction in visibility but not below 1 km (shown in Table S3). The visibility values of stations experiencing dust storm conditions ranged from 0.8 km down to 0 km, as shown in Fig. 3. The duration of the dust storm conditions (when visibility was < 1 km) ranged from 5 minutes (KROW at Roswell, New Mexico), up to 65 minutes (KHRX at Hereford, Texas). The ASOS station in Lubbock, Texas (KLBB) reported 0 km visibility for a continuous 10 minutes, which highlights the severity of this dust storm. The western stations in New Mexico experienced dust storm conditions around noon when wind speeds reached their maximum. Meanwhile, the eastern stations (mainly those in West Texas) experienced dust storm conditions in the late afternoon when

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the front collided with the dryline. Satellite observations from the GOES-16 Dust RGB (shown in Fig. S3) highlight the high concentrations of dust particles during these times. Satellite observations from GOES-16 showed that the dust particles from this dust storm made it to Oklahoma, Kansas, and Arkansas (data not shown). Previous studies also found that dust particles from this region are capable of traveling to neighboring states including Oklahoma (Park et al., 2007; Kandakji et al., 2020) and as far as the northeastern states, even into Canada (Doggett IV et al., 2002; Park et al., 2007).

This region of New Mexico and West Texas is prone to dust events (Park et al., 2009; Kandakji et al., 2020; Kelley and Ardon-Dryer, 2021), due to the proximity to the Chihuahuan Desert and many agriculture fields (Rivera Rivera et al., 2009; Lee et al., 2012). Studies found that many of the dust events in this region occur during December – May and more so in the springtime months (Stout, 2001; Novlan et al., 2007; Rivera Rivera et al., 2009). Severe dust storms have been observed in the past in this region (Lee and Tchakerian, 1995; Lee et al., 2009). Lee et al. (2009) analyzed the December 15, 2003, dust storm that started in New Mexico and moved eastward through West Texas. The dust storm was caused by an upper low-pressure system that brought in a cold front. During this dust storm, wind gusts in Lubbock, Texas were over 28 m s^{-1} and visibility was reduced to 0.4 km. In El Paso, Texas the minimum visibility reported was 2.8 km and wind gusts reached 23 m s^{-1} (Lee et al., 2009). The DS conditions during the event presented in this work were more severe compared to the DS on December 15, 2003, presented in Lee et al. (2009). The conditions of the current DS were also stronger (higher maximum wind gust and lower visibility values) than those reported in El Paso during the April 15, 2003, dust storm (Park et al., 2009; Rivera Rivera et al., 2009). Strong dust storms with similar meteorological conditions have been observed in other locations across the United States, including Arizona (Raman et al., 2014; Kim et al., 2017) and Utah (Nicoll et al., 2020). In Utah, Nicoll et al. (2020) examined a dust storm that occurred on April 14-15, 2015. An intense intermountain cyclone caused high wind gusts (up to 35 m s^{-1}) and dust storm conditions, with visibility down to 0.4 km. In Arizona, dust storms are common (Lei et al., 2016; Ardon-Dryer et al., 2023b). One of the largest and most famous dust storms recorded in Arizona (near Phoenix and Tucson), occurred on July 5, 2011 (Raman et al., 2014; Vukovic, et al., 2014; Lader et al., 2016). This dust storm developed due to thunderstorms (Lader et al., 2016) and had a peak wind gust of 29 m s^{-1} and visibility of 0 km (Raman et al., 2014; Vukovic, et al., 2014), similar to the conditions presented in this work.

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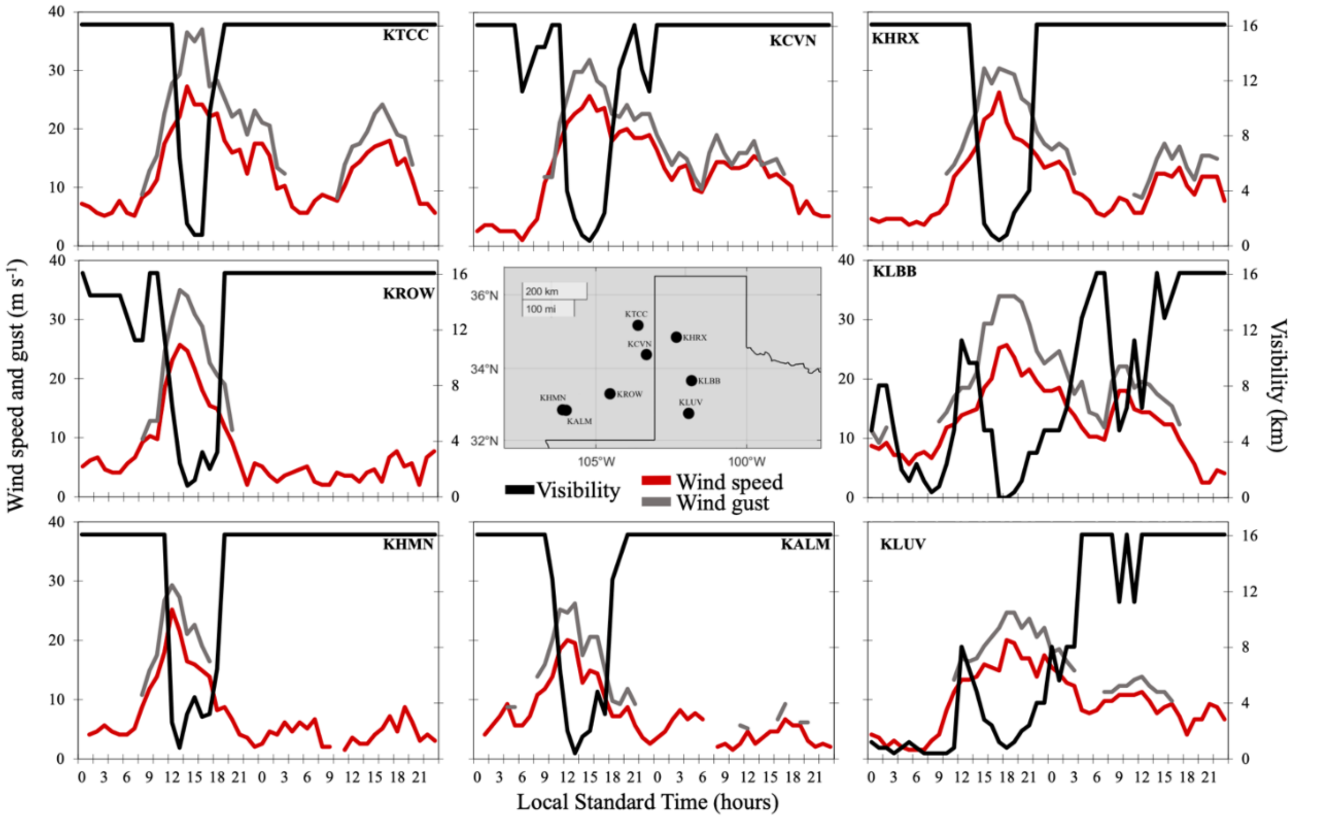

Figure 3. Observations of wind speed (red) and wind gust (gray) as well as visibility (black) from ASOS stations that experienced dust storm conditions (visibility < 1 km).

3.3 Impact of Dust Storm on PM Concentrations and Air Quality

Nineteen air quality stations were active across the New Mexico and West Texas region during the dust event presented in this study. Each of the PM stations showed an increase in PM values during the dust event, but not all PM stations had a strong impact by the dust as indicated by the varying hourly PM measurements across the region (Fig. 4). The maximum PM values at the peak of the dust for each station ranged from 13.6 μg m^{-3} (Foothills station at Albuquerque, New Mexico) up to 518.4 μg m^{-3} (station C1028 at Lubbock, Texas) for $PM_{2.5}$ and from 197.5 μg m^{-3} (Foothills station at Albuquerque, New Mexico) up to 9,983 μg m^{-3} (station 6ZM at Desert View, New Mexico) for PM_{10}. Details for each station can be found in Table S4. High PM concentrations during dust storms are common in this area (Ardon-Dryer et al., 2022a,b; Kelley and Ardon-Dryer, 2021), along with other locations across the United States (Hahnenberger and Nicoll, 2012; Lei et al., 2016; Achakulwisut et al., 2017) and around the world (Ardon-Dryer and Levin, 2014; Mamouri et al., 2016; Arhami et al., 2017).

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The duration when dust particles were in the air based on increase in PM values was similar to the duration based on visibility, mentioned in section 3.2. These durations based on PM values varied, some stations had an increase in PM values for a duration of 2 hours, while others for up to 12 hours. Despite the reduced visibility to 1.6 km during the dust event at the Albuquerque ASOS (KABQ), most of the PM stations in the area witnessed a small increase in $PM_{2.5}$ but a more significant increase in PM_{10} concentrations (as can be seen in Fig. 4 and Table S4). A spatial impact of the dust was also observed in Albuquerque, as stations in the southern part of Albuquerque had higher PM concentrations (with a stronger increase) compared to those located in the northern part of Albuquerque. When calculating the increased ratio of PM, which is indicated by the ratio of PM concentrations at the peak of the dust compared to the time before the dust, results showed an increase in PM across the region, even across Albuquerque. $PM_{2.5}$ concentrations during the dust event were on average 13.5 times higher compared to the time before the dust event (ratios vary from 3.0 up to 39.8), while for PM_{10} the concentration during the dust event was on average 216.9 times higher compared before the dust event (ratios vary from 11.3 up to 1426.1).

Higher hourly $PM_{2.5}$ concentrations for Lubbock, Texas (518.4 µg m^{-3}) were measured during this dust storm compared to those measured during the dust storm of December 15, 2003, when $PM_{2.5}$ concentrations reached 485.5 µg m^{-3} (Lee et al., 2009; Park et al., 2009). The hourly $PM_{2.5}$ concentration measured in Lubbock was higher than any hourly $PM_{2.5}$ concentration recorded over the last 20 years. However, daily values during this dust storm were lower compared to the highest daily record for Lubbock (Kelley et al., 2020). Higher hourly $PM_{2.5}$ and PM_{10} concentrations were measured in El Paso, Texas during previous dust storms (December 15, 2003, and April 15, 2003) compared to the one presented in this work (Rivera et al., 2009; Park et al., 2009). Observations of $PM_{2.5}$ and PM_{10} concentrations in this study were in a similar range to PM concentrations in other dust storms measured across the United States. For example, Nicoll et al. (2020) examined a dust storm that occurred across the Great Basin region of Utah in April 2015, where $PM_{2.5}$ and PM_{10} hourly concentrations reached 297.8 µg m^{-3} and 890 µg m^{-3}, respectively. Measurements of PM concentrations during various dust storms in Arizona also showed similar values of PM in comparison to the results of this dust event (Raman et al., 2014; Kim et al., 2017). There were some dust events in Arizona with much higher PM hourly concentrations (Eagar et al., 2017; Hyde et al., 2018) compared to this study. For example, Raman et al. (2014) reported high PM values in Phoenix Arizona during a convective dust event, with hourly maximum $PM_{2.5}$ and PM_{10} concentrations of 907 µg m^{-3} and 1974 µg m^{-3}, respectively. These different PM values could be attributed to the differences in regions and the cause of the dust event.

Since EPA and WHO refer to air quality levels based on daily values, daily average concentrations for February 26 were calculated for each of the PM stations (shown in Table S4). The calculation of daily values for each station showed a wide range of values. $PM_{2.5}$ daily concentrations ranged from 3.8 ± 2.7 µg m^{-3} (Foothills station at Albuquerque, New Mexico) up to 69.3 ± 121.3 µg m^{-3} (station C1028 at Lubbock, Texas), while PM_{10} daily concentrations ranged from 28.1 ± 42.3 µg m^{-3} (Foothills station at Albuquerque, New Mexico) up to 748.4 ± 2089.7 µg m^{-3} (station6ZM at Desert View, New Mexico). Only

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nine PM stations (three $PM_{2.5}$ and six PM_{10}) exceeded the EPA daily thresholds (35 μg m^{-3} for $PM_{2.5}$ and 150 μg m^{-3} for PM_{10}), indicated by the red daily average values in Fig. 4. Five of them were in southern New Mexico (6ZK, 6ZM, 6ZL, 6CM, and 6WM) and the remaining four were in West Texas (Lubbock, Amarillo, and two in El Paso). The stations whose PM_{10} daily values exceeded the EPA daily threshold ranged from 205.1 ± 320.9 μg m^{-3} (station C49 at El Paso, Texas) up to 748.4 ± 2089.7 μg m^{-3} (station 6ZM at Desert View, New Mexico). $PM_{2.5}$ daily values for stations that exceeded the EPA daily values ranged from 36 ± 39.9 μg m^{-3} (station C320 at Amarillo, Texas) up to 69.3 ± 121.2 μg m^{-3} (station C1028 at Lubbock, Texas). Analysis based on the new WHO thresholds for $PM_{2.5}$ (daily values of 15 μg m^{-3}) and PM_{10} (daily values of 45 μg m^{-3}), showed that nine of the $PM_{2.5}$ stations (60%) and 11 of the PM_{10} stations (84.6%), were above the WHO thresholds considered these locations experience a bad air quality level.

Some stations had low PM daily values, even below the EPA daily threshold, but high hourly values were measured during the time of the dust. On average hourly values were 2.9 times higher than the daily average values (shown in Table S4). For example station 5ZS in Hobbs, New Mexico had a $PM_{2.5}$ daily average concentration of 21.1 ± 33.7 μg m^{-3}, while the concentrations during the dust were 4.7 times higher (averadge of 99.7 ± 57.1 μg m^{-3}). Station 6Q in Las Cruces, New Mexico had $PM_{2.5}$ average concentration of 107 ± 28.3 μg m^{-3} which was 5.7 times higher than the daily average value (18.8 ± 28.8 μg m^{-3}). The $PM_{2.5}$ daily average concentration for C1028 in Lubbock, Texas, was 69.3 ± 121.3 μg m^{-3} while the average concentration during the dust was 2.2 times higher (153.9 ± 134.7 μg m^{-3}). Similar observations were found for PM_{10} stations. For example, the station Jefferson in Albuquerque, New Mexico had a daily PM_{10} concentration of 76.7 ± 199.3 μg m^{-3}, while the average concentration during the dust was 332.5 ± 435.8 μg m^{-3}, 4.7 times higher. Station 6ZM in Desert View, New Mexico, had PM_{10} daily average concentration of 748.4 ± 2089.7 μg m^{-3}, while the average PM_{10} concentration during the dust was 2.3 times higher (1752.6 ± 3039 μg m^{-3}). These examples highlight the fact that daily values might mask the tru exsposure and perhaps impact dust events might have, perhaps there is a need to find a better way to examine the impact of dust on air quality as suggested in Ardon-Dryer et al. (2023a).

Some studies found a correlation between wind speed and PM concentrations (Karami et al., 2017; Kim et al., 2017), while others could not find a strong relationship between the two (Kelley and Ardon-Dryer., 2021). Comparison of hourly PM concentrations and wind speeds for February 26, showed a low linear correlation for most of the stations (Table S4). For stations that measured $PM_{2.5}$ concentrations, R^2 values for linear regression ranged from 0.01 (North Valley station at Albuquerque, New Mexico) up to 0.47 (station 5ZS at Hobbs, New Mexico, and station C49 at El Paso, Texas). For stations that measure PM_{10} concentrations, R^2 values ranged from 0.3 (Jefferson station at Albuquerque, New Mexico) up to 0.6 (station C49 at El Paso, Texas). Only three PM_{10} stations (station C49 at El Paso, Texas, station 6CM at Anthony, New Mexico, and North Valley station at Albuquerque, New Mexico) had high linear correlation values ($R^2 \geq 0.5$). Other regression models were also examined, to potentially find a better regression value between wind speed and PM values. A Polynomial regression (with

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2nd-degree polynomial) presented much higher R^2 values compared to a linear regression. With R^2 values that ranged from 0.37 up to 0.9 for $PM_{2.5}$ and from 0.18 up to 0.9 for PM_{10}. 73.3% of the $PM_{2.5}$ stations and 84.6% of the PM_{10} stations had $R^2 \geq 0.5$ (see R^2 values in Table S4).

Next, the impact of this dust event on the presence of coarse particles (PM_{10}-$PM_{2.5}$) and the ratio between $PM_{2.5}/PM_{10}$ was examined. Across the study area, there were only nine stations that measured both $PM_{2.5}$ and PM_{10}. The majority (six) were in Albuquerque, while the remaining three were around the El Paso area. Calculations of $PM_{2.5}/PM_{10}$ and PM_{10}-$PM_{2.5}$ were made for each sensor for every hour. High PM_{10}-$PM_{2.5}$ values indicate the presence of coarse dust particles in the air. In Albuquerque, coarse particle concentrations were present in the air for 3-5 hours with concentrations that ranged from 40.9 µg m^{-3} up to 2031 µg m^{-3}. The south part of Albuquerque had a stronger impact by the dust storm as these stations (San Jose, Jefferson, and South Valley) showed higher PM_{10}-$PM_{2.5}$ values, with maximum values of 922.7 µg m^{-3} up to 2030.9 µg m^{-3} at the peak of the dust. In the El Paso area, the PM_{10}-$PM_{2.5}$ values during the dust event had a slightly wider range from 53 µg m^{-3} to 3236 µg m^{-3}. At the peak of the dust, PM_{10}-$PM_{2.5}$ values ranged from 870.5 µg m^{-3} to 3236 µg m^{-3} (sensor C41 is missing 2 hours of data from the peak of the dust). The presence of coarse particles in the El Paso area (stations C41, C49, and 6CM) lasted for 8-10 hours, as shown in Fig. S4. Some of the PM_{10}-$PM_{2.5}$ values were similar to those measured in past dust events in the region and also in other locations (Alghamdi et al., 2015; Ardon-Dryer and Kelley, 2022).

Observations based on $PM_{2.5}/PM_{10}$ were also performed. The $PM_{2.5}/PM_{10}$ ratio is an important indicator used to characterize the underlying atmospheric processes within the local environment, which allows for the identification of the source of the particles (Yu and Wang, 2010). Higher $PM_{2.5}/PM_{10}$ ratios (> 0.6) are generally associated with anthropogenic pollution, while lower ratios are associated with dust events (Jugder et al., 2014; Sugimoto et al., 2016; Jaafari et al., 2018; Fan et al., 2021; Ardon-Dryer et al., 2022b). $PM_{2.5}/PM_{10}$ values across the nine sensors decreased during the dust event mainly between 11:00 to 18:00 local time (Fig. S4). $PM_{2.5}/PM_{10}$ values across the nine stations ranged from 0.03 to 0.13 with an average of 0.07 ± 0.02 across all stations and times. These ratios were lower than values reported during many other dust events. For example, the ratio during a dust event was 0.4 in Taiwan (Tsai et al., 2012), 0.32 in Italy (Malaguti et al., 2015), 0.28 in Saudi Arabia (Alghamdi et al., 2015), and 0.25 in Tehran, Iran (Jaafari et al., 2018). In Washington state $PM_{2.5}/PM_{10}$ values ranged from 0.2 to 0.37 (Claiborn et al. 2000). These $PM_{2.5}/PM_{10}$ values were higher than those measured during this study's dust storm. Values of $PM_{2.5}/PM_{10}$ below 0.2 have been observed during dust events (Tong et al., 2012; Jaafari et al., 2018). Tong et al. (2012) examined the $PM_{2.5}/PM_{10}$ over multiple sites in the western United States and found the $PM_{2.5}/PM_{10}$ ratio ranged from 0.1 to 0.31. Although some of the $PM_{2.5}/PM_{10}$ values in this study were in that range majority were lower. Perhaps the differences in $PM_{2.5}/PM_{10}$ ratios found in this study were based on the fact that they represented hourly values, while most of the other studies were based on daily $PM_{2.5}/PM_{10}$ ratios. Calculations of daily $PM_{2.5}/PM_{10}$ values were found to be slightly higher (0.08 to 0.22) and in a similar range to those found in Tong et al. (2012).

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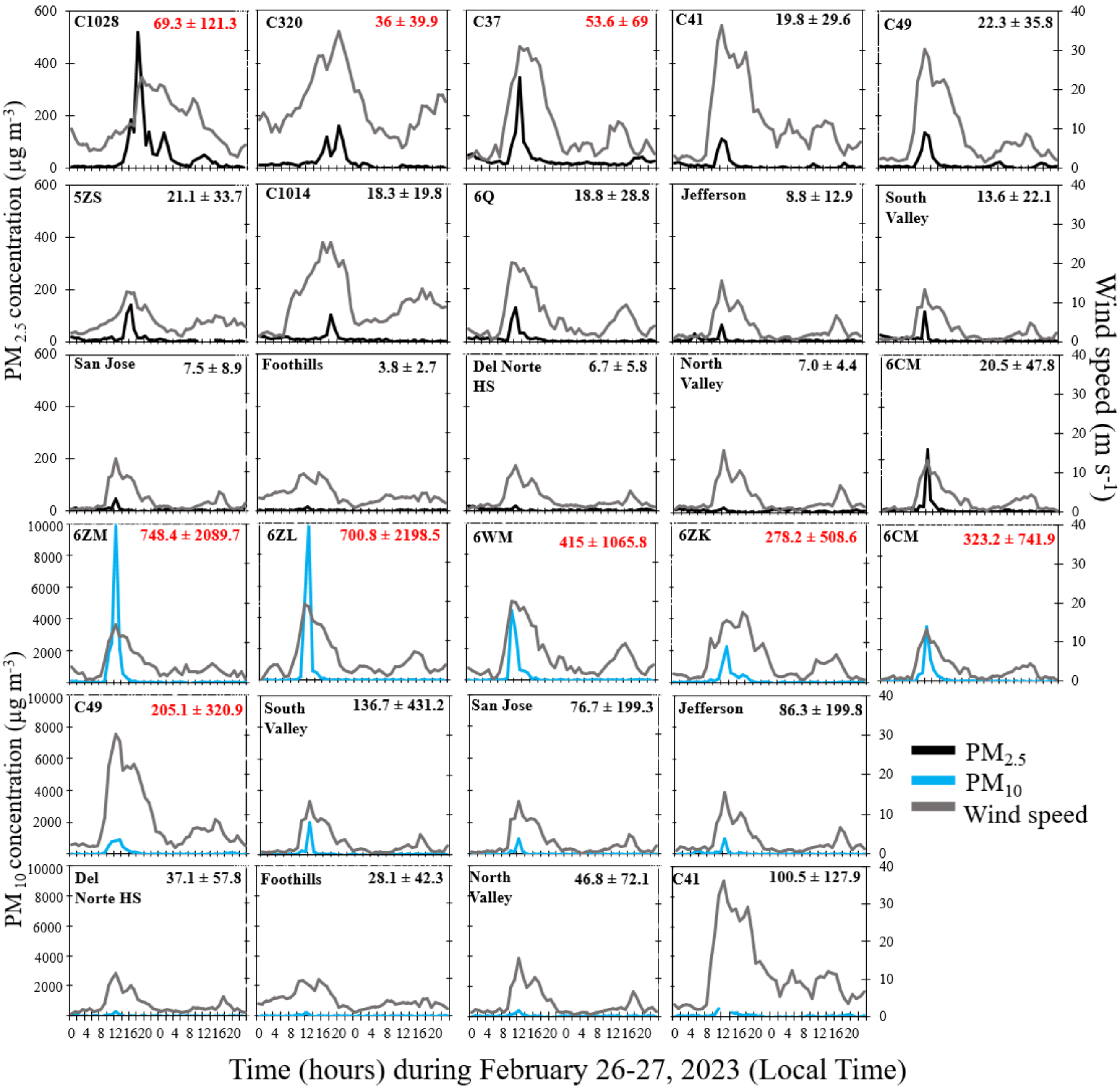

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Figure 4. Changes in $PM_{2.5}$ (black) and PM_{10} (blue) with wind speeds (grey) measured during the dust storm. The name of the station and daily average ± SD values are presented in black. Daily average ± SD values for stations that exceeded the EPA daily standards are presented in red.

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4 Conclusion

On February 26, 2023, an upper-level low-pressure system with a strong jet streak aided in the mixing of strong winds to the surface, which resulted in the formation of a dust storm over portions of New Mexico and West Texas. The dust first initiated in New Mexico during the morning hours and intensified as it moved eastward into West Texas. The average wind speed at the beginning of the dust storm was 15.6 m s^{-1} and during the dust storm wind speed reached up to 26.2 m s^{-1} with wind gusts up to 37 m s^{-1}. Visibilities ranged from 4 km down to 0 km defining the event as a dust storm (visibility < 1 km). Eight ASOS stations reported dust storm conditions for about 5 to 65 minutes. This dust storm had a big impact on the air quality in the area. Daily PM concentrations ranged from 36 ± 39.9 μg m^{-3} up to 69.3 ± 121.3 μg m^{-3} for $PM_{2.5}$ and 205.1 ± 320.9 μg m^{-3} up to 748.4 ± 2089.7 μg m^{-3} for PM_{10}. Nine PM stations exceeded the EPA daily threshold. High hourly $PM_{2.5}$ and PM_{10} concentrations during the dust storm reached a maximum of 518.4 μg m^{-3} and 9983 μg m^{-3} respectively. Dust particles were present in the air for up to 16 hours impacting millions of citizens across eastern New Mexico and West Texas. In some locations (e.g., Lubbock) this dust storm was the strongest ever reported, as it had the highest $PM_{2.5}$ concentrations recorded since the station became operatonal in 2001.

Data availability

Automatic surface observation systems (ASOS) are available from the Iowa University Mesonet (Iowa Mesonet, 2023). PM measurements for Texas were retrieved from the Texas Commission on Environmental Quality (TCEQ, 2023), while PM measurements from New Mexico were downloaded from the New Mexico Environment Department (New Mexico Environmental Department, 2023). PM for Albuquerque was provided form Mr. Patrick Hudson, a Senior Environment Health scientist for the city of Albuquerque's air quality program monitoring section. All measurements are available from the authors upon request.

Author contributions

KS performed the dust event meteorological overview. MR performed the meteorological data analysis from ASOS and PM analysis. KAD designed the study and coordinated the different aspects of the manuscript. All authors were actively involved in interpreting the results and in discussions on the manuscript.

Competing interests

The contact author has declared that none of the authors has any competing interests.

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References

Achakulwisut, P., Shen, L., and Mickley, L. J.: What controls springtime fine dust variability in the western United States? Investigating the 2002–2015 increase in fine dust in the U.S. Southwest. J. Geophys. Res. 122 (12), 449–12,467. https://doi. org/10.1002/2017JD027208, 2017.

Alghamdi, M.A., Almazroui, M., Shamy, M., Redal, M. A., Alkhalaf, A.K., Hussein, M.A., and Khoder, M.I.: Characterization and Elemental Composition of Atmospheric Aerosol Loads during Springtime Dust Storm in Western Saudi Arabia. Aerosol Air Qual. Res. 15: 440-453. https://doi.org/10.4209/aaqr.2014.06.0110, 2015.

Al Kheder, S., and Al Kandari, A.: The impact of dust on Kuwait International Airport operations: a case study. Int. J. Environ. Sci. Technol. 17, 3467 – 3474, https://doi.org/10.1007/s13762-020-02710-3, 2020.

Arcusa, S. H., McKay, N. P., Carrillo, C. M., and Ault, T. R.: Dust-drought nexus in the southwestern United States: A proxy-model comparison approach. Paleoceanogr. Paleoclimatol., 35, e2020PA004046. https://doi.org/10.1029/2020PA004046, 2020.

Ardon-Dryer, K. and Kelley, M. C.: Particle size distribution and particulate matter concentrations during synoptic and convective dust events in West Texas, Atmos. Chem. Phys., 22, 9161–9173, https://doi.org/10.5194/acp-22-9161-2022, 2022.

Ardon-Dryer, K. and Levin, Z.: Ground-based measurements of immersion freezing in the eastern Mediterranean, Atmos. Chem. Phys., 14, 5217–5231, https://doi.org/10.5194/acp-14-5217-2014, 2014.

Ardon-Dryer, K., Chmielewski, V., Burning E., and Xueting X.: Changes of Electric Field, Aerosol, and Wind Covariance in Different Blowing Dust Days in West Texas, Aeolian Res., 54, 100762, https://doi.org/10.1016/j.aeolia.2021.100762, 2022a.

Ardon-Dryer, K., Kelley, M. C., Xueting, X., and Dryer, Y.: The Aerosol Research Observation Station (AEROS), Atmos. Meas. Tech., 15, 2345–2360, https://doi.org/10.5194/amt-15-2345-2022, 2022b.

Ardon-Dryer, K., Clifford, K. R., and Hand, J. L.: Dust under the radar: Rethinking how to evaluate the impacts of dust events on air quality in the United States. GeoHealth, 7, e2023GH000953. https://doi.org/10.1029/2023GH000953. 2023a

Ardon-Dryer, K., Gill, T. E., and Tong, D. Q.: When a dust storm is not a dust storm: Reliability of dust records from the Storm Events Database and implications for geohealth applications. GeoHealth, 7, e2022GH000699. https://doi.org/10.1029/2022GH000699, 2023b.

Arhami, M., Hosseini, V., Shahne, M. Z., Bigdeli, M., Lai, A., and Shauer, J. J.: Seasonal trends, chemical speciation and source apportionment of fine PM in Tehran, J. Atmo. Environ., 153, 70-82, https://doi.org/10.1016/j.atmosenv.2016.12.046, 2017.

ASOS (Automatic Surface Observation System) User's Guide: https://apps.dtic.mil/sti/pdfs/ADA354716.pdf, Last accessed 11 January 2023, 1998.

Baylock, B. K.: GOES-2-go: Download and display GOES-East and GOES-west data, Github [code], https://github.com/blaylockbk/goes2go.

Benjamin, S. G., Weygandt, S. S., Brown, J. M., Hu, M., Alexander, C., Smirnova, T. G., Olson, J. B., James, E., Dowell, D. C., Grell, G. A., Lin, H., Peckham, S. E., Smith, T. L., Moninger, W. R., Kenyon, J. S., and Minikan, G. S.: A North American hourly assimilation and model forecast cycle: The rapid refresh, Mon. Weather Rev.144, 1669–1694, https://doi.org/10.1175/MWR-D-15-0242.1, 2016.

Bogan, M., Al, B., Kul, S., Zengin, S., Oktay, M., Sabak, M., Gumusboga, H., and Bayram, H.: The effects of desert dust storms, air pollution, and temperature on morbidity due to spontaneous abortions and toxemia of pregnancy: 5-year analysis. Int. J. Biometeorol. https://doi.org/10.1007/s00484-021-02127-8, 2021.

Claiborn, C.S., Finn, D., Larson, T.V., and Koenig, J.Q.: Windblown Dust Contributes to High $PM_{2.5}$ Concentrations, J. Air Waste Manag. Assoc., 50:8, 1440-1445, DOI: 10.1080/10473289.2000.10464179, 2000.

Doggett IV, A. L., Gill, T. E., Peterson, R. E., Bory, A. J.-M., and Biscaye, P. E.: Meteorological characteristics of a severe wind and dust emission event; Southwestern USA 6-7 April 2001, 21st AMS Conference on Severe Local Storms, August, American Meteorological Society, Boston, MA, San Antonio, TX, 2002.

Eagar, J., Herckes, P., and Hartnett, H.: The characterization of haboobs and the deposition of dust in Tempe, Arizona from 2005 to 2014, Aeol. Res., 24, 81-91, https://doi.org/10.1016/j.aeolia.2016.11.004, 2017.

EPA NAAQS Table: https://www.epa.gov/criteria-air-pollutants/naaqs-table, last access: 30 December, 2023.

https://doi.org/10.5194/egusphere-2024-113
Preprint. Discussion started: 19 January 2024

Fan, H., Zhao, C., Yang, Y., and Yang, X.: Spatio-Temporal Variations of the $PM_{2.5}/PM_{10}$ Ratios and Its Application to Air Pollution Type Classification in China. Front. Environ. Sci. 9:692440. doi: 10.3389/fenvs.2021.692440, 2021.

Fuell, K. K., Guyer, B. J., Kann, D., Molthan, A. L., and Elmer, N.: Next generation satellite RGB dust imagery leads to operational changes at NWS Albuquerque. J. Operational Meteor., 4 (6), 75, 91, doi: http://dx.doi.org/10.15191/nwajom. 2016.0406, 2016.

Gorris, M.E., Ardon-Dryer, K., Campuzano, A., Castañón-Olivares, L.R, Gill, T.E., Greene, A., Hung, C-Y., Kaufeld KA., Lacy, M., and Sánchez-Paredes, E.: Advocating for coccidioidomycosis as a nationally reportable disease in the United States and encouraging disease surveillance across North and South America, J. Fungi, 9, 83. https://doi.org/10.3390/jof9010083, 2023.

Goudarzi, G., Daryanoosh, S. M., Gidini, H., Hopke, P. K., Sicard, P., De Marco, A., Rad, H.D., Harbizadeh, A., Jahedi, F., Mohammadi, M. J., Savari, J., Sadeghi, S., Kaabi, Z., and Omidi Khaniabadi, O.: Health risk assessment of exposure to the Middle-Eastern Dust storms in the Iranian megacity of Kermanshah. J. Pub Health., 148, 109-116, http://dx.doi.org/10.1016/j.puhe.2017.03.009, 2017.

Hagen, L. J. and Woodruff, N. P.: Air Pollution from Dustorms in the Great Plains, J. Atmo. Environ., 7, 323-332, 1973.

Hahnenberger, M., and Nicoll, K.: Meteorological Characteristics of Dust Storm Events in the Eastern Great Basin of Utah, U.S.A. Atmos. Environ., 60, 601–12, https://doi.org/10.1016/j.atmosenv.2012. 06.029, 2012.

Helmus, J. J., and Collis, S. M.: The Python ARM Radar Toolkit (Py-ART), a library for working with weather radar data in the Python programming language. United States: N. p., Web. doi:10.5334/jors.119, 2016.

Herrera-Molina, E. Gill, T.E., Ibarra-Mejia, G. Jeon, S. and Ardon-Dryer, K. Associations Between Dust Exposure and Hospitalizations in a dust-prone city, Lubbock, Texas, USA, Air Qual. Atmos. Health, https://doi.org/10.1007/s11869-023-01489-9. 2023.

Hyde, P., Alex Mahalov, A., and Li, J.: Simulating the meteorology and PM10 concentrations in Arizona dust storms using the Weather Research and Forecasting model with Chemistry (Wrf-Chem), J. Air Waste Manag. Assoc., 68:3, 177-195, DOI: 10.1080/10962247.2017.1357662, 2018.

Iowa State University Iowa Environmental Mesonet (IEM) ASOS-AWOS-METAR Data Download: https://www.mesonet.agron.iastate.edu/request/download.phtml?network=TX_ASOS, last accessed: 30 December 2023.

Jaafari, J., Naddafi, K., Yunesian, M., Nabizadeh, R., Hassanvand, M. S., Ghozikali, M. G., Nazmara, S., Shamsollahi, H. R and Yaghmaeian, K.: Study of PM10, PM2.5, and PM1 levels in during dust storms and local air pollution events in urban and rural sites in Tehran, Hum. Ecol. Risk Assess., 24:2, 482-493, DOI: 10.1080/10807039.2017.1389608, 2018.

Jugder, D., Shinoda, M., Kimura, R., Batbold, A., and Amarjargal, D.: Quantitative analysis on windblown dust concentrations of PM_{10} ($PM_{2.5}$) during dust events in Mongolia. Aeolian Res. 14, 3–13, https://doi.org/10.1016/j.aeolia.2014.04.005, 2014.

Kandakji, T., Gill, T. E., and Lee, J. A.: Identifying and characterizing dust point sources in the southwestern United States using remote sensing and GIS. Geomorphology, 353, 107019. https://doi.org/10.1016/j.geomorph.2019.107019, 2020.

Karami, S., Ranjbar, A., Mohebalhojeh, A. R., and Moradi, M.: A rare case of haboob in Tehran: Observational and Numerical study, J. Atmo. Res., 185, 169-185, https://doi.org/10.1016/j.atmosres.2016.10.010, 2017.

Kelley, M.C., Brown, M.M., Fedler, C.B., and Ardon-Dryer, K.: Long-term measurements of PM 2.5 concentrations in Lubbock, Texas. Aerosol and Air Qual. Res. 20, 1306–1318. https://doi.org/10.4209/aaqr.2019.09.0469, 2020.

Kelley, M.C., and Ardon-Dryer, K., Analyzing Two Decades of Dust Events on the Southern Great Plains Region of West Texas, Atmos. Pollut. Res., 101091, https://doi.org/10.1016/j.apr.2021.101091, 2021.

Kim, D., Chin, M., Kemp, E. M., Tao, Z., Peters-Lidard, C. D., and Ginoux, P.: Development of high-resolution dynamic dust source function – A case study with a strong dust storm in a regional model, J. Atmo. Environ., 159, 11-25, http://dx.doi.org/10.1016/j.atmosenv.2017.03.045, 2017.

Lader G, Raman A, Davis JT, and Waters, K.: Blowing dust and dust storms: one of Arizona's most underrated weather hazards. NOAA tech Memor NWS-WR-290, 2016.

Lee, J. A. and Tchakerian, V. P.: Magnitude and Frequency of Blowing Dust on the Southern High Plains of the United States, 1947–1989, Ann. Am. Assoc. Geogr., 85:4, 684-693, 10.1111/j.1467-8306.1995.tb01820.x, 1995.

Lee, J., Gill. T., Mulligan, K., Acosta, M., and Perez, A.: Land use/land cover and point sources of the 15 December 2003 dust storm in southwestern North America. Geomorphology, 105 (1-2), 18-27, https://doi.org/10.1016/j.geomorph.2007.12.016, 2009.

Lee, J., Baddock, M., Mbuh, M., and Gill, T.: Geomorphic and land cover characteristics of Aeolian dust storces in West Texas and eastern New Mexico, USA. Aeol. Res., 3(4) 459-466. https://doi.org/10.1016/j.aeolia.2011.08.001, 2012.

Lei, H., Wang, J.X.L., Tong, D.Q., and Lee, P.: Merged dust climatology in Phoenix, Arizona based on satellite and station data. Clim Dyn **47**, 2785–2799. https://doi.org/10.1007/s00382-016-2997-7, 2016.

https://doi.org/10.5194/egusphere-2024-113
Preprint. Discussion started: 19 January 2024

Li, J., T. Kandakji, J. A. Lee, J. Tatarko, J. Blackwell, T. E. Gill, and Collins, J. D.: Blowing Dust and Highway Safety in the Southwestern United States: Characteristics of Dust Emission “Hotspots" and Management Implications. Sci. Total Environ., 621, 1023–32, https://doi.org/10.1016/j.scitotenv.2017.10.124, 2018.

Malaguti, A., Mircea, M., La Torretta, T.M., Telloli, C., Petralia, E., Stracquadanio, M. and Berico, M.: Chemical Composition of Fine and Coarse Aerosol Particles in the Central Mediterranean Area during Dust and Non-Dust Conditions. Aerosol Air Qual. Res. 15: 410-425. https://doi.org/10.4209/aaqr.2014.08.0172, 2018.

Malig, B. J. and Ostro, B. D.: Coarse particles and mortality: evidence from a multi-city study in California, J. Occup. Environ. Med., 66, 832–839, https://doi.org/10.1136/oem.2008.045393, 2009.

Mamouri, R.-E., Ansmann, A., Nisantzi, A., Solomos, S., Kallos, G., and Hadjimitsis, D. G.: Extreme dust storm over the eastern Mediterranean in September 2015: satellite, lidar, and surface observations in the Cyprus region, Atmos. Chem. Phys., 16, 13711–13724, https://doi.org/10.5194/acp-16-13711-2016, 2016.

May, R. M., Goebbert, K. H., Thielen, J. E., Leeman, J. R., Camron, M. D., Bruick, Z., Bruning, E. C., Manser, R. P., Arms, S. C., and Marsh, P. T.: MetPy: A meteorological python library for data analysis and visualization [Software]. Bull. Am. Meteorol. Soc., 103(10), E2273–E2284. https://doi.org/10.1175/BAMS-D-21-0125.1, 2022.

Middleton, N., Tozer, P., and Tozer, B.: Sand and dust storms: underrated natural hazards. 43 (2), 390-409. https://doi.org/10.1111/disa.12320, 2019.

Mu, H., Otani, S., Shinoda, M., Yokoyama, Y., Onishi, K., Hosoda, T., Okamoto, M., and Kurozawa, Y.: Long-Term Effects of Livestock Loss Caused by Dust Storm on Mongolian Inhabitants: A Survey 1 Year after the Dust Storm. Yonago Acta Medica, 56, no. 1, 39–42, 2013.

New Mexico Environmental Department Current Air Quality: https://aqi.air.env.nm.gov/, last accessed: 5 January 2023.

Nickling, W.G. and Brazel, A.J.: Temporal and spatial characteristics of Arizona dust storms (1965-1980). J. Climatol., 4:645-660, https://doi.org/10.1002/joc.3370040608, 1984.

Nicoll, K., Hahnenberger, M., and Goldstein, H. L.: ‘Dust in the wind’ from source-to-sink: analysis of the 14-15 April 2015 storm in Utah, Aeolian Res., 46, 100532, https://doi.org/10.1016/j.aeolia.2019.06.002, 2020.

Novlan, D. J., Hardiman, M., and Gill, T. E.: A synoptic climatology of blowing dust events in El Paso, Texas from 1932 – 2005, paper presented at the 16th Conference on Applied Climatology, Am. Meteorol. Soc., San Antonio, TX, 2007.

Park, S. H., Gong, S. L., Zhao, T. L., Vet, R. J., Bouchet, V. S., Gong, W., Makar, P. A., Moran, M. D., Stroud, C., and Zhang, J.: Simulation of entrainment and transport of dust particles within North America in April 2001 ("Red Dust Episode"), J. Geophys. Res. Atmos., 112, D20209, doi:10.1029/2007JD008443, 2007.

Park, S. H., Gong, S. L., Gong, W., Makar, P. A., Moran, M. D., Stroud, C. A., and Zhang, J.: Sensitivity of surface characteristics on the simulation of windblown dust source in North America, Atmos. Environ., **43**, 3122–3129, 2009.

Pérez, L., Tobias, A., Querol, X., Kunzli, N., Pey, J., Alastuey, A., Viana, M., Valero, N., Gonzalez-Cabre, M., and Sunyer, J.: Coarse particles from Saharan dust and daily mortality, Epidemiol., 19, 800–807, https://doi.org/10.1097/ede.0b013e31818131cf, 2008.

Raman, A., Arellano Jr, A., and Brost, J.: Revisiting haboobs in the southwestern United States: An observational case study of the 5 July 2011 Phoenix dust storm. Atmo. Environ. 89, 179-188. https://doi.org/10.1016/j.atmosenv.2014.02.026, 2014.

Rivera Rivera, N. I., Gill, T. E., Gebhart, K. A., Hand, J. L., Bleiwess, M. P., and Fitzgerald, R. M.: Wind modeling of Chihuahuan Desert, J. Atmo. Environ., 43, 2, 347-354, https://doi.org/10.1016/j.atmosenv.2008.09.069, 2009.

Schultz, J.A., and Meisner, B.N.: The 24 February 2007 North Texas wind and dust storm: An impact weather event. Natl. Weather Dig., 33, 165–184, 2009.

Schweitzer, M., Calzadilla, A., Salamo, O., Sharifi, A., Kumar, N., Holt, G., Campos, M., and Mirsaeidi, M.: Lung health in era of climate change and dust storms. Environ Res. 163, 36-42. https://doi.org/10.1016/j.envres.2018.02.001, 2018.

Stout, J.E.: Dust and environment in the southern high Plains of North America. J. Arid Environ. 47 (4), 425–441. https://doi.org/10.1006/jare.2000.0732, 2001.

Stout, J. E. and Arimoto, R.: Threshold wind velocities for sand movement in the Mescalero Sands of Southeastern New Mexico, J. Arid Environ., 74, 11, 1456-1460, https://doi.org/10.1016/j.jaridenv.2010.05.011, 2010.

Sugimoto, N., Shimizu, A., Matsui, I., and Nishikawa, M.: A method for estimating the fraction of mineral dust in particulate matter using $PM_{2.5}$-to-PM_{10} ratios. Particuology, 28, 114–120. https://doi.org/10.1016/j.partic.2015.09.005, 2016.

Texas Commission on Environmental Quality (TCEQ) Air Quality and Monitoring: https://www.tceq.texas.gov/airquality/monops, last access: 30 December 2023.

Tong, D. Q., Dan, M., Wang, T., and Lee, P.: Long-term dust climatology in the western United States reconstructed from routine aerosol ground monitoring, Atmos. Chem. Phys., 12, 5189–5205, https://doi.org/10.5194/acp-12-5189-2012, 2012.

Tong, D. Q., Gorris, M. E., Gill, T.E., Ardon-Dryer, K., Wang, J., and Ren, L.: Dust storms, Valley fever, and public awareness. GeoHealth, 6, e2022GH000642. https://doi.org/10.1029/2022GH000642, 2022.

Tong, D., Feng, I., Gill, T. E., Shepenski, K., and Wang, J.: How Many People Were Killed by Windblown Dust Events in the United States? Bull. Am. Meteorol. Soc., 104 (5), 1067-1084, https://doi.org/10.1175/BAMS-D-22-0186.1, 2023.

Toure, N. O., Gueye, N. R.-D., Diokhane, A. M., Jenkins, G. S., Li, M., Drame, M. S., Coker, K. R., and Thiam, K.: Observed and modeled seasonal air quality and respiratory health in Senegal during 2015 and 2016. GeoHeath, 3, 423–442. 10.1029/2019GH000214, 2019.

Tsai, J.H., Huang, K.L., Lin, N.H., Chen, S.J., Lin, T.C., Chen, S.C., Lin, C.C., Hsu, S.C. and Lin, W.Y.: Influence of an Asian Dust Storm and Southeast Asian Biomass Burning on the Characteristics of Seashore Atmospheric Aerosols in Southern Taiwan. Aerosol Air Qual. Res. 12: 1105-1115. https://doi.org/10.4209/aaqr.2012.07.0201, 2012.

Vukovic, A., Vujadinovic, M., Pejanovic, G., Andric, J., Kumjian, M.R., Djurdjevic, V., Dacic, M., Prasad, A.K., El-Askary, H.M., Paris, B.C., Petkovic, S., Nickovic, S., Sprigg, W.A., apr 2014. Numerical simulation of an "American haboob.". Atmos. Chem. Phys. 14 (7), 3211–3230. https://doi.org/10.5194/acp-14-3211-2014.

Yu, H.L. and Wang, C.H.: Retrospective prediction of intraurban spatiotemporal distribution of $PM_{2.5}$ in Taipei. Atmos. Environ. 44 (25), 3053–3065, https://doi.org/10.1016/j.atmosenv.2010.04.030, 2010.

World Health Organization (WHO) global air quality guidelines: https://iris.who.int/bitstream/handle/10665/345329/9789240034228-eng.pdf, last accessed: 30 December 2023.

WMO (World Meteorological Organization): WMO Technical Regulations Annex II Manual on Codes International Codes. I.1, 2019.

Zobeck, T. M. and VanPelt, R. S.: Wind induced dust generation and transport mechanics on a bare agriculture field, J. Haz. Mat., 132, 26-38, https://doi.org/10.1016/j.jhazmat.2005.11.090, 2006.