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Claire Rowan Date

Dust Storms and Respiratory Emergency Department Visits

in the Southwestern United States

By

Claire Rowan

Master of Public Health

Epidemiology

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Dr. Stefanie Ebelt

Committee Chair

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B.S.P.H.

Texas A&M University School of Public Health

2020

Thesis Committee Chair: Stefanie Ebelt, Sc.D.

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A thesis submitted to the Faculty of the

Rollins School of Public Health of Emory University

In partial fulfillment of the requirements for the degree of

Master of Public Heath

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Abstract

Dust Storms and Respiratory Emergency Department Visits in the Southwestern United States
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Dust storms are associated with many varying adverse health effects such as cardiovascular and respiratory disorders, and motor vehicle accidents. Past studies additionally have found links between total mortality, hospital admissions, and emergency department (ED) visits. This study aims to provide a better understanding of the potential links between dust storms and respiratory-related ED visits in four southwestern states of the U.S. The IMPROVE monitoring program collects detailed data on pollutants; the in-depth pollutant information collected can be used to identify dust storms using a validated algorithm. Using a case-crossover design to study acute health events, we estimated odds ratios for respiratory, asthma, and chronic obstructive pulmonary disease (COPD) ED visits overall, and by state, for dust storm compared to non-dust storm days.

We found increased risk of ED visits for all respiratory diseases and asthma with dust storms in the previous three days, with strongest associations in Arizona. For example, the odds of respiratory ED visits were approximately 6.7% higher two and three days after a dust storm. In Arizona, the association of asthma emergency department visits and dust storms three days prior was: OR of 1.100, 95% CI: (1.010, 1.197). No significant associations were found for COPD or in California, likely due to limited power in the number of dust events and ED visits.

The increasing frequency of dust storms has been associated with climate change through the desertification of soil and increasing ocean temperatures. Dust storms are liked to higher air temperatures, increasing carbon dioxide in the atmosphere, increasing snow melt and lessening glacial formation during winter months. The observed findings in this analysis on all respiratory and asthma emergency department visits add to the existing literature on dust storms and adverse respiratory health effects.

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<u>**Table of Contents**</u>

1. Introduction

Dust storms are an important contributor to environmental health concerns, with elevated dust levels causing a significant number of short and long term health effects, and affecting many components of health and stages of life globally (1). Dust storms, classified by ambient dust exceeding acceptable and baseline levels, can take place anywhere in the world but are most common in the Sahara, Asia, the Middle East and the United States (US) (2). The substrates in these storms varies by area, but typically consist of particulate matter (PM), silica, dialuminium dioxide, iron (III) oxide, calcium oxide, water vapor, organic matter, bacterial communities, and more (3, 4).

Currently in the US, dust storms are most common in the southwest, specifically the Great Basin, the Mohave, Sonoran, and Chihuahuan Deserts, the semiarid Columbia Plateau, Colorado Plateau, and southern Great Plains (5). Dust from international sources can also impact dust levels in the US due to transport via winds, causing higher dust concentrations beyond the origin area of the dust (6). Climate change is projected to cause greater areas of arid climates to form around the world, specifically in the southwestern US (7). As such, there are predicted increases in the concentration of dust and lengths of dust event seasons, lending greater importance to understanding the health effects of the increasing threat of dust storms (8).

Dust storms are linked to many varying adverse health effects such as cardiovascular disorders, respiratory disorders, and motor vehicle accidents among others (9). Studies completed outside the US have found links between total mortality, cardiovascular and respiratory mortality, hospital admissions, and pediatric asthma emergency department (ED) visits. For example, in Taiwan, Asian dust storms have been linked to an increase in total and cardiovascular mortality; similar results have been observed from Saharan dust in Spain (10, 11).

Khaniabadi et al. (2017) found an increase of respiratory mortality and chronic obstructive pulmonary disease (COPD) hospital admissions in Iran from Middle Eastern Dust storms (12). Increases were observed for respiratory, asthma, cardiovascular, and all-cause hospital admissions in Kuwait, Australia, and Cyprus. (13-15). Middleton et al. (2008) found an association between an increase in respiratory hospital admissions in Cyprus during the warm months alone. The authors hypothesize this seasonal discrepancy as a result not controlling for cause of hospital admissions, small sample size, and limited power (15). Asthma pediatric emergency department visits increased in Trinidad following African dust clouds (16). Some studies have also been conducted in the US, which have found increases in total non-accidental and cardiovascular mortality, increases in total and respiratory intensive care unit admissions, and total hospitalizations on days of dust storms (17-19).

This study aims to provide a better understanding of the potential links between dust storms and respiratory-related emergency department visits in four southwestern states of the U.S. (Arizona, California, Nevada, and Utah), which are frequently impacted by dust storms. Previous studies in the US have used exposure to dust events as measured from the US National Weather Service, a relatively inconsistent tool for reporting dust storms as storms are reported from local officials and the public without verification (17, 18). Several federal networks do measure air quality throughout the US, including the EPA Air Quality System (AQS), the Chemical Speciation Network (CSN) and Interagency Monitoring of PROtected Environments (IMPROVE). While the air monitoring data provide an important resource, these networks do not identify dust storms per se. To address this gap, Tong et al. (2012) developed an algorithm to identify dust storms using the routine monitoring data from the IMPROVE monitors, and validated the results using satellite imagery (20). Data from IMPROVE were specifically prioritized for this algorithm because of the detailed aerosol composition data collected and monitor siting criteria in rural areas that reduce the influence of urban emissions in potentially obscuring the dust storm identification (20). Here, we apply a novel dataset of dust storm days identified at 10 IMPROVE monitoring sites in the four southwestern states, using the Tong et al. (2012) algorithm, to estimate associations with respiratory ED visits. This study is an effort to add to the growing evidence between adverse health effects and dust events using an improved exposure metric compared to previous US-based studies.

2. Methods

2.1. Dust Storm and Other Air Quality Data

Several U.S. federal agencies operate the IMPROVE program for air pollution monitoring in US National Parks, Monuments, and Wilderness Areas. IMPROVE data sites collect detailed 24-hour average data on particle mass and composition every 3, or 6 days depending on the site. For this study, we acquired data for the 2005-2016 period from IMPROVE sites in California (2 sites), Arizona (5 sites), Nevada (2 sites), and Utah (1 site).

Using an algorithm developed by Tong et al., 2012, which enables differentiation of windblown anthropogenic dust from wildfires, a database of dust storm days at each IMPROVE site was developed. This algorithm uses five criteria that allows for the differentiation between natural and anthropogenic origins of dust: (1) high PM_{10} and $PM_{2.5}$ concentrations, (2) a low ratio of PM2.5 to PM10, (3) high concentrations of natural elements of dust (including silicon, calcium, potassium, iron, and titanium), (4) low concentrations of anthropogenic elements of dust (including arsenic, zinc, copper, lead, sulfate, nitrate, organic carbon, and fine elemental carbons), and (5) low proportion of anthropogenic pollution elements copper, zinc, lead, and potassium relative to silicon, when comparing aerosol to surface soil composition (20). With this algorithm, these storms are validated against satellite imagery of confirmed dust events and can therefore be considered a "gold standard" of dust storm classification in the US.

The resulting exposure dataset included a 0/1 indicator variable identifying days without and days with a dust event, respectively, at each IMPROVE site; days with no IMPROVE measurements were coded as missing for the dust event indicator. Variables measured at the IMPROVE sites included: aluminum, arsenic, bromine, calcium, chloride, chlorine, chromium, copper, fine elemental carbons, iron, hydrogen, potassium, $PM_{2.5}$, PM_{10}, magnesium, manganese, molybdenum, nitrate, nitrite, sodium, ammonium, nickel, fine organic carbon, phosphorus, lead, rubidium, sulfur, selenium, silicon, soil, sulfate, strontium, titanium, vanadium, zinc, and zirconium. From this suite of IMPROVE measurements, the pollutants included in the current analysis for descriptive purposes included PM_{10}, $PM_{2.5}$, and $PM_{2.5}$ components of ammonium nitrate, ammonium sulfate, arsenic, calcium, elemental carbon, organic carbon, copper, iron, lead, potassium, silicon, titanium, zinc all measured in $\mu g/m^3$.

As ozone is associated with adverse health effects and dew point and temperature are associated with dust events, data on these air quality variables were acquired for inclusion in epidemiologic analyses (18, 21). These data are not collected by the IMPROVE monitors and were thus obtained through other sources including the US EPA's Air Quality System Data Mart via the R package RAQSAPI (22). We acquired ozone data from AQS monitors located in the same counties as the IMPROVE monitors. The distances between the IMPROVE and ozone AQS sites ranged from 0.12 to 129.70 km apart with an average of 30.24 km. We also considered acquisition of other criteria pollutant data, however there were no AQS sites for CO, NO_2, or SO_2 in the counties with IMPROVE monitors. These gaseous pollutants are generally driven by urban emission sources and were not considered important confounders of dust events in the rural areas represented by IMRPOVE sites. Meteorology data were obtained from the Daymet Daily Surface Weather 1 km gridded product, and linked to patient ZIP codes surrounding the location of each IMPROVE monitor (23).

2.2. Emergency Department Visit Data

Emergency department (ED) visit data were collected from a database of patient-level billing records for ED visits between 2005 and 2016 from Arizona (Arizona Department of Health Services, Bureau of Public Health Statistics; 2008-2016), California (California Health and Human Services Agency, Office of Statewide Planning and Development; 2005-2016), Nevada (Center for Health Information Analysis; 2009-2016), and Utah (Utah Department of Health: Office of Health care Statistics; 2005-2016). For the purposes of this analysis, ED visits were defined as both patients seen in the ED as outpatients and discharged and admitted in-patients in the ED. Variables used in this project included the admission date, primary and secondary International Classification of Diseases (ICD) diagnosis codes, and ZIP code of the patient’s residence.

ICD diagnosis codes (version 9 prior to October 1, 2015; version 10 after and including October 1, 2015) were used to identify emergency department visit outcomes of interest. The outcomes considered were: all respiratory diseases (ICD-9 codes: 491-493, 496; ICD-10 codes: J41-J45), asthma alone (ICD-9 code 493; ICD-10 code J45), and COPD alone (ICD-9 code 491, 492, and 496; ICD-10 code J41-J44). The main outcomes were defined as ED visits with the ICD diagnosis codes of interest occurring in any diagnosis field (i.e., primary or secondary); emergency department visits when asthma was the primary reason for the visit comparing to any ED visit with asthma as a concern was considered in a secondary analysis.

For each outcome, ED visits were selected for inclusion in the analysis based on geographic proximity of patient residential location to an IMPROVE monitoring location. Buffer zones of 5, 15, 25, and 50 km were considered, with the smallest buffers expected to provide the most accurate exposure assessment due to the proximity of the IMPROVE monitor, but the smallest number of ED visits within the buffer area.

2.3. Application of Case-Crossover Analysis

The goal of this study was to estimate associations between dust storm days and respiratory ED visits. Given the unique ability for a case-crossover design to study acute health events, it is well suited for the application of dust storms, a short event with unknown consequences and lag times until potential outcomes.

Typically, case-crossover studies use monthly study periods, with the case day as the day on which the outcome occurred, and control days of all of the other, similar days within the month period (i.e., if the case day was the second Tuesday in August, the control days would be all of the other Tuesdays during August). This scenario of controlling for the day of the week is relevant when studying exposures such as anthropogenic air pollution or collisions from distracted driving which might be affected by week-day traffic.

It was determined that there was no need to control for the specific day of the week given dust storms are a natural phenomenon with no correlation to the day of the week (24). A data shell was created within the measured dates, consisting of strata, each with 4 days, spaced 6 days apart. All control days are within a 24-day window, allowing for control of seasons.

The confounders used in this analysis included the average, maximum, and minimum temperature, vapor pressure, precipitation, and dew point from Daymet (23). Ozone 8-hour mean and daily maximum in parts per million (PPM) with the pollutant standard and observation percent were used. The squared and cubic terms were calculated and used as confounders for average, maximum, and minimum temperature, dew point, and ozone (both mean and maximum) to allow for potential non-linear effects. We additionally controlled for federal holidays by including an indicator variable in the model.

Individuals who experience adverse health effects do not always experience symptoms immediately after a potential triggering effect. Past studies have observed adverse effects from respiratory causes between one and two weeks after days with high air pollution concentrations (25, 26). This occurrence was accounted for in analysis with lag structures, where day 0 was the day of the dust event and lag 1 was one day after. We assessed lags up to day 6 before the ED visit. In assessing lag 0 through lag 5, we assessed associations in independent outcome datasets. Due to the exposure data collection methods, the dataset analyzed in lag 6 is the same outcome dataset as lag 0. Using these lag structures, allows for independent analysis of these data sets.

Using SAS software, Version 9.4 of the SAS System for Windows. Copyright © 2013 SAS Institute Inc., we conducted a conditional logistic regression analysis in which results were conditional on the strata of dates that the ED visit fell within. We estimated odds ratios for all respiratory conditions, asthma, and COPD ED visits associated with dust storms at lag days 0 through 6. Models were also stratified by state level (e.g., all states, Arizona, and California) for each outcome. For each outcome, a sensitivity analysis was additionally completed, comparing the base model's 50 km buffer zones for the patient's ZIP code and a smaller 15 km buffer zone for all respiratory outcomes and states. Finally, in sensitivity analyses, we also considered lags through 14 days prior to ED visits to determine if there were any potential emergency department visits that were significantly associated past the 6-day base model. All models controlled for temperature, dew point, ozone, and federal holidays.

3. Results

3.1. Dust Event and Emergency Department Visit Descriptive Statistics

Over the January 2005 to December 2016 time period, 23 independent dust events were identified in the four states. Several events were expansive enough to be observed at multiple sites, resulting in the observation of 37 dust events across all 10 IMPROVE monitors (Table 1).

Over the same time period, 1,614,480 emergency department visits were observed among patients living in ZIP codes with centroids within 50 km of the 10 monitoring sites. Table 1 presents the numbers of ED visits for each outcome, for data periods available in each state. As Nevada had no observed dust event days, the epidemiologic analyses included Arizona, California, and Utah.

Table 1. Number of ED visits per outcome and dust storm days for subsets of data, 2005-2016.

Site	# of dust event days*	# of ED visits (all resp)*	# of ED visits (asthma)*	# of ED visits (primary asthma)*	# of ED visits (COPD)*	Maximum Temperature (°C)†	Dew Point (°C Td)†	Mean 8-hr Ozone (ppm)†
ALL SITES	**23**	**1,614,480**	**748,301**	**548,742**	**432,751**	**25.93 (8.18)**	**2.86 (6.17)**	**0.037 (0.014)**
AZ	14	411,803	187,883	32,545	109,592	27.50 (8.50)	4.26 (8.25)	0.041 (0.009)
BALD1	*1*	*20,158*	*7,669*	*1,321*	*6,828*	*18.92 (8.65)*	*-1.66 (8.01)*	*0.042 (0.008)*
CHIR1	*13*	*16,281*	*4,222*	*1,900*	*5,620*	*23.60 (7.87)*	*0.79 (8.55)*	*0.043 (0.008)*
INGA1	*0*	*4,569*	*2,149*	*293*	*906*	*13.47 (9.43)*	*-0.99 (7.02)*	*0.040 (0.008)*
PEFO1	*1*	*13,280*	*5,229*	*2,297*	*3,338*	*19.84 (9.27)*	*-4.10 (7.96)*	*0.042 (0.008)*
SAGU1	*10*	*357,515*	*168,614*	*26,734*	*92,900*	*28.44 (8.00)*	*5.06 (7.90)*	*0.041 (0.009)*
CA	7	1,151,942	543,804	145,479	303,837	25.44 (7.94)	2.41 (5.13)	0.036 (0.015)
DEVA1	*2*	*61*	*17*	*7*	*24*	*25.71 (11.41)*	*0.47 (7.61)*	*0.043 (0.009)*
SAGO1	*4*	*1,151,881*	*543,787*	*145,472*	*303,813*	*25.44 (7.94)*	*2.41 (5.13)*	*0.036 (0.015)*
UT	6	5,585	1,895	455	1,642	*16.93 (10.59)*	*-2.58 (6.75)*	*0.046 (0.008)*
CANY1	*6*	*5,585*	*1,895*	*455*	*1,642*	*16.93 (10.59)*	*-2.58 (6.75)*	*0.046 (0.008)*
NV	0	45,150	14,719	4,435	17,680	-	-	-
GRBA1	*0*	*27,806*	*7,591*	*1,820*	*12,881*	-	-	-
JARB1	*0*	*17,344*	*7,128*	*2,615*	*4,799*	-	-	-

* within the 50 km buffer

† maximum temperature, dew point, and ozone are notated as: mean (standard deviation)

3.2. Comparing Pollutant Concentrations on Dust and Non-Dust Days

Pollutants that were used in the algorithm that identified dust event days were PM_{10}, $PM_{2.5}$, ammonium nitrate, ammonium sulfate, arsenic, calcium, elemental carbon, organic carbon, copper, iron, lead, potassium, silicon, titanium, zinc (20). As expected, these pollutants were observed in higher concentrations on days with dust events than on days without dust events. PM_{10} concentrations on days with dust events were, on average, 47.44 $\mu g/m^3$ (6 times) higher than the non-dust event day average of 8.79 $\mu g/m^3$. $PM_{2.5}$ concentrations also elevated by approximately 3 times on dust event (average of 12.34 $\mu g/m^3$) compared to non-dust event days (average of 3.79 $\mu g/m^3$). Figure 1 displays the differences in these pollutants between dust event days and non-dust event days with 95% confidence intervals on dust event and non-dust events days during the study period while table provides the specific measured concentrations of this figure. Many more pollutants were measured by the IMPROVE sites, however were not included as these were not identified by Tong et al. (2012) to be a significant indicator of dust events (20).

Figure 1. Pollutant Concentrations on Dust Event and non-Dust Event Days.

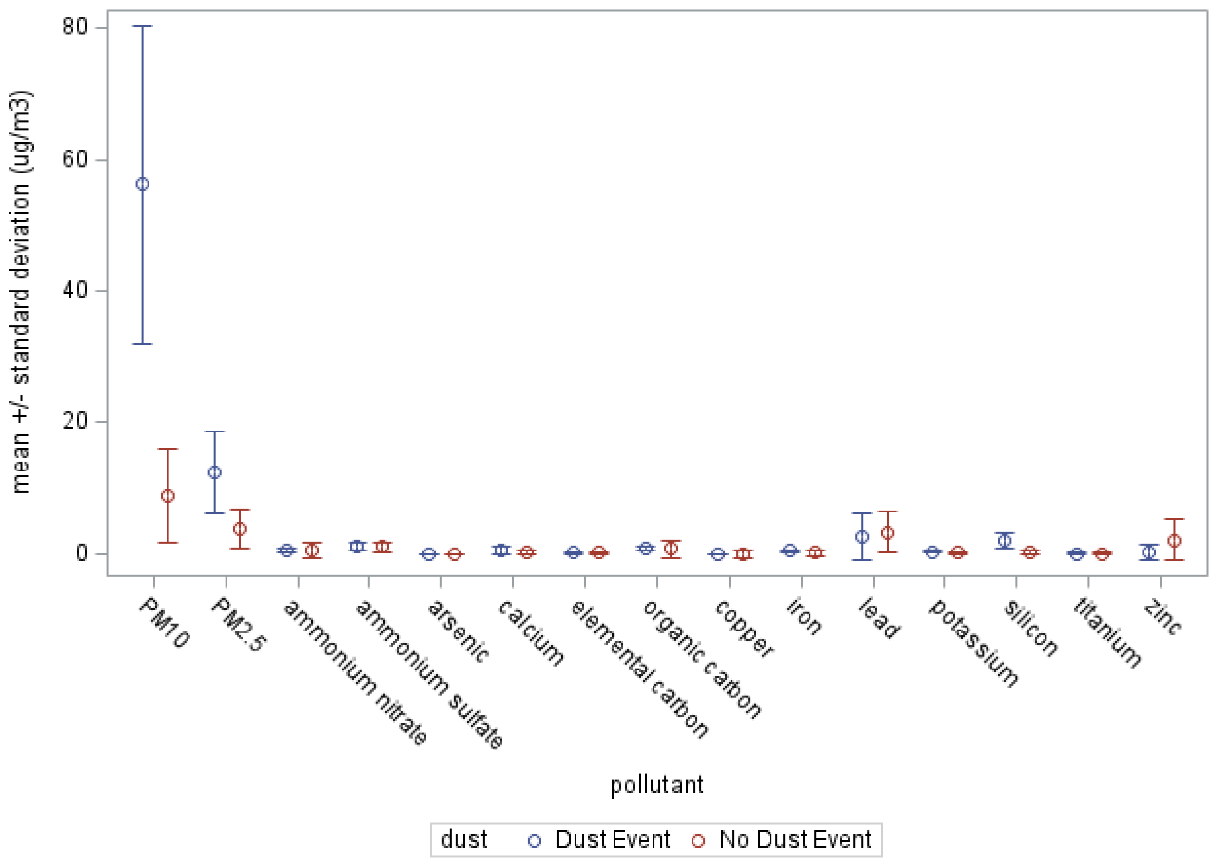


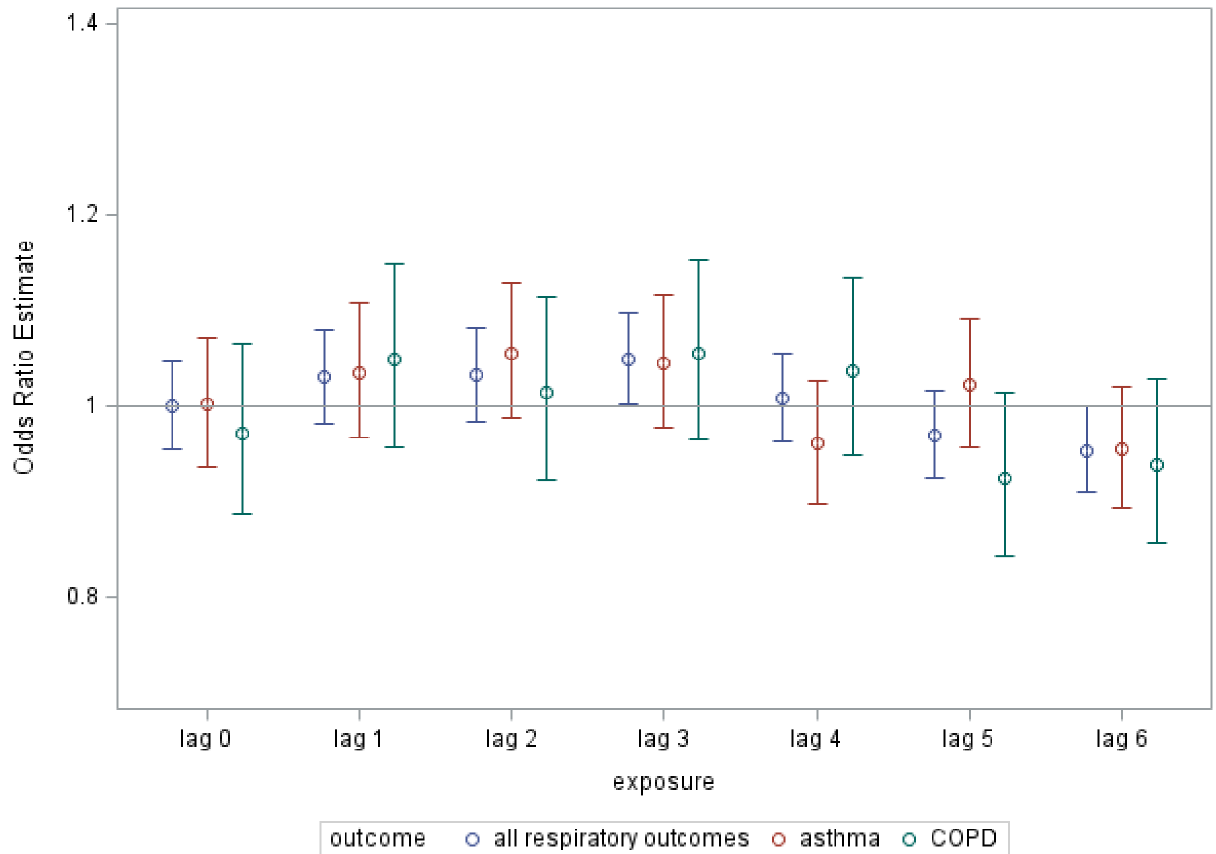
Table 2. Pollutant Concentration of Dust Event and non-Dust Event Days.

	Dust Event Day			Non-Dust Event Day		
Variable	N	Mean	Standard Deviation	N	Mean	Standard Deviation
PM_{10}	129	56.23	24.17	26181	8.79	7.07
$PM_{2.5}$	122	12.34	6.32	25516	3.79	2.99
ammonium nitrate	117	0.39	0.29	24435	0.46	1.17
ammonium sulfate	123	1.13	0.61	25400	1.00	0.72
arsenic	123	<0.01	<0.01	25727	<0.01	<0.01
calcium	123	0.51	0.48	25726	0.08	0.32
elemental carbon	112	0.06	0.07	24146	0.15	0.18
organic carbon	114	0.79	0.42	24191	0.72	1.28
copper	123	<0.01	<0.01	25727	-0.06	0.57
iron	123	0.37	0.22	25725	0.08	0.49
lead	122	2.70	3.56	24758	3.19	3.12
potassium	123	0.26	0.15	25726	0.05	0.13
silicon	123	1.90	1.11	25725	0.21	0.28
titanium	123	0.03	0.02	25726	<0.01	0.07
zinc	123	0.19	1.20	25684	2.08	3.18

3.3. Associations of Dust Storms and Respiratory ED Visits

In our primary model, we estimated the associations of dust storms and ED visits for the all respiratory, asthma, and COPD outcomes with all sites combined. Figure 2 presents odd ratio (OR) estimates with 95% confidence intervals (CI) for the effect of dust events on the same day (lag 0) and preceding days up to lag 6. The pattern of observed association across lag days was similar for the three outcomes, with strongest ORs generally observed at lag 3 (e.g., for all respiratory ED visits, OR of 1.049; for asthma ED visits OR of 1.044; and for COPD ED visits, OR of 1.055) with weaker ORs observed at shorter and longer lags.

Figure 2. Odds Ratio Estimates for All Respiratory, Asthma, and COPD Outcomes.



3.3.1. Secondary Analyses – Stratified by State

To determine if the observed results were consistent across all states within outcomes, the conditional logistic regression was run for Arizona and California independently. Nevada had no observed dust events during the study period and Utah did not contribute sufficient emergency department visits, and thus Utah-specific analyses lacked statistical power for conducting independent analyses. Figure 3 shows the ORs and 95% confidence intervals for the association of dust storms and all respiratory ED visits, overall and by state. Similar trends were observed in Arizona as for all sites combined (Figure 2). For Arizona, the odds of respiratory ED visits were significantly elevated both two and three days after a dust storm [ORs of 1.066 (95% CI: 1.004, 1.133) and 1.068 (95% CI: 1.008, 1.133), respectively]. Results for California were consistent with the null, with no systematic pattern across lags.

Figure 3. Odds Ratio Estimates for All Respiratory Outcomes Stratified by State.

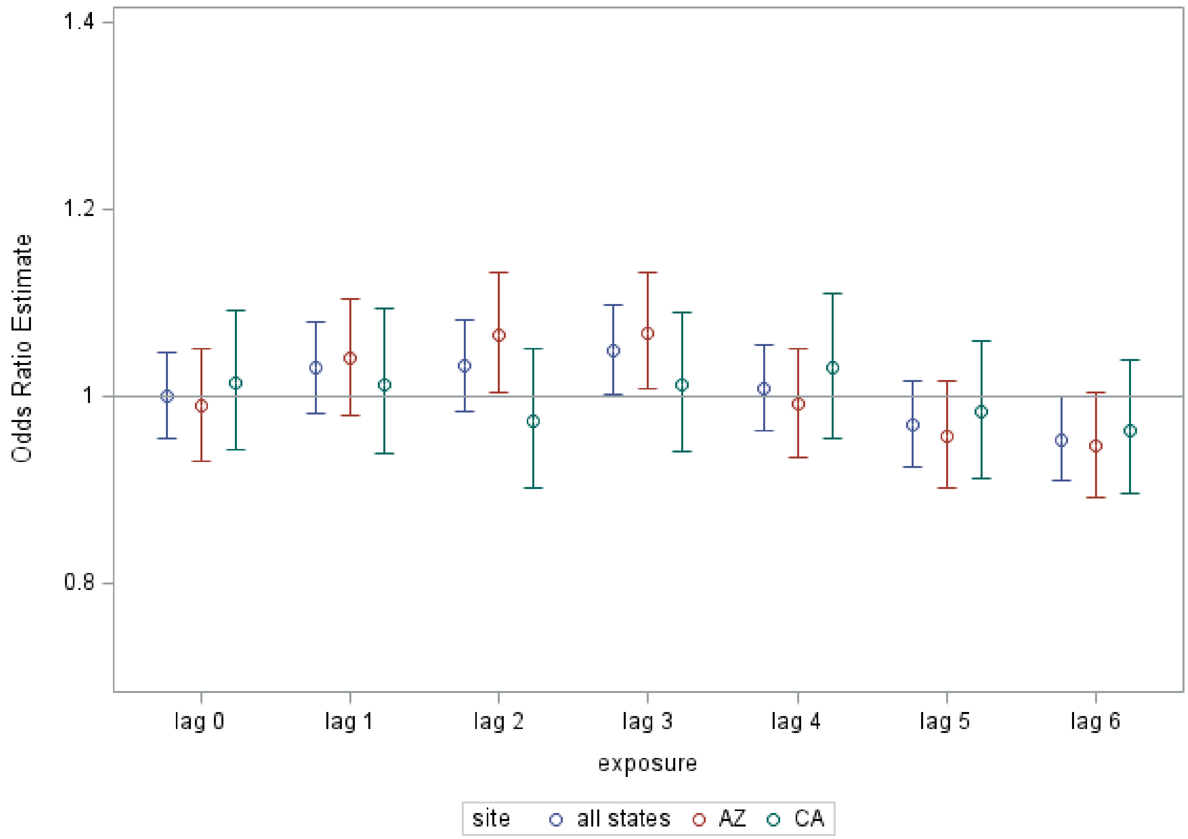
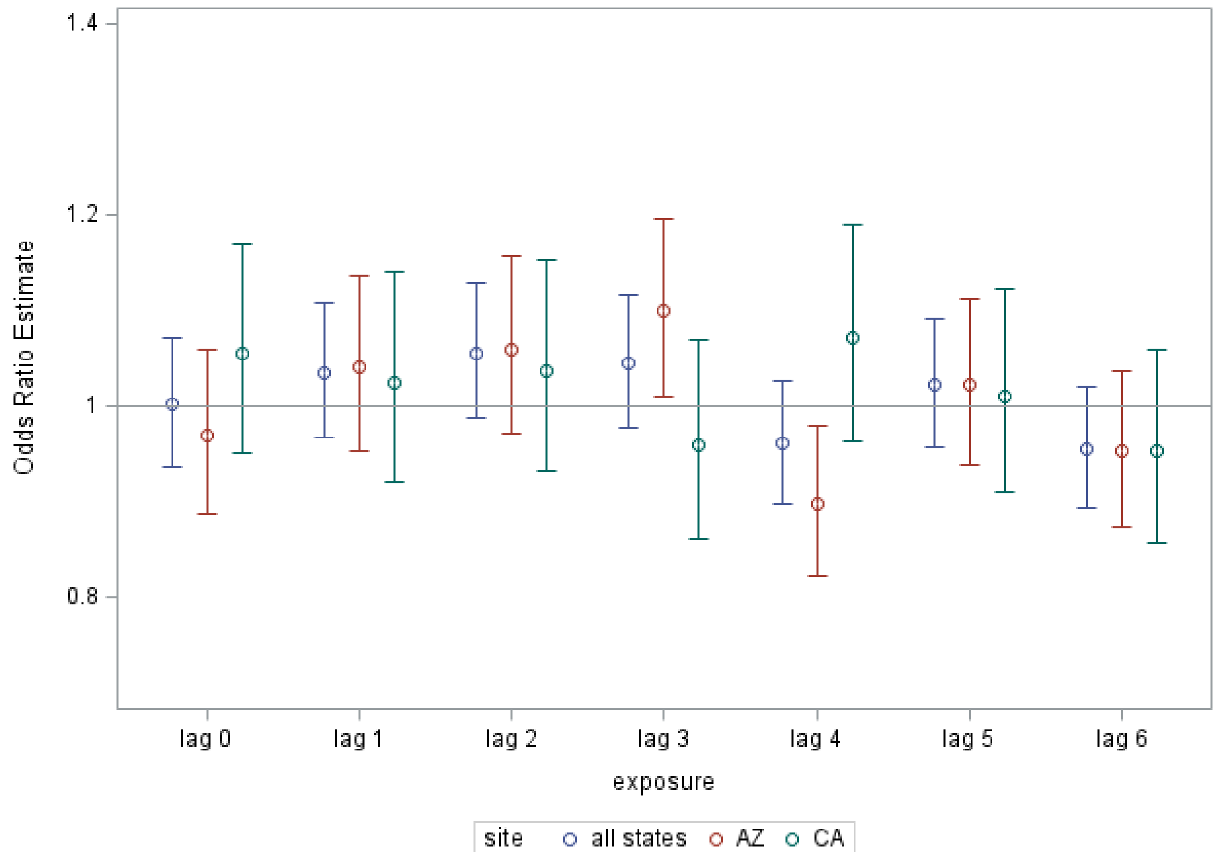


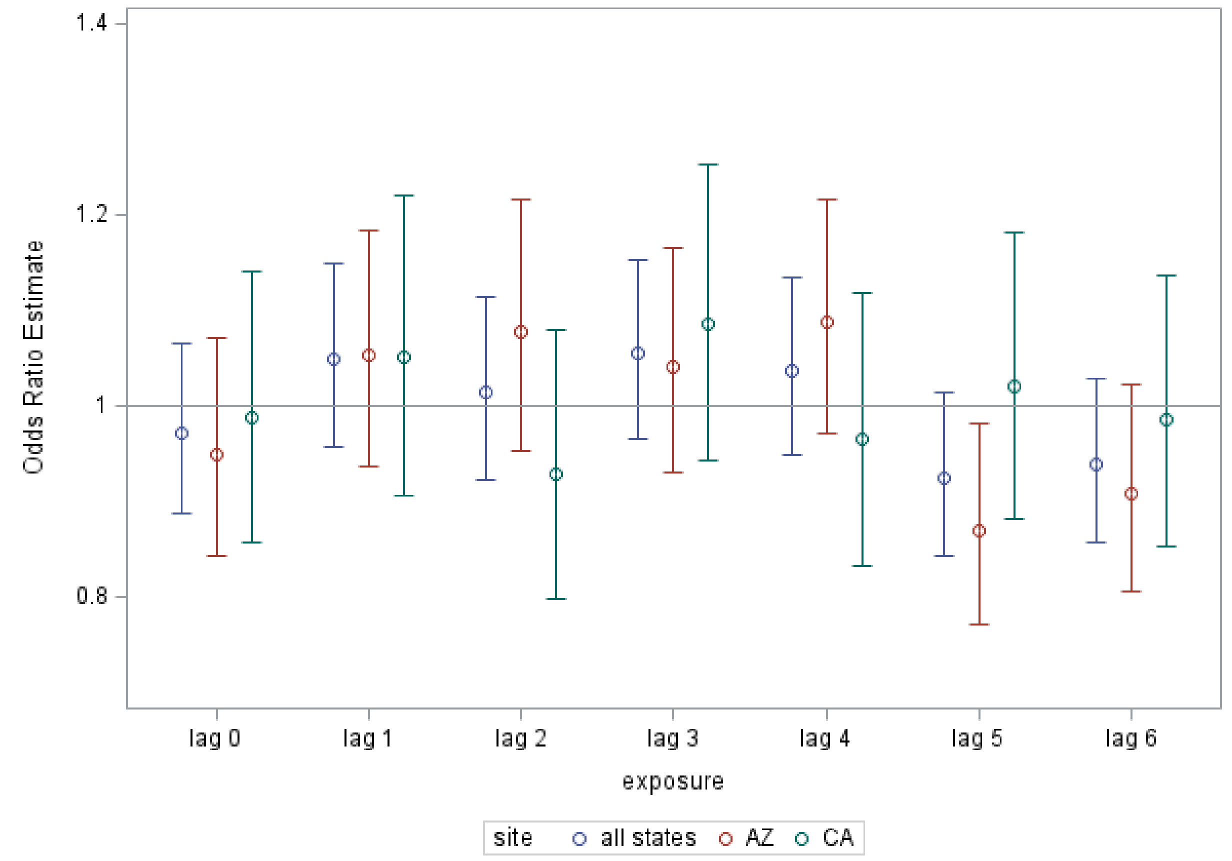
Figure 4 presents associations of dust storms with asthma ED visits, stratified by state (excluding NV and UT). State-specific associations for asthma had larger confidence intervals compared to overall analyses incorporating data from all sites (Figure 2), as expected given the lower ED visit counts contributing to each state-specific analysis. Similar to the pattern of effects observed for respiratory ED visits, we observed a significant increased risk of asthma emergency department visits three days after a dust event (1.100, 95% CI: (1.010, 1.197)) in Arizona. We also observed a protective effect four days after a dust event (0.898, 95% CI: (0.823, 0.979)).

Figure 4. Odds Ratio Estimates for All Asthma Outcomes Stratified by State.



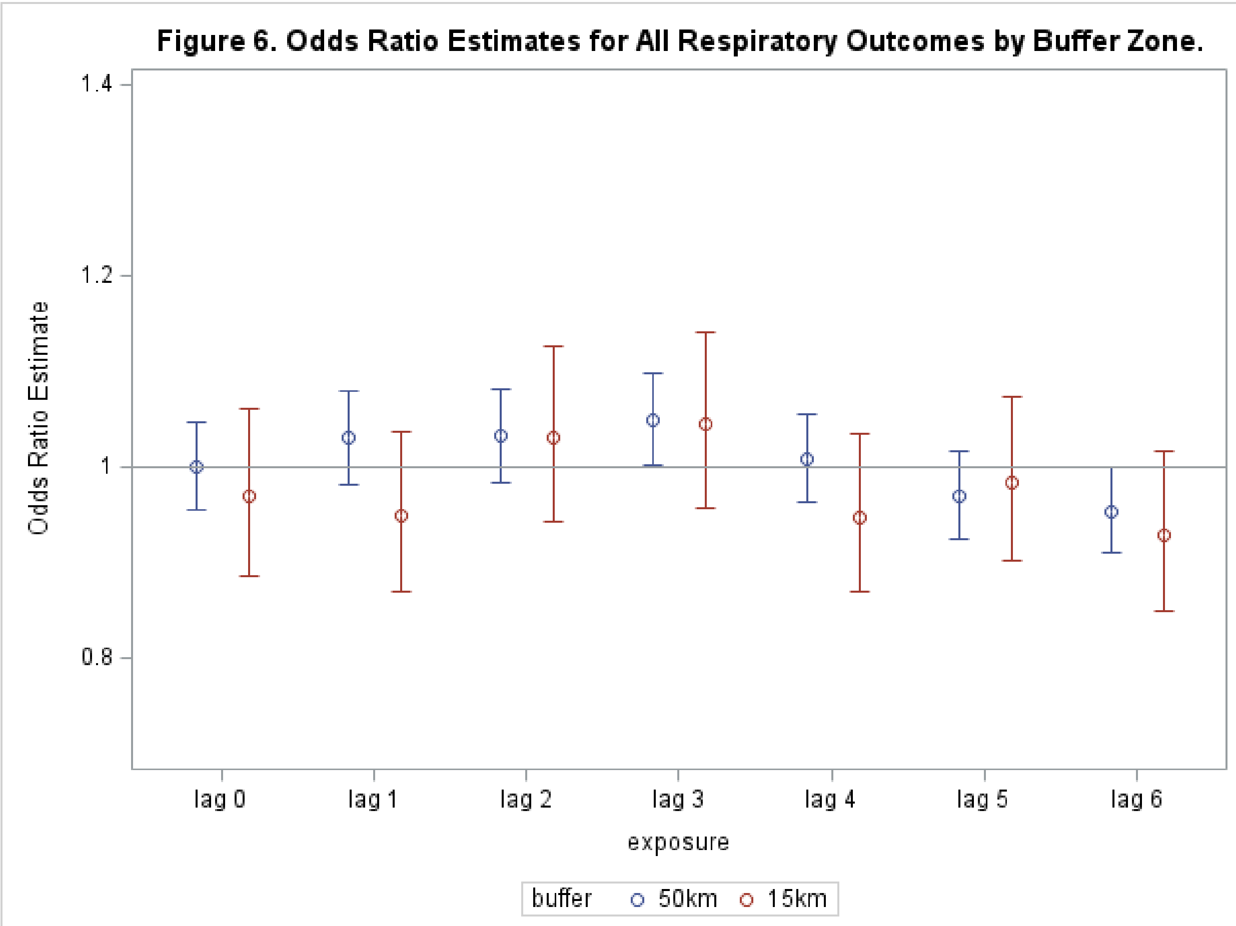
Stratifying the odds ratio estimates by state for COPD outcomes (Figure 5) resulted in wide confidence intervals (average range: 0.237) and similar, but delayed patterns across state level data when compared to respiratory and asthma outcomes. For example, strongest positive associations in Arizona were observed for dust events at lag 4 (OR of 1.088); and a significant protective effect five days after a dust event (OR: 0.870, 95% CI: (0.772, 0.982)).

Figure 5. Odds Ratio Estimates for All COPD Outcomes Stratified by State.

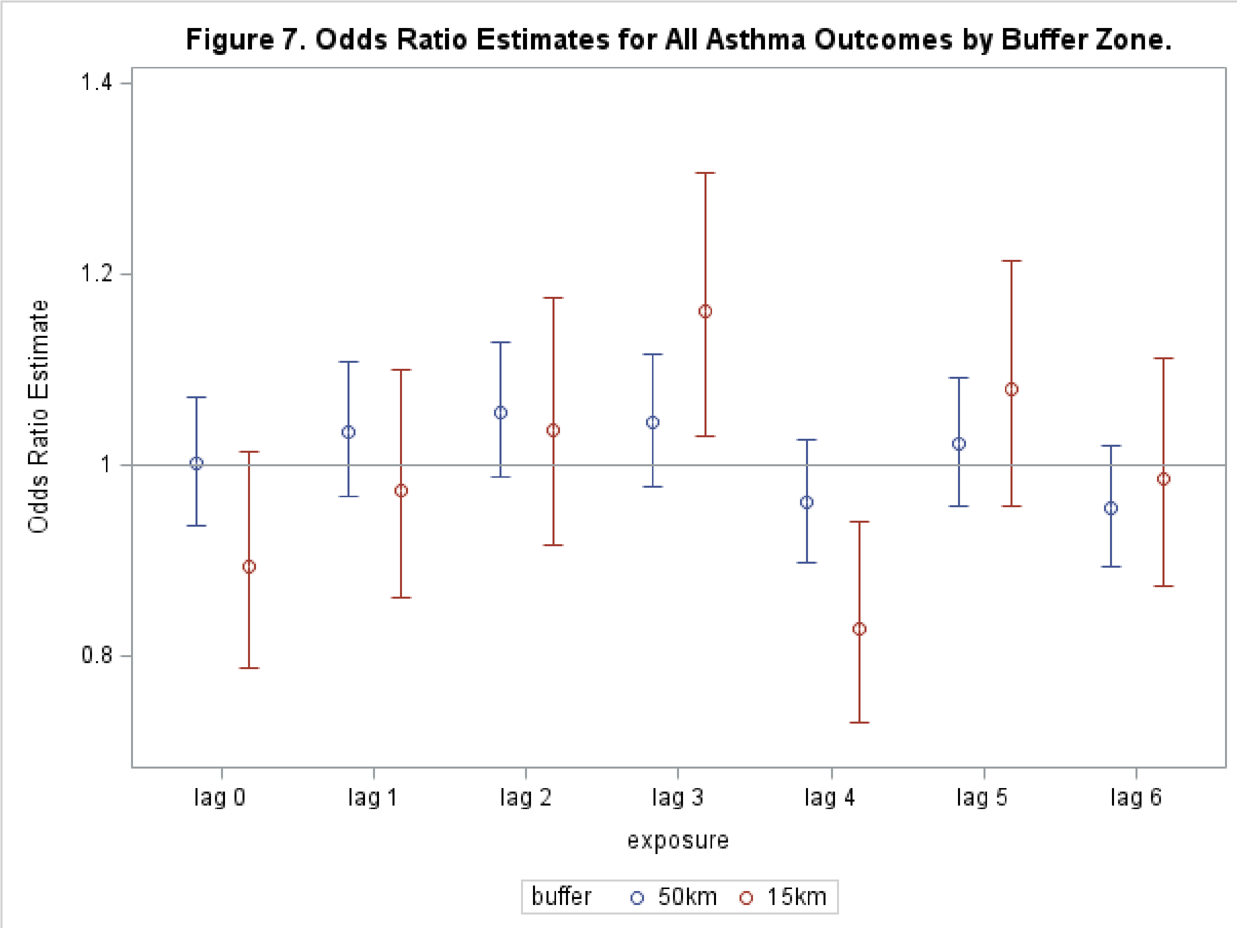


3.3.2. Secondary Analyses – Buffer Zones

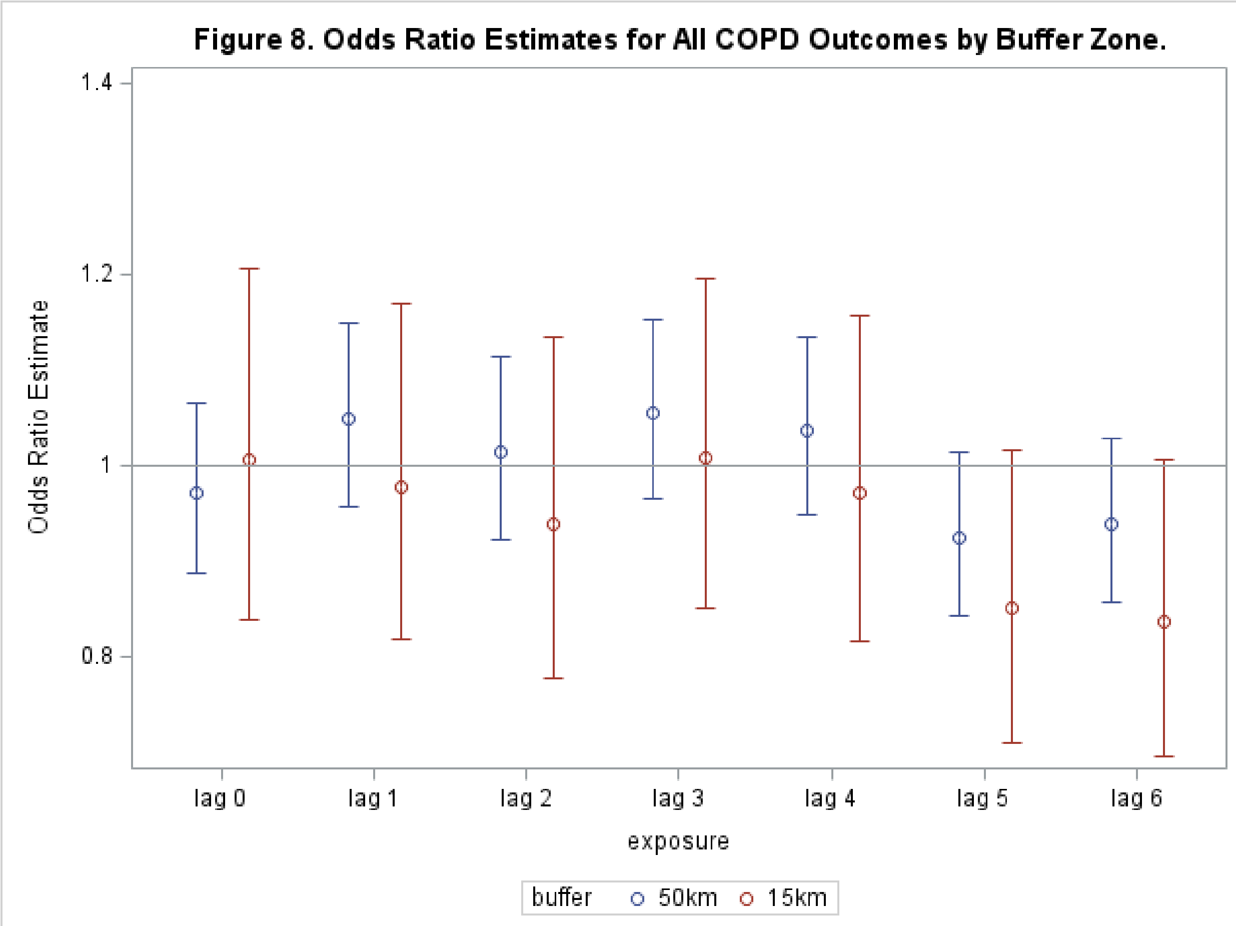
The primary analysis included ED visits by patients residing in a buffer zone of 50 km from each IMPROVE monitoring site. This buffer was chosen to enable inclusion of sufficient numbers of emergency department visits, and thus statistical power, for the analysis. Since 50 km is a large distance, and may be prone to exposure measurement error for patients living at the furthest distances, we assessed the representativeness of associations among patients living within a smaller buffer zone of 15 km of each IMPROVE site. These analyses excluded ED visits from patient ZIP codes at distances of further than 15 km from the IMPROVE site, thus reducing power. Figure 6 shows a comparison of results from analyses of dust storms and respiratory ED visits from the 50km buffer and the 15km buffer zones. While no statistically significant results were observed due to the wide confidence intervals, the results from the different buffer zones showed similar patterns.



The same pattern was generally observed for asthma ED visits (Figure 7), although the lag 3 and lag 4 results were accentuated (further from the null, with results of 1.160, 95% CI: (1.030, 1.307) and 0.829, 95% CI: (0.731, 0.941), respectively) when examining ED visits from the 15 km vs. 50 km buffer zone.

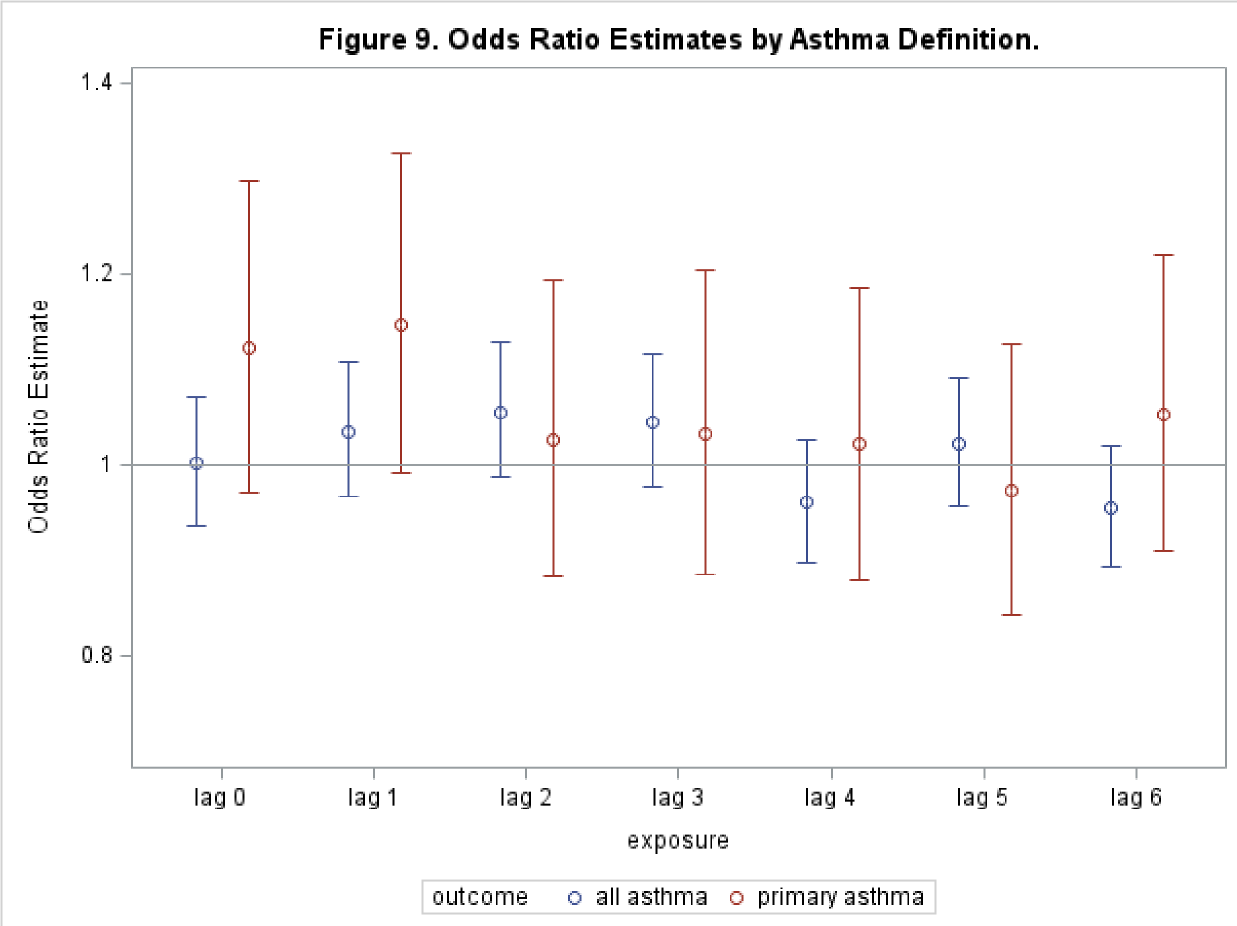


For COPD ED visits, results were consistent with the null across all lags for both buffer zone sizes (Figure 8).



3.3.3. Secondary Analyses – Definition of Asthma

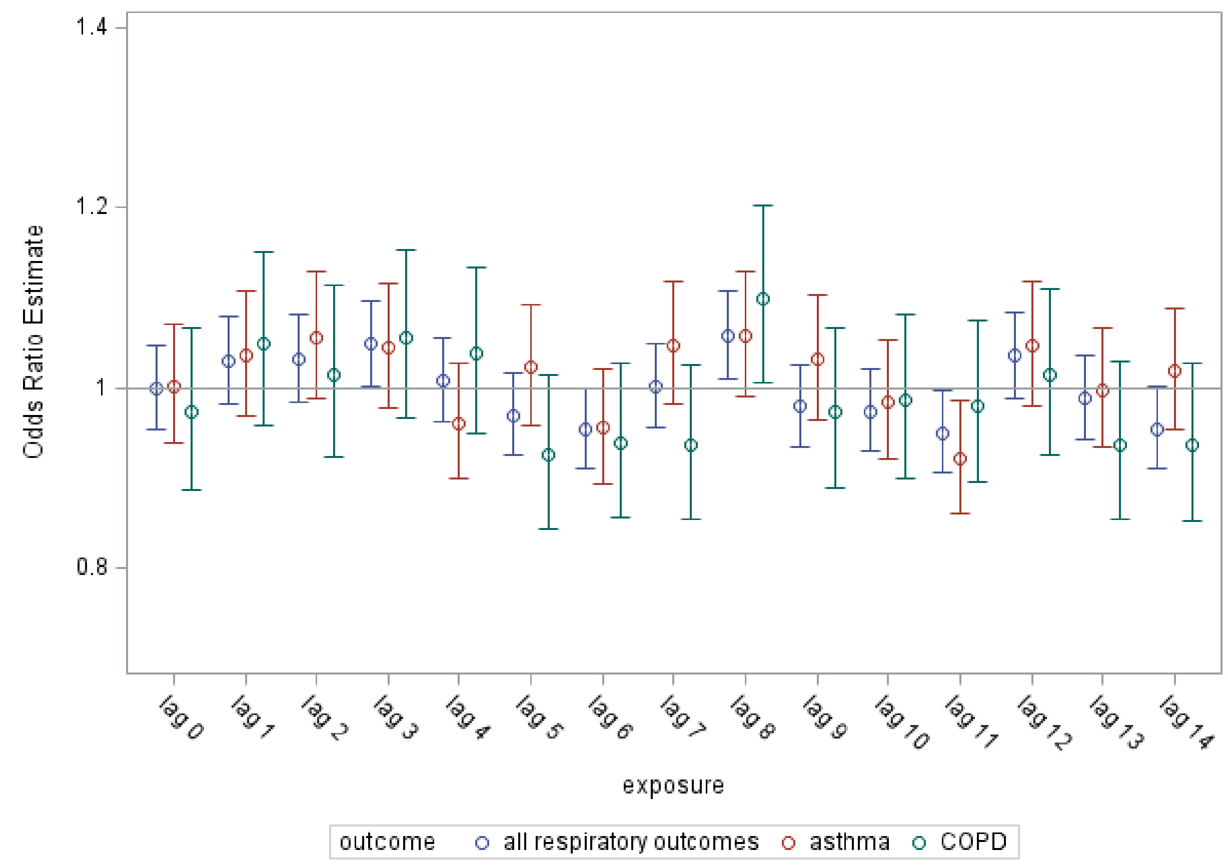
We compared associations for asthma ED visits among different definitions of asthma, comparing our main definition ('any asthma') that included emergency department visits with an asthma ICD code (either the reason for the visit or a co-existing condition at the time of the visit) versus a 'primary asthma' that included emergency department visits only with a primary ICD code for asthma. Overall, the comparison did not show substantial differences in results of models with dust storms (Figure 9). While confidence intervals were larger for primary asthma, as anticipated given the lower counts, slightly stronger associations were observed for primary asthma compared to any asthma at lags 0 and 1.



3.3.4. Secondary Analyses – Additional Lags

While extending lags beyond the case crossover window introduces repeating case and control strata, we considered lags up to day 14 prior to ED visits to determine potential longer-term adverse respiratory health effects from dust events. Similar patterns in the width of the confidence intervals were observed in the extended lags when compared to the base model lag 0 through lag 6. The association between outcomes and ED visits varied systematically across lags with the strongest positive association at lag 3 (OR: 1.002 – 1.055) and lag 8 (OR: 1.100 – 1.057) and the strongest protective effects at lag 6 (OR: 0.939 – 0.956) and lag 11 (OR: 0.922 – 0.980).

Figure 10. Odds Ratio Estimates with Additional Lags.



4. Discussion

In this study, we applied a monitoring-based metric of dust storms leveraging data collected from the IMPROVE monitoring network, and ED visits by patients living in ZIP codes surrounding the IMPROVE monitors in the Southwestern US during 2005-2016. We estimated associations for all respiratory conditions, asthma, and COPD, considering dust storm lags, states, buffer zones, and outcome definitions. Overall, we observed associations of dust storms in the preceding 2-3 days and ED visits for all respiratory diseases and asthma, particularly in Arizona. No significant observations were found for COPD or in California, likely attributable to the low ED visit counts and low number of observed dust storms, respectively, resulting in limited power.

The total number of observed dust events in this study of 23 was much lower than the numbers of dust events observed in other studies with larger observation periods. Crooks et al. (2016) observed 209 dust events across the US between 1993 and 2005 while Chan and Ng (2011) observed 380 dust events between 1994 and 2007 in Taipei, Taiwan (10, 17). These studies used different metrics for measuring dust storms including the US National Weather Service (NWS) storm database for Crooks et al. (2016) and the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite by Chan and Ng (2011). The NWS database used by Crooks et al. (2016) is a relatively inconsistent tool for reporting as dust storms are reported from local officials and the public without verification before inclusion in the database (17). In MODIS observations, graphical data from the satellite is used to triangulate the location of the dust storm and is compared to background concentrations of PM_{10} but is limited in the ability to detect storms as different than clouds and is only available to collect data during the day (10). Our monitoring-based metric was limited to days with available monitoring data, which was only 1-in-3 or 1-in-6 days, and thus limited statistical power in analyses. Despite the increased statistical power available in the previous Crooks at al. (2016) and Chan and Ng (2011) studies, we expect that the monitoring-based exposure measurement used in the current analysis is more accurate to actual occurrences of dust events than the measures used in previous studies.

The ORs found in this analysis are of a similar magnitude as ORs found by Chen & Ng (2011) in Taipei and Crooks et al. (2016) in the U.S. These studies found similar associations of between a 7.4 and 2.7% increase in total mortality following a dust storm (10, 17). Figure 6 through 8's comparison across different buffer zones showed expected results. Confidence intervals were larger as the number of observations included in the analysis is reduced from a smaller buffer zone. The 15 km buffer was expected to have a more accurate exposure estimate and lower error in the exposure estimate when compared to the 50 km buffer as it is closer to the IMPROVE monitoring site. As there was no systematic improvement in the OR estimates, this was indicative that using the larger buffer zone as the base model in the analysis was appropriate. Some results at the smaller buffer are observed to be more extreme than the 50 km buffer, potentially due to a low sample size.

Results from figure 9, comparing the definitions of asthma, were as expected with wider confidence intervals as a result of fewer observations. All asthma observations included all ED visits, even if asthma was the primary or secondary cause of the emergency department visit, while primary asthma only included the former. The increased OR estimates observed in the primary asthma outcomes in the immediate few days following a dust event suggest that dust storms could potentially be a driver of exacerbations of asthma, and are less commonly the other reasons for an emergency department visit. The observed findings in this analysis on all respiratory and asthma emergency department visits add to the existing literature on dust storms and adverse respiratory health effects.

The increasing frequency of dust storms has been linked to climate change through the desertification of soil and increasing ocean temperatures (27). While the effect that dust storms had on climate change was noted as early as 1967 with Bryson and Baerreis suggested that without “adequate grass cover”, deserts would be more stable, and cooler temperatures would result from less direct heat to the ground (28). It’s now known that dust storms are liked to higher air temperatures, affect sulfur dioxide in the atmosphere, cloud formation, and marine life, therefore increasing carbon dioxide in the atmosphere (29). In addition, evidence points to global dust storm movement and substance deposition playing a part in increasing snow melt and lessening glacial formation during winter months (30). Goudie (2009) suggests that dust storm activity in the future will rely on anthropogenic land modification, normal climate variability, and global warming caused climate change (29). While there is limited study on future dust storm activity in the U.S., evidence points to drastic environmental change in South Africa as a result of eroding dunes and increased dust movement (31). As dust storms are integral to global health, and the future of dust storms appears to be both increasing in frequency and intensity, climate protection and reduction in dust storms will be closely linked in the coming future.

There are several strengths to highlight for this analysis, including multi-year study periods in four US states where dust storms are of concern, and use of a validated dust event metric based on ground-level monitoring data. There were also several limitations to acknowledge. Limitations include the missing data in the IMPROVE sites due to the 1-in-3 and 1-in-6 day sampling schedules, as well as lack of representativeness of urban areas for our study. IMPROVE monitor siting purposefully targets rural areas; thus, observed associations in this study do not capture the impact of dust storms on large population centers in Arizona, California, Nevada, or Utah. IMPROVE data is only collected every three days, making it impossible to observe over time with moving averages and requiring all lags to be interpreted as individual data sets. Additionally, the majority of IMPROVE sites are in national or state parks, often in areas with fewer homes and people. These areas have fewer people, with fewer measured ED visits and a lowered ability to detect associations for less common outcomes such as COPD. Conversely, the locations of IMPROVE sites in rural areas does provide strengths in the lack of confounding variables from urban air pollutants. Data on urban pollutants was not available at the IMPROVE sites, but as these are far from heavy traffic, this was not considered to be a concern to this study. The measured increases observed in the risk of adverse respiratory health effects and asthma three days after a dust storm add to the growing literature highlighting the risk of dust storms on human health.

5. Conclusion

Using a monitoring-based exposure metric, we observed associations among respiratory ED visits and dust storms. The results add to growing evidence of the health threat posed by dust storms. The dust storm metric was limited by lack of daily monitoring data; future research will incorporate satellite and models for enhanced dust storm characterization.

6. References

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