Association of short-term exposure to ground-level ozone and respiratory outpatient clinic visits in a rural location – Sublette County, Wyoming, 2008–2011[☆]

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ABSTRACT

Objective: Short-term exposure to ground-level ozone has been linked to adverse respiratory and other health effects; previous studies typically have focused on summer ground-level ozone in urban areas. During 2008–2011, Sublette County, Wyoming (population: ~10,000 persons), experienced periods of elevated ground-level ozone concentrations during the winter. This study sought to evaluate the association of daily ground-level ozone concentrations and health clinic visits for respiratory disease in this rural county.

Methods: Clinic visits for respiratory disease were ascertained from electronic billing records of the two clinics in Sublette County for January 1, 2008–December 31, 2011. A time-stratified case-crossover design, adjusted for temperature and humidity, was used to investigate associations between ground-level ozone concentrations measured at one station and clinic visits for a respiratory health concern by using an unconstrained distributed lag of 0–3 days and single-day lags of 0 day, 1 day, 2 days, and 3 days.

Results: The data set included 12,742 case-days and 43,285 selected control-days. The mean ground-level ozone observed was 47 ± 8 ppb. The unconstrained distributed lag of 0–3 days was consistent with a null association (adjusted odds ratio [aOR]: 1.001; 95% confidence interval [CI]: 0.990–1.012); results for lags 0, 2, and 3 days were consistent with the null. However, the results for lag 1 were indicative of a positive association; for every 10-ppb increase in the 8-h maximum average ground-level ozone, a 3.0% increase in respiratory clinic visits the following day was observed (aOR: 1.031; 95% CI: 0.994–1.069). Season modified the adverse respiratory effects: ground-level ozone was significantly associated with respiratory clinic visits during the winter months. The patterns of results from all sensitivity analyses were consistent with the *a priori* model.

Conclusions: The results demonstrate an association of increasing ground-level ozone with an increase in clinic visits for adverse respiratory-related effects in the following day (lag day 1) in Sublette County; the magnitude was strongest during the winter months; this association during the winter months in a rural location warrants further investigation.

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1. Introduction

Ozone occurs both in earth's upper atmosphere (stratosphere), where it protects against ultraviolet radiation, and at ground-level (troposphere), where it can cause adverse respiratory effects and is a major component of air pollution (Environmental Protection Agency, 2013c). The two main classes of ozone precursors are volatile organic compounds (VOCs) and nitrogen oxides (NO_x) (Environmental Protection Agency, 2013c). VOCs refer to all carbon-containing gas-phase compounds in the atmosphere and the oil and gas industry is the largest industrial source of VOCs (Environmental Protection Agency, 2014). Exposure to elevated ground-level ozone can affect the health of any person; however, such populations as the young, seniors, and persons with pre-existing respiratory health conditions are particularly susceptible (Environmental Protection Agency, 2013a, 2013c; Villeneuve et al., 2007). Symptoms of adverse respiratory health effects can include shortness of breath; coughing; wheezing; eye, nose or throat irritation; and pain or burning when taking a deep breath. Adverse respiratory-related effects after ground-level ozone exposure have been extensively documented in studies and include induction of respiratory illness symptoms, increased asthma attacks, increased hospital admissions, increased daily mortality, and other markers of morbidity (Meng et al., 2011; Medina-Ramon et al., 2006; Peel et al., 2005; Yang et al., 2003). In previous studies, adverse respiratory-related effects caused by elevated ground-level ozone occurred most commonly during the summer months in urban centers (Environmental Protection Agency, 2013b; North Carolina Department of Health and Human Services, 1999; Paulu and Smith, 2008; Yamazaki et al., 2009).

During January–March of 2008 and 2011, ground-level ozone concentrations exceeded the U.S. Environmental Protection Agency national ambient air-quality standard level of 75 ppb (Environmental Protection Agency, 2013b). Studies completed in Sublette County suggested that snow cover, combined with high concentration of ground-level ozone precursors trapped within a relatively small volume of air (an inversion), could be the cause of the high wintertime ground-level ozone concentrations (Schnell et al., 2009). In response to the elevations, the Wyoming Department of Environmental Quality (WY DEQ) started in-house weather forecasting to evaluate the potential for elevated ground-level ozone (personal communication, Wyoming Department of Environmental Quality, 2011). The ground-level ozone forecasting occurs daily during the months of January–March to give expected conditions for the current and next two days. The ozone updates give the public information about expected ground-level ozone concentrations that will help persons make decisions about outside activity (Wyoming Department of Environmental Quality, 2014). Ozone notifications are distributed to the public via websites, Sublette County newspapers, radio stations, and online news sources (Wyoming Department of Environmental Quality, 2014). Persons can also call a toll free number and sign up for email updates (Wyoming Department of Environmental Quality, 2014). WY DEQ and industry have developed short-term emission reduction ozone contingency plans that are implemented on days with forecasted conditions that favor elevated ozone levels (Wyoming Department of Environmental Quality, 2014).

Residents of Sublette County have expressed concern regarding possible health effects from ground-level ozone and sought information from public health officials on local adverse health effects (personal communication, Wyoming Department of Health (WDH), 2011). Information on adverse health effects from ground-level ozone specifically in Sublette County has been lacking, although a vast literature provides strong evidence regarding the adverse health impacts of ground-level ozone (Environmental Protection Agency, 2013a). We evaluated the association between

daily ambient ground-level ozone concentrations and adverse acute respiratory-related effects among persons residing and seeking health care within Sublette County and examined seasonal differences in these associations.

2. Materials and methods

2.1. Setting

Sublette County is located in western Wyoming and is $\geq 4,800$ square miles. This region of Wyoming has experienced recent population growth; from 2000 to 2010, the population increased 73.1%, from 5920 to 10,247 (2.1 persons/square mile) (United States Census Bureau, 2010). Six communities are located in the county, ranging from 93 persons to 2030 persons (United States Census Bureau, 2010). Sublette County is an area of year-round tourism for outdoor activities, including hiking, snow skiing, snowmobiling, and other activities. Active oil and gas development is also occurring in Sublette County; the number of drilling rigs increased from two in 1996 to 49 in 2006 and the number of oil and gas wells increased from 1900 in 2000 to $> 10,000$ in 2008 (personal communication, Wyoming Department of Environmental Quality, 2011).

Two area health clinics provide both primary and urgent care. Because no hospital is available in Sublette County, patients commonly seek care at one of the two area primary care clinics; if needed, ill patients are transferred out of the county to one of the hospitals in the surrounding communities. Hospitals with specialized and emergent care are located approximately 80 miles north and 100 miles south of the main population centers in the county.

The Air Quality Division (AQD) Monitoring Section of the WY DEQ has the responsibility to protect, conserve, and enhance the quality of Wyoming's air resource and AQD monitors air quality in accordance with the National Ambient Air Quality Standards (Wyoming Department of Environmental Quality, 2014). AQD operates and maintains a network of ambient air quality monitors (Wyoming Department of Environmental Quality, 2014). Since 2005, WY DEQ has monitored ground-level ozone and fine particulate matter (PM_{2.5} or particles $\leq 2.5 \mu\text{m}$ in diameter) in Sublette County. During January 1, 2008–December 31, 2011, a total of 13 monitors recorded ground-level ozone data for selected periods; four of these monitoring stations also recorded PM_{2.5} data. Eight of the 13 monitors are part of the EPA Air Quality System, and the other five monitors were part of a yearlong air toxins study during February 2009–March 2010. In addition to hourly ground-level ozone, some monitoring stations recorded full meteorologic data daily, including wind direction, wind speed, temperature, humidity, barometric pressure, and solar radiation.

2.2. Health data

Health outcome data were obtained from electronic billing records of the only two area clinics for January 1, 2008–December 31, 2011. Information collected included a unique identification number, *International Classification of Diseases* (9th rev) (ICD-9) diagnostic codes, date of birth, age, and sex. All visits for an adverse respiratory effect were included with the following primary ICD-9 diagnostic codes (all two-digit extensions were used unless otherwise specified): acute bronchitis (466), asthma (493), chronic obstructive pulmonary disease (491–492, and 496), pneumonia (480–486), upper respiratory tract infection (460–465, and 477), and other respiratory (786.09) during the study period.

2.3. Ambient air pollution and meteorologic data

Daily maximum 8-h ground-level ozone and 24-h average temperature and humidity data were obtained from WY DEQ for all 13 monitoring stations. Monitoring stations were assessed on completeness of data and correlations between 8-h maximum ground-level ozone. The two monitoring stations, Boulder (56-035-0099) ($n=1249$) and Daniel (56-035-0100) ($n=1363$), had the most complete ground-level ozone data for the study period, but the Boulder monitoring station was closest to the oil and gas field and a low proportion of the Sublette County population resided near the monitor. After review and analysis of the air data, the Daniel monitoring station was selected to represent the ground-level ozone exposures *a priori* for Sublette County for the following reasons: (1) the Daniel monitoring station had the most complete daily data for ground-level ozone concentrations, temperature, and humidity for January 1, 2008–December 31, 2011; (2) the Daniel monitoring station was highly correlated with other monitoring stations in population centers with missing data (e.g. the Pinedale monitoring station (56-035-010)); and (3) in other ground-level ozone health effect studies, using a central monitoring station has been reported to be a surrogate measure for ground-level ozone exposures for the population of that area (Environmental Protection Agency, 2013a).

2.4. $PM_{2.5}$ data

Three $PM_{2.5}$ monitoring stations collected hourly data, and one collected data every third day. The monitoring stations were assessed on completeness of data, correlations between $PM_{2.5}$ stations, and correlations to the Daniel monitoring station.

2.5. Statistical analyses

Descriptive statistics were conducted to evaluate the distribution of visits to the area health clinics, ground-level ozone concentrations from all 13 monitoring stations, and meteorology conditions. Descriptive statistics calculated for each of the monitoring sites included mean, median, minimum, maximum, number of observation days, and standard deviation. In addition, correlations of 8-h maximum ground-level ozone concentrations between the monitoring stations were calculated to assess if concentrations at different monitoring stations were associated.

A time-stratified case-cross over design was used to estimate the association of ground-level ozone concentrations and clinic visits for respiratory-related illnesses. Case-crossover analysis uses conditional logistic regression to compare the exposure on the case-day with the weighted average of the exposure on the selected control-days to estimate adjusted odds ratios (Lu and Zeger, 2007; Jaakkola, 2003; Carracedo-Martinez et al., 2010). The case-crossover study design inherently controls for factors that do not vary within person (e.g., age, sex, genetics) and adjusts for confounding by longer term trends and meteorological factors (Lu and Zeger, 2007; Jaakkola, 2003; Carracedo-Martinez et al., 2010).

Case-days were designated for each person who visited either of the two area clinics for one of the defined respiratory disease diagnoses and represent the day of the clinic visit. For the case-crossover analysis, a month was chosen as the stratum to minimize confounding by meteorology, seasonality, and other factors that have longer-term variations. Control-days were matched to case-days by day of week within the same month of the case-day. For example, if the case-day was on the second Tuesday in January, the selected control-days were all other Tuesdays in January.

Adjusted odds ratios (aORs) and 95% confidence intervals (95% CIs) were estimated. The *a priori* lag structure was an unconstrained distributed lag of the same-day 8-h maximum average

ground-level ozone concentrations (lag 0) and ground-level ozone lag 0–3 days before the case- or control-day. Temperature and humidity parameters were included *a priori* the day of the clinic visit (lag 0) and were determined by model fit. The model contained same-day (lag 0 day) 24-h temperature, lag 0 temperature squared; same-day (lag 0 day) humidity; and an unconstrained distributed lag 0–3 days 8-h maximum average ground-level ozone concentrations. Separate models for each single-day ground-level ozone lag (0, 1, 2, and 3 days) with the same temperature and humidity parameters were also evaluated. Further analysis was conducted to determine if respiratory-related health effects from the ground-level ozone differed by season. Season was assessed two ways: (1) WY DEQ ozone season (January–March) and non-ozone season (April–December) and (2) the 6 warmest months (May–October) and the 6 coldest months (November–April). WY DEQ has defined ground-level ozone season according to the months in which exceedances had previously occurred; during these months, WY DEQ issued ground-level ozone action days when needed. Temperature data from the Daniel monitoring station was used to calculate median temperature by month for the study period to determine the 6 warmest and 6 coldest months.

In addition to these analyses, the following sensitivity analyses were performed: exclusion of ground-level ozone action days (WY DEQ forecast day with ground-level ozone exceeding 75 ppb) days (19 days); exclusion of days after a ground-level ozone action day (19 days); and exclusion of days with ground-level ozone concentrations ≥ 75 ppb (6 days for the Daniel monitoring station). Models with alternative adjustment for temperature (average, minimum, and maximum) and humidity were evaluated to assess the robustness of the model. Sensitivity analyses were also evaluated by using ground-level ozone data from the Boulder monitoring station and a two-pollutant model including $PM_{2.5}$.

This study underwent review by CDC's for human subjects protection and was determined to be nonresearch. WDH's Institutional Review Board also determined this study exempt from review.

3. Results

3.1. Health data

Females accounted for 52.7% (6717) of the 12,742 case-days. The mean age of clinic visits for respiratory illness was 31.2 years (median, 28.6 years; range: 4 months–98 years). Of the respiratory-related visits, 38% (4863) were among children aged ≤ 17 years, 53% (6,758) were among adults aged 18–64 years, and 9% (1,121) were among persons aged ≥ 65 years. In Sublette County, females accounted for 45.8% (4693) of the total population of 10,247, persons aged ≤ 17 years accounted for 23.2% (2377), and persons aged ≥ 65 years accounted for 8.8% (902) of the population (United States Census Bureau, 2010).

3.2. Ambient air pollution and meteorologic data

The 8-h maximum ground-level ozone averages followed a similar pattern year-to-year with the highest concentrations early in the year (February–April) and the lowest concentrations later in the year (October–December). All monitoring station data followed the same pattern. Fig. 1 displays the 8-h maximum ground-level ozone averages for all 13 monitoring stations for January 1, 2008–December 31, 2011. Ground-level ozone concentrations were moderately to highly correlated between the different monitoring stations (range: 0.61–0.94), except for data collected at the Wyoming Range monitoring station, which was less correlated

Fig. 1. 8-h maximum ground-level ozone for all 13 monitoring stations, Sublette County, Wyoming January 2008–December 2011. Boulder, Daniel, Big Piney, Wyoming Range, Jonah, Pinedale CastNet, Juel Spring, Pinedale, FARS, SADR, MARB, Lab1, BARG.

with the other monitoring stations (range: 0.61–0.82). The Wyoming Range monitor was in the far northwest corner of the county, located at ≥ 1000 feet higher in elevation than all other monitors and was not near a population center or an oil or gas field. Table 1 displays the results of the descriptive analyzes for ground-level ozone data from the Daniel and Boulder stations and data for PM_{2.5}, temperature, humidity, case-days, and control-days. The Daniel monitoring station was used *a priori* for ground-level ozone exposure and the Boulder monitoring station was used to represent ground-level ozone exposure in sensitivity analyzes.

3.3. PM_{2.5} data

Available data from the PM_{2.5} monitors ranged from < 1 year to 3 years. PM_{2.5} correlations between the four stations were low (range: 0.15–0.51). The station with the most data, Pinedale high school PM_{2.5} monitoring station, was chosen to be used in the two-pollutant model (ground-level ozone and PM_{2.5}) and was poorly correlated with the Daniel ozone monitoring station (correlation coefficient 0.21).

3.4. Time-stratified case-crossover

A total of 12,742 case-days and 43,285 control-days were included in the analyzes. Repeat visits within 7 days (2790/15,532) were not included as separate case-days. The aORs for clinic visits for the defined respiratory codes associated with ground-level ozone concentrations by the cumulative unconstrained distributed lag 0–3 day model and single-lag models are displayed in Fig. 2.

Table 1
Descriptive analyzes of Daniel and Boulder ground-level ozone and meteorological monitoring stations and PM_{2.5} monitoring station, Sublette County, Wyoming, January 1, 2008–December 31, 2011.

Parameter	Observation days	Mean	SD	Median	Minimum	Maximum
Boulder ozone (ppb)	1429	49	10	49	22	123
Daniel ozone (ppb)	1363	47	8	47	19	84
PM _{2.5} (μg/m ³) ^a	1068	4.14	2.57	3.91	–2.5	16.13
Temperature (°C) ^b	55,828	0.65	10	–0.18	–29	21
Humidity (%) ^b	55,999	64	17	68	19	97
Case-day ozone (ppb)	12,742	47	8	47	23	84
Control-day ozone (ppb)	43,285	47	8	47	23	84

^a Pinedale High School PM_{2.5} monitoring station.
^b Daniel monitoring station.

Fig. 2. Results per 10 ppb increase in the 8-h maximum ground-level ozone, *a priori* lag model; adjusted for temperature and humidity. UCD=unconstrained distributed.

Although not significant at the $P < 0.05$ level, the results for a lag of 1 day indicate an association between ground-level ozone concentrations and an increase clinic visits in the following day. A 3% increase in adverse respiratory-related clinic visits was associated with every 10-ppb increase in the 8-h maximum ground-level ozone concentrations (aOR: 1.031; 95% CI: 0.994–1.069). The other lag models (0, 2, and 3 days and unconstrained distributed lag 0–3 days) were consistent with a null association.

3.5. Seasonal differences

The magnitude of adverse respiratory-related effect was larger during the DEQ ozone season (January–March; mean 49 ground-level ozone concentration) compared with the non-DEQ ozone season (April–December; mean 46 ground-level ozone concentration) and the year-round estimates. Season modified the effect; the strongest association of adverse respiratory-related clinic visits the following day for every 10-ppb increase in the 8-h maximum ground-level ozone concentrations was during the coldest months (DEQ ozone season January–March; aOR: 1.077; 95% CI: 1.020–1.137) (Fig. 3). Defining season by the coldest 6 months and the warmest 6 months demonstrated similar results for lag 1 day, but the results were attenuated (November–April; aOR: 1.053; 95% CI: 1.003–1.105) (Fig. 4). The patterns of results were consistent with the *a priori* model, but the magnitude of the association increased during the coldest months, regardless of how season was defined.

3.6. Sensitivity analyzes

The results of the sensitivity analyzes were consistent with the primary analysis (see Supplement Tables 1–7). The results from the two-pollutant model were also consistent with the primary analysis and the other sensitivity analyzes (Fig. 5).

Fig. 3. Results per 10-ppb increase in the 8-h maximum ground-level ozone Department of Environmental Quality (DEQ) ozone season and non-DEQ ozone season; adjusted for temperature and humidity. January–March. April–December.

4. Discussion

Although the majority of our results are consistent with the null, $P > 0.05$, in the *a priori* model, the lag 1 results indicate an association between ground-level ozone concentrations and an increase in respiratory clinic visits. Specifically, every 10-ppb increase in the 8-h maximum ground-level ozone concentration was associated with a 3% increase in respiratory clinic visits the next day (lag 1 day) (aOR: 1.030; 95% CI: 0.999–1.070). This association was robust in sensitivity analyses and when adjusting for $PM_{2.5}$. Our results are consistent with a meta-analysis reporting that adverse respiratory effects from ground-level ozone are similar with and without PM adjustment (Meng et al., 2011). $PM_{2.5}$ is primarily a traffic-related pollutant and has been reported to be inversely correlated with other pollutants during the cool season; therefore we expected that the magnitude of effect for ground-level ozone on respiratory-related clinic visits in this region would not change after adjustment (Mar and Koenig, 2009; Stieb, et al., 2009). Of note, our models were not limited to those days that exceeded the regulatory standard; we evaluated and identified respiratory-related health impacts across the entire range of the 8-h maximum ground-level ozone observed (19–84 ppb) and not only for those days that exceeded the regulatory standard.

The results of this study are consistent with other studies of ground-level ozone-associated adverse health effects. Single-city studies have observed associations between hospital admissions or emergency department visits for adverse respiratory effects and ground-level ozone concentrations (Environmental Protection Agency, 2013b; Villeneuve, et al., 2007). In a meta-analysis, findings demonstrated that hospital admissions on the day after (lag 1 day) an increase in ground-level ozone concentrations were consistently higher, compared with the hospital admissions on the

Fig. 5. Results per 10 ppb increase in the 8-h maximum ground-level ozone; adjusted for $PM_{2.5}$, temperature, and humidity. UCD=unconstrained distributed.

same day (lag 0 day) for all comparisons (Meng et al., 2011). Of all air pollutants present at ground-level, ozone has the smallest margin between natural background levels and those that are considered harmful to human health (Syri et al., 2001).

Regarding the winter in Sublette County, we determined that ground-level ozone concentrations were associated with an increase in clinic visits the next day (lag 1 day). Sublette County differs from other areas of the world with ground-level ozone monitoring in that the elevated ground-level ozone concentrations occur primarily in the cold season (February and March) versus the warmer summer months in urban areas (Environmental Protection Agency, 2013b; Medina-Ramon et al., 2006). Seasonal differences in adverse respiratory-related health effects in Sublette County were assessed by using two different definitions for *winter season*; the adverse respiratory-related-health related effects were stronger during the winter months in Sublette County regardless

Fig. 4. Results per 10-ppb increase in the 8-h maximum ground-level ozone 6 warm months and 6 cold months; adjusted for temperature and humidity. May–October. November–April.

of how *winter season* is defined. A meta-analysis observed associations between ground-level ozone and adverse respiratory effects during the summer (largest effect), all year, and during the cold season (Meng et al., 2011). The meta-analysis included studies completed in North America, Europe, Asia, and Australia, with the majority of locations encompassing temperate areas with more typical summertime ground-level ozone. However, some study locations included areas with colder climates similar to Wyoming's. The results of the meta-analysis and this study indicate that ground-level ozone-associated adverse respiratory-health effects are widespread.

A prior study completed in northern Alberta, Canada, reported that health effects are associated with ground-level ozone in both the cold and warm season, with a larger association between ozone and emergency department visits occurring during the summer months (Villeneuve et al., 2007). Although the climates of northern Alberta and Wyoming are similar, the seasonal ground-level ozone patterns are different (Villeneuve et al., 2007). Ground-level ozone levels in Wyoming are higher during the winter months, whereas in Alberta, the ground-level ozone concentrations are higher during the summer months (Villeneuve et al., 2007). The difference in seasonal ground-level ozone patterns might explain the differences observed between the two studies. As stated previously, this is not the first study to report that ground-level ozone levels can have an effect during the winter months, but in this area of Wyoming, the adverse respiratory-related effects were stronger during the winter months than the more typical summer elevations in ground-level ozone in other areas. The larger effect of ground-level ozone during the warmer months has been consistent with the knowledge of time activity patterns; people tend to spend more time outdoors during the warmer months (Environmental Protection Agency, 2013b). However, in Sublette County, certain occupations require outside activity all year, which coupled with the elevated wintertime ground-level ozone concentrations, might account for the stronger effect of winter season in our study. Analysis by occupation type was not able to be explored in this study because data regarding occupation were lacking. Future studies are warranted to help explain the differences observed in this region, including further research into the formation of wintertime ground-level ozone.

The removal of the DEQ ozone notification days and the days immediately after a notification day had no effect on the results. If the association between clinic visits and ground-level ozone was purely a function of persons seeking care because of the perceived health effects when ground-level ozone concentrations were expected to be high, removing these days would have attenuated the magnitude of association. Further, no change in the magnitude of association was observed when the days with ground-level ozone concentrations ≥ 75 ppb were excluded from the analysis, demonstrating that results are not being driven by or only a result of the days with an 8-h maximum ground-level ozone higher than the regulatory standard of 75 ppb (Environmental Protection Agency, 2013b).

This study has certain potential limitations. This is one of few studies to measure health clinic visits rather than emergency department visits or hospital admissions to examine the association of ground-level ozone with adverse respiratory effects. In this rural setting, no local emergency department or hospitals exist. Clinic visits differ from hospital emergency department visits because primary care occurs at these clinics (including follow-up visits). We were unable to distinguish follow-up visits from new visits, yet the time-stratified case-crossover design was chosen to minimize biases by controlling for seasonal variation, personal risk factors, and day-of-week and calendar effects. All models included ground-level ozone measurement data from a central monitoring station, which might not have been representative of personal

exposure; that exposure could not be assessed in this study (Stafoggia et al., 2010; Jaffe et al., 2003). However, using a central ground-level ozone monitoring station is a common technique for these types of studies and would probably attenuate the observed associations, and not lead to spurious associations (Mar and Koenig, 2009; Medina-Ramon et al., 2006). The sample size might have limited the statistical power to detect associations, and we were unable to evaluate interactions by groups. Because of the limited PM_{2.5} data, not all potential confounding by PM_{2.5} might have been controlled for in this study.

5. Conclusion

A limited number of studies have examined adverse respiratory effects of ground-level ozone exposure among persons-residing in rural communities. The results from this study provide evidence of an association between ground-level ozone concentrations and adverse respiratory effect-related clinic visits in Sublette County, Wyoming. Our recommendations from this study are to improve awareness and education of the public and healthcare providers of the adverse respiratory-related effects from ozone in Sublette County. The stronger association between increases in ground-level ozone and adverse respiratory health effects during the cooler months in a rural location warrants further investigation.

Conflict of interest

All the authors has no financial disclosures.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.envres.2014.10.033>.

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