

Association between asthma hospital visits and ozone concentration in Maricopa County, Arizona (2007-2012)

1. Introduction:

Asthma is a chronic disease that affects a considerable number of adults and children alike. It has also been a growing public health challenge in industrialized countries for the last few decades where it reached epidemic levels, despite the introduction of new medications (W. Eder, M.J. Ege, & E. von Mutius, 2006; N. Le Moual et al., 2013). While there is a general consensus that, based on available data, the prevalence of asthma has been on the rise in western countries, the underlying causes of this increase are much less clear. On the one hand, it could partially be attributed to the advent of diagnostic tools and improved reporting, whereas on the other hand, the role of air pollution, other environmental factors, genetics, and life style changes cannot be ignored (K.L. Ebi & G. McGregor, 2008; P.E. Sheffield, K. Knowlton, J.L. Carr, & P.L. Kinney, 2011). Nonetheless, based on available evidence, it is now accepted that air pollution is a risk factor for asthma (A. Oosterlee, D. Marjon, E. Lebet, & B. Brunekreef, 1996; A. Venn, S. Lewis, M. Cooper, R. Hubbard, & J. Britton, 2001). Not only has this effect been found to be statistically significant, the biological mechanism through which exposure to air pollutants exacerbates the severity of asthma symptoms has also been explained (J. Cienciewicki, S. Trivedi, & S.R. Kleeberger, 2008; J.F. Gent et al., 2003; J.C. Slaughter, T. Lumley, L. Sheppard, J.Q. Koenig, & G.G. Shapiro, 2003). Ozone is one of the pollutants that were found to be associated with increased risk of asthma hospitalizations and deaths in studies worldwide including the U.S. (S.M. Babin et al., 2007; Centers for Disease Control and Prevention, 2010; R.J. Delfino, H. Gong, Jr., W.S. Linn, E.D. Pellizzari, & Y. Hu, 2003; R.J. Delfino et al., 2014; M. Jerrett et al., 2009; K.M. Mortimer, I.B. Tager, D.W. Dockery, L.M. Neas, & S. Redline, 2000). Additionally, ozone was found to be associated with development of new asthma cases in some studies (N. Künzli et al., 2009; W.F. McDonnell, D.E. Abbey, N. Nishino, & M.D.

Lebowitz, 1999; L. Modig, K. Torén, C. Janson, B. Jarvholm, & B. Forsberg, 2009). Although there is a general consensus in the literature on the adverse effect of ozone on asthma symptoms and hospitalizations (R.T. Burnett, J.R. Brook, W.T. Yung, R.E. Dales, & D. Krewski, 1997), some studies have produced inconclusive or conflicting results. This discordance is not completely unexpected and can be partly explained by differences in study population, designs, and analytic approach (L.J. Akinbami, C.D. Lynch, J.D. Parker, & T.J. Woodruff, 2010; P.L. Delamater, A.O. Finley, & S. Banerjee, 2012). Several studies have examined the association between asthma hospitalizations and/or emergency department visits in some metropolitan areas including Los Angeles, and Seattle because of the known link between air pollution in highly populated areas and asthma hospital visits and admissions (L.J. Akinbami, et al., 2010; P.L. Delamater, et al., 2012).

Maricopa County has grown considerably in the recent decades from less than a million inhabitants to one of the most populous counties in the nation with close to four million residents (United States Census Bureau, 2013). This rapid growth was probably accompanied by a comparable increase in traffic volume producing high level of volatile organic compounds, which are one of the main precursors of ozone (K.L. Ebi & G. McGregor, 2008; Ø. Hodnebrog et al., 2012). Consequently, epidemiological studies have found a higher risk of asthma hospitalizations/admissions among those living in close proximity to highways and street with high traffic volume (A. Oosterlee, M. Drijver, E. Lebet, & B. Brunekreef, 1996; P. van Vliet et al., 1997). Given this reality and the fact that the Phoenix metropolitan area is among the most polluted cities in the nation (American Lung Association, 2013), it is important to examine the potential effect of ozone level on hospital visits/admission among Maricopa County residents.

Therefore, the objective of this study was to evaluate the association between ozone concentration and asthma hospitalization from inpatient hospitalizations (IP) and emergency department (ED) visits in Maricopa County for the period from January 2007 through December 2012.

2. Materials and Methods:

2.1. Data sources: Inpatient (IP) and emergency department (ED) visits occurring in Maricopa County with one of asthma diagnosis codes (49300, 49301, 49302, 49310, 49311, 49320, 49321, 49322, 49381, 49382, 149390, 49391, and 49392) from January 1, 2007 through December 31, 2012 were extracted from the hospital discharge database (HDD) accessible to the Maricopa County Department of Public Health (MCDPH). Extracted data include the date of visit (only the day of the visit but not the time was available) and patient's address, which was used to geocode the records. Hourly ozone and temperature measurement from 16 monitoring stations distributed throughout Maricopa County urban and suburban areas were provided by the Maricopa County Air Quality Department (MCAQD) as displayed in figure 1.

2.2. Data management: Thiessen polygons were drawn around each air quality monitoring station to determine the most plausible source of exposure for each individual patient. Thiessen polygons are generated to ensure that any point (an asthma patient) inside the polygon is closer to the polygon center (ozone monitor) than any other polygon center (ozone monitor) in the area. This approach was used to ensure that all patients are assigned an ozone reading from closest monitor.

Mean daily ozone and temperature measurements were calculated from hourly measurements in preparation to merge them with patient data. Daily measurements were chosen to match the time scale of hospitalization records which are available only in daily format. Patient data were then divided by location into subsets corresponding to each Thiessen polygon as previously discussed. Each patient subset was merged with daily ozone and temperature data from the corresponding monitoring station by date and all subsets were appended together to form the full dataset containing patient's admission date along with ozone and temperature measurements. Lastly, the total patient daily counts indexed by visit date (days) and the overall daily mean of ozone and temperature measurement were calculated, along with the day of the week, to prepare the dataset for time-series analysis. Hospitalizations records and ozone/temperature reading in two exposure areas (Cave Creek and Rio Verde) had very small number of asthma visits during the study period and were excluded from the analysis (Figure 1).

2.3. Statistical analysis: We used time plots and the distributed lag linear and non-linear model (DLNM) (K. Bhaskaran, A. Gasparri, S. Hajat, L. Smeeth, & B. Armstrong, 2013; A. Gasparri, 2011) to evaluate the association between asthma hospital visits and ozone level while accounting for trend, season, temperature, and day of the week. Time plots were used to illustrate the overall pattern over time. The association between the daily number of asthma hospital visits and ozone concentration was evaluated using a Poisson model taking into account the effect of seasonality, long term trend, temperature, and the day of the week. Also, a lag component was added to the model to evaluate how long the effect of ozone exposure on the number of asthma hospitalizations lasts. Distribution of the model residuals over time was checked for signs of anomalies or indications for deviation from the model assumptions.

3. Results:

3.1. Descriptive

A total of 90,381 asthma hospitalizations were retrieved from the dataset (daily median=39, range: 8-122). Asthma hospitalizations were highest in 2008 (16,949), from November through December, and lowest in 2011 (13,213) and from June-July (Figure 2, top panel). By contrast, the average daily ozone concentration ranged from 27.05 in 2012 to 30.15 in 2008 and from 13.96 in December to 40.58 in May (Figure 2, bottom panel). Additionally, the median number of daily asthma hospitalized visits during weekdays [median=39; range (16-115)] did not vary considerably from the number of visits during weekends [median=40; range (14-122)].

Similarly, mean daily ozone concentration ranged from 29.34 on weekdays to 30.09 in weekends (table 1).

The final model was Poisson regression with daily asthma hospitalization count as the dependent variable and ozone as the independent variable adjusted for temperature and day of the week.

There was a significant association between the daily count of asthma hospitalizations and ozone concentration with a relative risk (RR) of 1.046; 95% CI(1.029-1.064) or equivalently 4.6% for every 10ppb increase in ozone level. The ozone effect seemed to decrease gradually after the first day of exposure and levels-off by lag day 5 (figure 3).

4. Discussion:

Our findings suggest that ozone level is positively associated with asthma hospital visits and that this effect lasts for several days after the exposure. Our results are in agreement with other studies that reported comparable, but slightly varying, effect size or relative risk estimates (A.G. Barnett et al., 2005; S. Cakmak, R.E. Dales, & F. Coates, 2012; B. Fauroux, M. Sampil, P.

Quenel, & Y. Lemoulllec, 2000; A. Holmen et al., 1997). These variations are not surprising and can probably be due to the differences in study population and statistical modeling methods (L.J. Akinbami, et al., 2010; P.L. Delamater, et al., 2012; T.F. Mar & J.Q. Koenig, 2009). For instance, an approximate 10% increase in asthma ED visits was reported by a study conducted in Seattle per 10 ppb increase in ozone, which may seem substantially higher from the estimate (RR=4.6%) reported here in Maricopa County. A closer look, however, reveals that the study from Seattle only used data from May through October characterized by high ozone levels which may explain the higher RR estimates.

Maricopa County has been growing noticeably over the past decades and has ozone concentrations which often exceed the national ambient air quality standards (NAAQS). Accordingly, it is important from a public health standpoint to estimate the effect of ozone concentrations on asthma hospital visits and, to our knowledge, this the first study to evaluate this effect in Maricopa County. Two of the main challenges in environmental and time-series analysis pertain to the method of exposure assessment and the time scale of the analysis. To increase the validity of the exposure variable and account for geographic variation, we chose to assign individuals to the closest air monitoring station rather than use a county-wide average over all stations. Because we were particularly interested in the lag time from exposure to hospitalization, we wanted to use a finer time scale than monthly or weekly. Additionally, the hospitalization information did not have time of admission which prevented us from examining a time scale smaller than daily.. The range of daily average ozone measurements reported in this study was within the acceptable standards set by the US EPA. However, data presented here are based on daily average which is an aggregation of the hourly recordings. Meaning, that an

individual station could have exceeded the US EPA limit at a given hour of the day and that would not be discernable from the data presented here. In fact, there were 12 high ozone days (8-hour maximum ozone >75 ppb) in the Phoenix metropolitan area in 2012 alone. Similarly, the daily number of asthma hospital visits probably varied by admission type, age groups and other demographic characteristics not considered here. However, it has been reported that for asthma and respiratory disease, children are more sensitive to ozone concentrations compared to adults (R.J. Delfino, et al., 2014; N. Künzli, et al., 2009; Arie Oosterlee, et al., 1996) and were probably affected disproportionately (T.F. Mar & J.Q. Koenig, 2009). Day of the week did not have any considerable effect on the asthma RR indicating that ozone's persistence in the ambient environment does not—in general—vary by different day of the week over our study area. This is supported by known temporal dynamics of ozone which tends to follow a diurnal pattern within urban areas, even on weekends, and a more constant pattern in suburban and rural areas (J.W. Gregg, C.G. Jones, & T.E. Daws, 2003; J.H. Seinfeld & S.N. Pandis, 2006).

Currently, the NAAQS list ozone concentrations higher than 75 ppb in an eight-hour average as unhealthy for sensitive groups. However, according to some advocate groups, the current standards need to be reviewed and updated (American Lung Association, 2013); this review is currently in progress by the U.S. Environmental Protection Agency (US EPA) in accordance with requirements in the 1990 Amendment to the Clean Air Act (US Environmental Protection Agency). Future areas for research include examining both the number of high ozone days and the magnitude of ozone levels and their impact on asthma hospital visits among the local population. As with other hospital discharge data, it should be acknowledged that some asthmatic patients may not seek treatment at hospitals depending on the severity of their conditions and the

influence of socio-economic factors on healthcare access. Consequently, the actual number of people with asthma as well as the magnitude of symptoms experienced in Maricopa County is probably higher than reported here.

5. References:

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7. Tables

Table 1: Descriptive statistics

Variable	# of observations	Mean	Median	St. dev.	Min.	Max.
Asthma hospitalizations count (per day)	2192	41.23	39	15.37	8	122
Mean daily temp (F).	2192	74.05	73.7	15.9	35.11	102.62
Mean daily ozone (ppb)	2192	28.67	29.53	11.39	3.37	59.09
Date					2007	2012

Table 2: Ozone coefficients and RR for asthma hospital visit counts obtained from Poisson model.

Model	Coefficient	St. Err.	z-score	P-value	RR	95% CI
Model ¹	-0.051	0.007	-7.404	<0.0001	0.95	0.937-0.963
Model ²	1.046	0.009	5.107	<0.0001	1.047	1.029-1.065
Model ³	1.045	0.008	5.386	<0.0001	1.047	1.029-1.064

¹ Not adjusted

² Adjusted for trend and seasonality

³ Adjusted for trend, seasonality, temperature and day of the week.

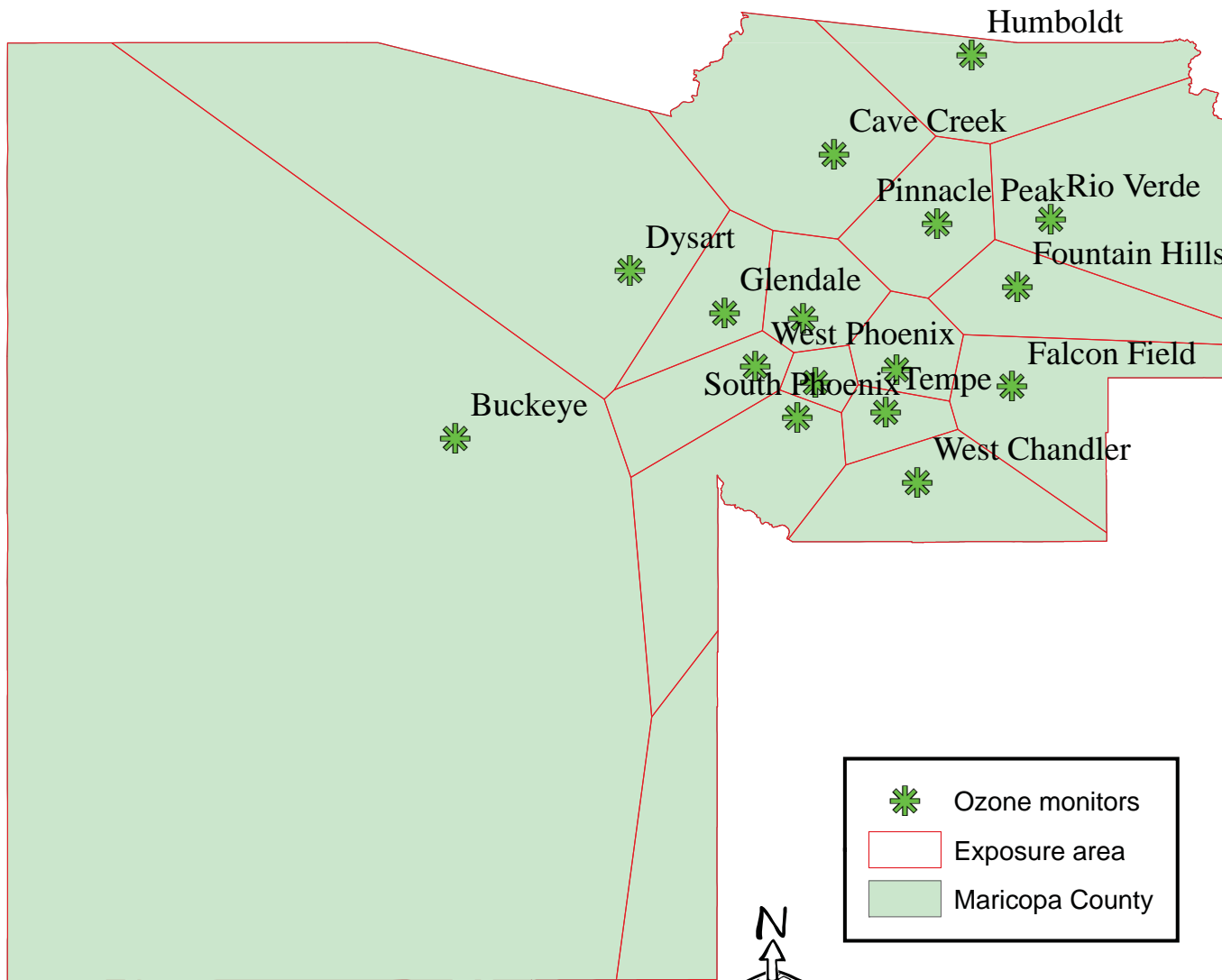
8. Figures legends




Figure 1: Geographic distribution of location of ozone monitors throughout Maricopa County with illustration of Thiessen polygons used to identify ozone exposure areas for each monitor.

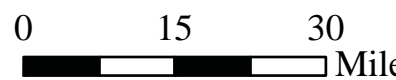
Figure 2: Geographic distribution of asthma patients visiting hospitals in Maricopa County (2007– 2012).

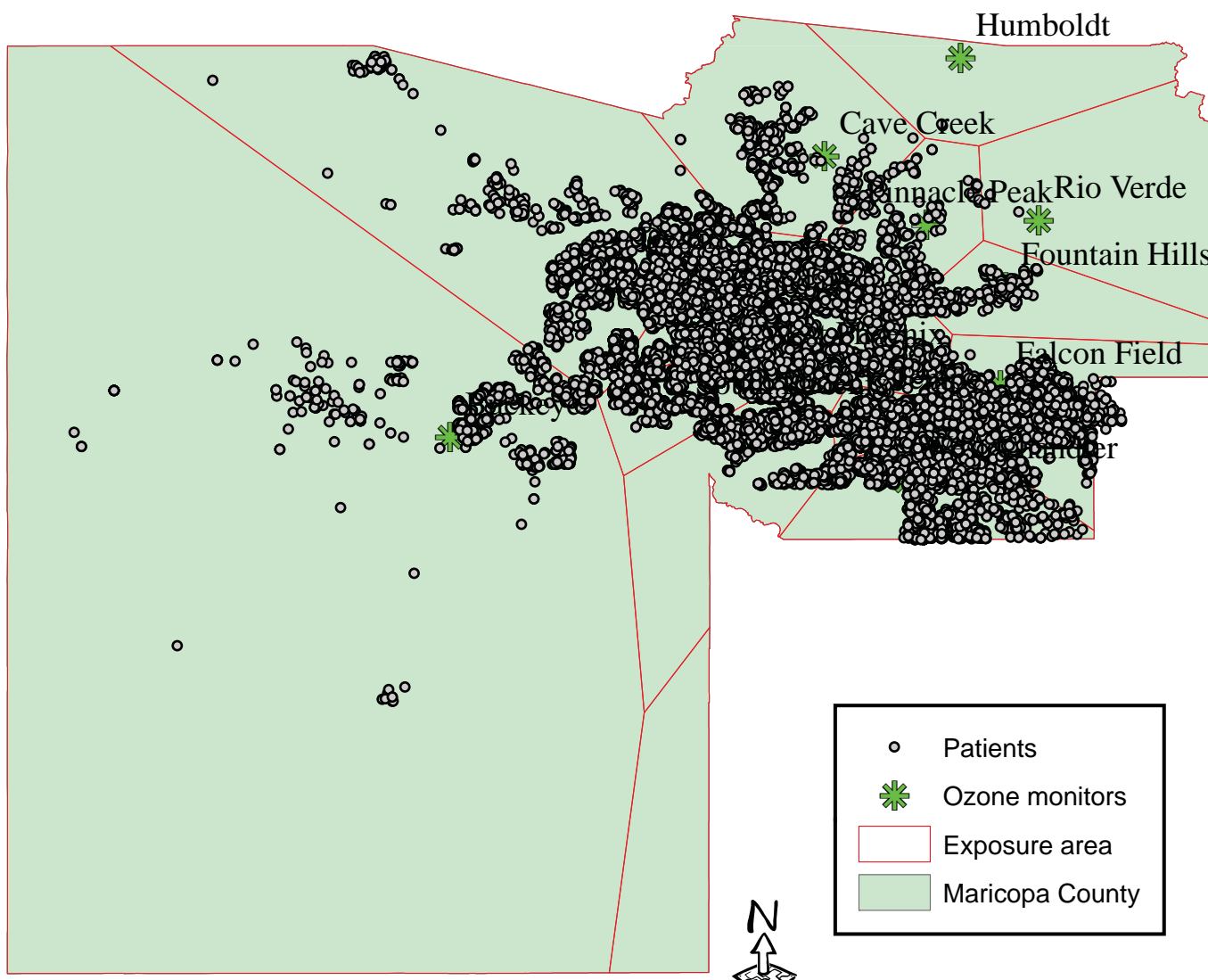
Figure 3: Time plots of the count of asthmatic patient hospital visits (top panel) and ozone levels (bottom panel) in Maricopa County (2007– 2012).

Figure 4: Relative risk (RR) of asthma hospital visits in Maricopa County for ozone lags 1-7.

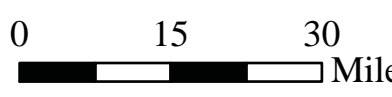


	Ozone monitors
	Exposure area
	Maricopa County

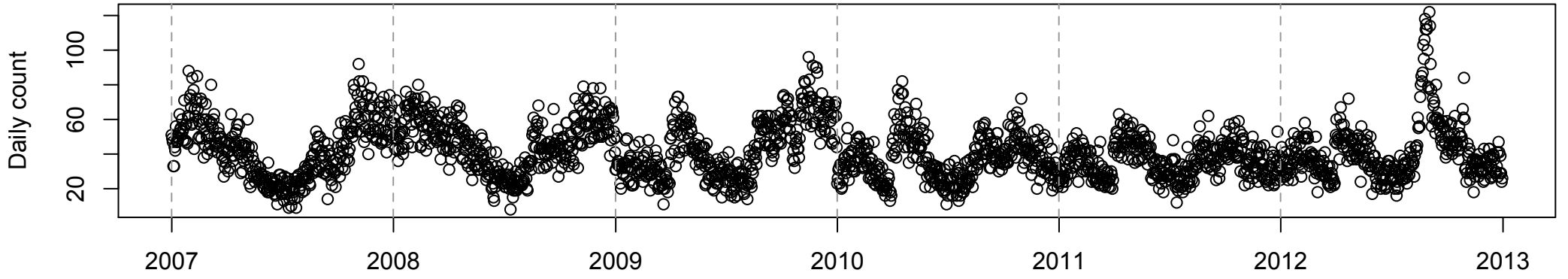




○	Patients
✱	Ozone monitors
□	Exposure area
■	Maricopa County



Asthma hospital visits



Ozone levels

