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Longitudinal trends in asthma emergency department visits, pollutant and pollen levels, and weather variables in the Bronx from 2001–2008

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ABSTRACT

Objective: To evaluate how asthma-related emergency department visits (AREDV), air pollutant levels, pollen counts, and weather variables changed from 2001 to 2008 in the Bronx, NY. **Methods:** 42,065 daily AREDV values (1 January 2001 to 31 December 2008) were collected using our institution's Clinical Looking Glass software. Daily values of sulfur dioxide (SO₂), carbon monoxide (CO), ozone (O₃), nitrogen dioxide (NO₂), temperature, and humidity were obtained from the National Climatic Data Center's Bronx station. Daily tree pollen counts were obtained from the Armonk counting station near the Bronx. Median values for each variable were analyzed using the Mann-Whitney test to compare 2001–2004 and 2005–2008 values. Simple linear regression examined associations between AREDV and individual pollutants. Due to seasonal variations of the variables, each season was considered separately. **Results:** There were significant decreases for AREDV, SO₂, CO, and humidity for all seasons, and for NO₂ in the spring and winter. Significant increases occurred for O₃ in the spring, fall, and winter; for temperature in the summer and winter; and for tree pollen in the spring. Significant positive associations were found between AREDV and SO₂, CO, NO₂, and humidity, respectively, while significant negative associations were found between AREDV and O₃ and temperature, respectively. **Conclusions:** From 2001 to 2008, significant: a) decreases in AREDV, SO₂, CO, and humidity for all seasons, and decreases in NO₂ for the spring and winter; and b) increases in O₃, temperature, and spring tree pollen were observed. By tracking and anticipating environmental and pollutant changes, efforts can be made to minimize AREDV.

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Urban; seasonal; healthcare utilization; New York City; air quality

Introduction

Asthma is a common disease that affects 24.6 million children and adults in the USA [1]. The prevalence of asthma and the number of asthma-related emergency department visits (AREDV) in the Bronx, NY significantly surpass the national rates [2]. The prevalence of asthma in the Bronx is 13.0% [3] in comparison to the national rate of 7.7% [4]. The number of AREDV in the Bronx is 231.4 [5] per 10,000 residents, which greatly exceeds the 69.7 [6] visits per 10,000 residents nationally.

Air pollutants increase the severity of asthma and the number of AREDV [7]. A previous study indicated that an increase in pollutants including particulate matter with a diameter of 2.5 µm or less (PM_{2.5}), particulate matter with a diameter of 10 µm or less (PM₁₀), sulfur dioxide (SO₂), carbon monoxide (CO),

and nitrogen dioxide (NO₂), along with a decrease in ozone (O₃) were linked to an increase in AREDV [8]. While the study observed how these pollutants and AREDV were associated, it did not evaluate how long-term pollutant and AREDV values were associated and changed over time. Other studies also observed changes in pollutants including SO₂, O₃, NO₂, and pollen and assessed how they were associated with AREDV rates over a relatively short period of time (one year for the first study, and four years for the second study) [9,10].

Daily pollutant values were previously collected in the Bronx, NY from the years of 2001–2008 (i.e. 1 January 2001–31 December 2008). These pollutants include PM_{2.5}, PM₁₀, SO₂, CO, O₃, NO₂, and tree pollen. Particle pollutants (PM_{2.5} and PM₁₀) are a mixture of particles of varying diameter found in the air

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that are known to cause decreased lung function, asthma exacerbations, along with onset and progression of other lung diseases [11]. SO_2 is a colorless pollutant emitted from fossil fuel consumption and industrial processes that causes respiratory irritation, respiratory dysfunction, and bronchitis [11]. CO is a colorless gas produced from fossil fuels, such as the burning of coal and wood, which has an affinity to hemoglobin that is much greater than that of oxygen. This allows CO to displace oxygen in red blood cells and no longer allow oxygen to be carried to the organs throughout the body, which can result in respiratory distress [11]. O_3 is a colorless gas found in large amounts in the earth's atmosphere. Ground-level O_3 is formed from natural sources and human activity and is believed to be a plausible cause of increased respiratory diseases, such as asthma [11]. NO_2 is a common pollutant produced from road traffic, as they are emitted from motor-engines in the exhaust. It is known to have an effect of lung damage, lung inflammation, coughing, wheezing, and respiratory infections [11,12]. Tree pollen is a common allergen found in the air that has been associated with severe exacerbations of asthma [13]. Data analysis in this current study was used to understand how the pollutant values changed throughout the years. Any associations found when comparing the change in pollutant values to the change in daily adult and pediatric AREDV values collected during the same time period were then evaluated. Using this information, any association between changes in each environmental factor and changes in AREDV over time can be better understood. Our goal was to evaluate daily pollutant values within the Bronx, NY from 2001–2008 and assess how changes in those values are associated with changes in AREDV.

Methods

Participants and background

Participants in this retrospective cross-sectional study included both adult and pediatric patients (i.e. individuals under 18 years of age) of all genders requiring AREDV, leading to a total of 42,065 adult and pediatric AREDV being collected. The aggregate number of daily AREDV at two major Bronx hospitals (Montefiore Medical Center's Moses and Weiler divisions) were obtained and analyzed from 1 January 2001 to 31 December 2008. Daily values of SO_2 , CO, O_3 , NO_2 , temperature, humidity, and tree pollen were collected and analyzed during the same time period. Due to missing data on $\text{PM}_{2.5}$ and PM_{10} , these pollutant values were not included in our analysis. Only the daily

number of AREDV and no personally identifiable information were collected and used for the statistical analysis. The study, due to our collection and analysis of de-identified data, was determined to be exempt by the Einstein-Montefiore Institutional Review Board.

Asthma-related emergency department visits

The number of daily AREDV from 2001–2008 were identified using our institution's Clinical Looking Glass (CLG[®]) software. CLG[®] is a user-friendly interactive software application developed to evaluate health care quality, effectiveness, and efficiency. The system integrates clinical and administrative datasets allowing non-statisticians to produce epidemiologically cogent reports in order to globally assess care quality. Pediatric and adult patients were identified with a primary diagnosis of asthma (International Classification of Diseases, Ninth Revision, ICD-9 493.0) upon discharge from the emergency department (ED) to yield the aggregate daily AREDV values. As a result of the variations of AREDV between the seasons, the AREDV numbers were considered separately for the four seasons. The winter consisted of dates ranging from 21st December to 19th March. The spring ranged from 20th March to 20th June. The summer spanned from 21st June to 21st September and the fall included dates from 22nd September to 20th December. The AREDV numbers were grouped into two four-year time periods (2001–2004 and 2005–2008) in order to observe how the data varied across the eight-year period.

Pollutant, weather, and pollen values

Daily values of SO_2 (in ppb), CO (in ppm), O_3 (in ppm), NO_2 (in ppb), temperature (in °F) and humidity (in %) were obtained from the National Climatic Data Center's (NCDC) Bronx Station from 1st January 2001 to 31st December 2008. Daily tree pollen counts (in grains/ m^3 of air) were obtained from the Armonk counting station near the Bronx. As a result of seasonal variations in pollutant and weather-related values, data were analyzed separately for each of the four seasons.

Statistical analyses

Individual, seasonal graphs were created for SO_2 , CO, O_3 , NO_2 , and tree pollen—with each graph accompanied by AREDV data—in order to compare the values of 2001–2004 vs. 2005–2008; for example, spring 2001–2004 NO_2 and AREDV vs. spring 2005–2008 NO_2 and AREDV.

In order to evaluate how pollutants and AREDV varied from 2001–2004 to 2005–2008, median values of pollutants and AREDV per season were calculated and outlier values (values falling in the upper and lower 2% of the range) were removed. As these outcomes of interest did not follow normal distribution, the Mann-Whitney test was used to compare the median values of the two time periods, which allowed us to observe any significant change for each value from 2001–2004 to 2005–2008. Simple linear regression analysis was employed to assess the association between AREDV and individual pollutants during the period of 2001–2008. The above analyses were done for each of the four seasons separately due to the seasonal variability of asthma, pollutants and environmental factors. Findings with p values ≤ 0.05 were considered as statistically significant. Analyses were conducted using SPSS version 25.0 (IBM Corp., Armonk, NY) and graphs were generated using Excel v.16.16.5.

Results

Seasonal AREDV: 2001–2004 vs. 2005–2008

A total of 42,065 adult and pediatric (19,348 (46%) adult and 22,717 (54%) pediatric) AREDV were collected throughout the eight-year time period. Daily values of SO₂, CO, O₃, NO₂, temperature, humidity, and tree

pollen were collected over 744 days for spring, 744 days for summer, 720 days for fall, and 703 days for winter seasons. The AREDV values decreased from 2001–2004 to 2005–2008 in all four seasons. In the winter, the AREDV values peaked in: late-January 2001, early-January 2002, mid-March 2002, and late-January 2003. The values then decreased and remained at a relatively constant level for the remaining years (Figures 1 and 2). In the spring, the AREDV values increased until a peak in early-April 2003, and then decreased for the remaining time. The winter, spring, summer, and fall seasons all showed statistically significant decreases in AREDV median values from 2001–2004 to 2005–2008 (Table 1).

Seasonal SO₂: 2001–2004 vs. 2005–2008

The SO₂ values decreased from 2001–2004 to 2005–2008 for all four seasons. In the winter, the SO₂ values peaked in mid- and late-January 2001, decreased sharply, and then gradually decreased throughout the next seven years (Figures 1 and 2). In the spring, the SO₂ values peaked in early-May 2001, then decreased until a slight increase in mid-April 2005, to where it continued to decrease until 2008 (Supplemental Figures 1 and 2). The winter, spring, summer, and fall seasons all had significant statistical

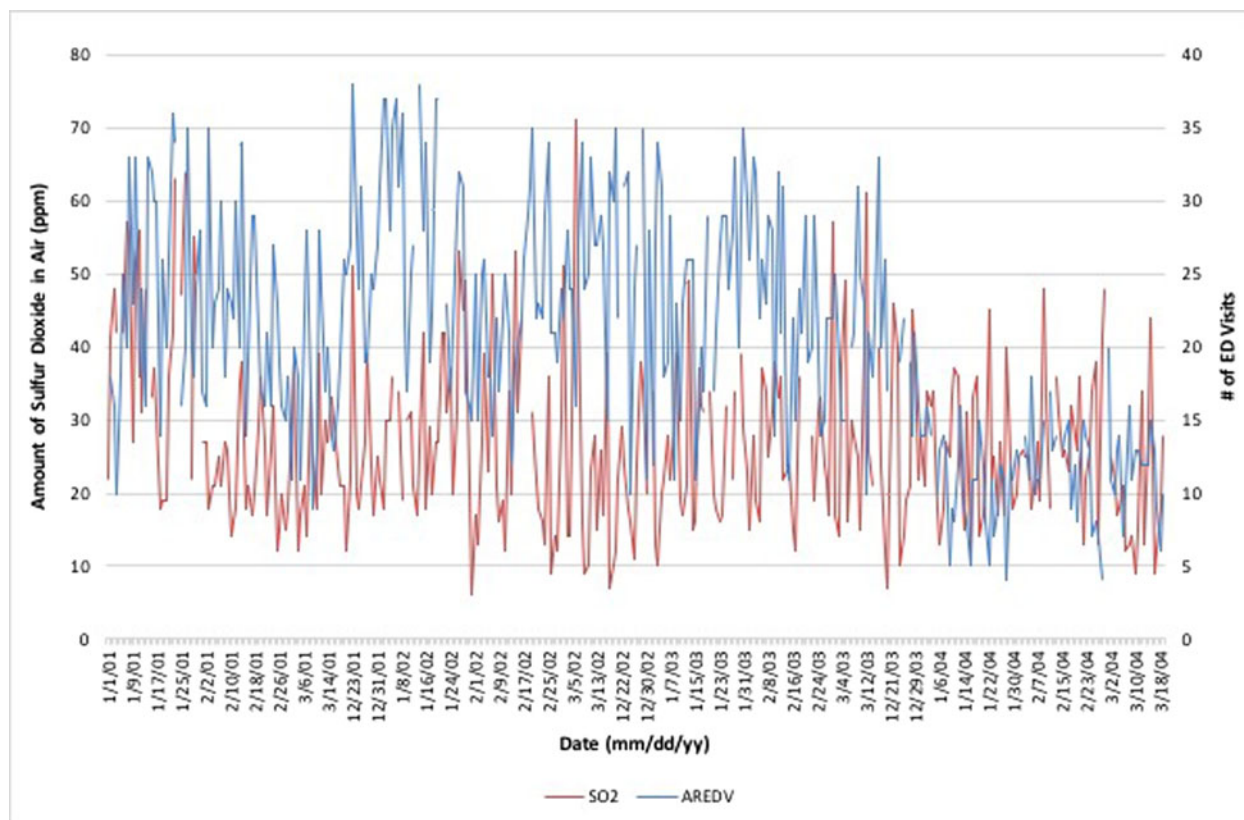


Figure 1. Winter SO₂ (ppb) and asthma-related emergency department visits (AREDV) from 2001 to 2004. Data for AREDV are from the Clinical Looking Glass (CLG[®]) software and data for SO₂ are from the National Climatic Data Center's Bronx station.

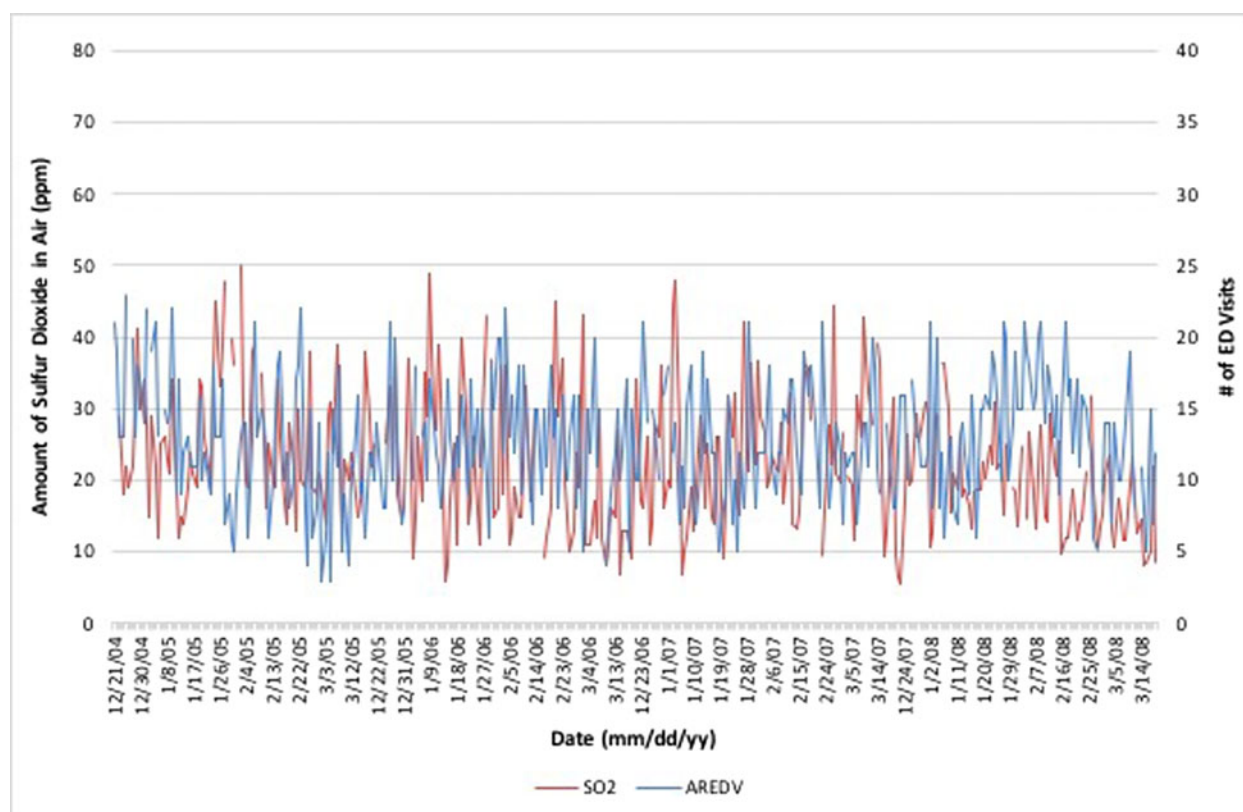


Figure 2. Winter SO₂ (ppb) and asthma-related emergency department visits (AREDV) from 2005 to 2008. Data for AREDV are from the Clinical Looking Glass (CLG[®]) software and data for SO₂ are from the National Climatic Data Center's Bronx station.

Table 1. Seasonal adult and pediatric AREDV median values from 2001–2004 and 2005–2008 collecting using the CLG[®] software from Montefiore Medical Center's Moses and Weiler Hospitals in the Bronx, NY.

Season	AREDV Median Value		<i>p</i> value ^a
	2001–2004	2005–2008	
Spring	17	11	<0.001
Summer	10	6	<0.001
Fall	18	14	<0.001
Winter	20	12	<0.001

CLG[®]: Clinical Looking Glass; AREDV: asthma-related emergency department visit.

Spring: 20 March to 20 June; Summer: 21 June to 21 September; Fall: 22 September to 20 December; Winter: 21 December to 19 March.

^a*p*-values obtained using Mann-Whitney test to compare the asthma-related emergency department visits for each season by each time period.

Significance was assessed if *p* values were ≤ 0.05.

decreases in SO₂ median values from 2001–2004 to 2005–2008 (Table 2).

Seasonal CO: 2001–2004 vs. 2005–2008

CO values decreased from 2001–2004 to 2005–2008 for all four seasons. In the winter, CO values peaked in late-January 2001, and decreased thereafter to where the values remained at a roughly constant level. Spring CO levels gradually increased until a peak in

early-June 2003, and then gradually decreased for the remaining time (Supplemental Figures 3 and 4). Statistically significant decreases in CO median values from 2001–2004 to 2005–2008 occurred in the winter, spring, summer, and fall (Table 2).

Seasonal O₃: 2001–2004 vs. 2005–2008

Winter O₃ values started low every January and then increased until a peak at mid-March every year for the eight-year time period (Supplemental Figures 9 and 10). Overall, the winter O₃ values gradually increased from 2001–2004 to 2005–2008. Spring O₃ values did not experience any major peaks. However, values increased gradually from 2001–2004 to 2005–2008 and maintained a greater median value than winter O₃ values. Fall O₃ values peaked every early-October and decreased thereafter throughout the eight-year period (Supplemental Figures 11 and 12). The overall O₃ values increased from 2001–2004 to 2005–2008. The winter, spring, and fall seasons had statistically significant increases in O₃ median values from 2001–2004 to 2005–2008. For the summer, the median values decreased, although there was no statistical significance (Table 2).

Table 2. Seasonal air pollutant median values from 2001–2004 and 2005–2008 collected from the NDC station and Armonk counting station in the Bronx, NY region.

Season	SO ₂ (ppb)		CO (ppm)		p-Value ^a		O ₃ (ppm)		p-Value ^a		NO ₂ (ppb)		p-Value ^a		Tree Pollen (grains/m ³)		p-Value ^a
	2001–2004	2005–2008	2001–2004	2005–2008	2001–2004	2005–2008	2001–2004	2005–2008	2001–2004	2005–2008	2001–2004	2005–2008	2001–2004	2005–2008	2001–2004	2005–2008	
Spring	12.00	9.00	0.80	0.60	<0.001	0.037	0.034	0.037	<0.001	0.037	43.00	42.00	0.026	0.026	102.50	155.0	0.017
Summer	9.00	7.15	0.80	0.60	<0.001	0.040	0.041	0.040	0.625	0.040	41.00	39.00	0.438	0.438	0	0	0.039
Fall	16.00	13.00	0.80	0.60	<0.001	0.018	0.016	0.018	<0.001	0.018	37.00	37.00	0.204	0.204	0	0	0.039
Winter	25.00	20.95	0.80	0.70	<0.001	0.019	0.017	0.019	<0.001	0.019	41.00	39.00	0.005	0.005	0	0	0.039

NDC: National Climatic Data Center; SO₂: sulfur dioxide; CO: carbon monoxide; O₃: ozone; NO₂: nitrogen dioxide.

Spring: 20 March to 20 June; Summer: 21 June to 21 September; Fall: 22 September to 20 December; Winter: 21 December to 19 March.

^ap-values obtained using Mann-Whitney test to compare the pollutant values for each season by each time period.

Significance was assessed if p values were ≤ 0.05.

Seasonal NO₂: 2001–2004 vs. 2005–2008

NO₂ values peaked every mid-March for all eight years, but overall, gradually decreased from 2001–2004 to 2005–2008. In the spring, NO₂ values peaked during mid-May and mid-June of 2001 (Supplemental Figures 7 and 8). Overall, the values gradually decreased from 2001–2004 to 2005–2008. The winter and spring seasons exhibited statistically significant decreases in NO₂ median values from 2001–2004 to 2005–2008. In the summer, the median value decreased, although the decrease was not statistically significant. The fall median value remained the same and was also not statistically significant (Table 2).

Spring tree pollen: 2001–2004 vs. 2005–2008

Spring tree pollen values peaked every late-April to early-May throughout the eight-year time period (Supplemental Figures 5 and 6). Overall, the tree pollen increased from 2001–2004 to 2005–2008. In the spring, the median tree pollen value showed a statistically significant increase (Table 2).

Seasonal temperature: 2001–2004 vs. 2005–2008

In the winter and summer seasons, the median temperature showed a statistically significant increase from 2001–2004 to 2005–2008. The spring median temperature remained the same and the fall median temperature increased, although there was no statistical significance (Table 3).

Seasonal humidity: 2001–2004 vs. 2005–2008

Median humidity values experienced decreases for all four seasons from 2001–2004 to 2005–2008. In the winter, median humidity values exhibited a statistically significant decrease from 2001–2004 to 2005–2008. The spring, summer, and fall median humidity values all significantly decreased (Table 3).

Simple linear regression analysis

Both SO₂ and CO had a significant positive association with AREDV in all four seasons, however the strongest association was found in the spring season for SO₂ and in the winter season for CO. O₃ was negatively associated with AREDV for the spring, fall, and winter seasons and the strongest association occurred during the winter. However, O₃ was positively associated with AREDV in the summer season. This positive association between O₃ and AREDV was

Table 3. Seasonal temperature and humidity median values from 2001–2004 and 2005–2008 collected from the NCDC Station and Armonk Counting Station in the Bronx, NY region.

Season	Temperature (°F) Median Value		<i>p</i> -Value ^a	Humidity (%) Median Value		<i>p</i> -Value ^a
	2001–2004	2005–2008		2001–2004	2005–2008	
Spring	60	60	0.81	67.6786	57.3333	<0.001
Summer	75	76	0.04	65.6607	58.5687	<0.001
Fall	51	52	0.90	65.5000	57.9844	<0.001
Winter	36	38	0.04	56.3211	55.0441	0.03

NCDC: National Climatic Data Center.

Spring: 20 March to 20 June; Summer: 21 June to 21 September; Fall: 22 September to 20 December, Winter: 21 December to 19 March.

^a*p*-values obtained using Mann-Whitney test to compare temperature and humidity values for each season by each time period.

Significance was assessed if *p* values were ≤ 0.05 .

comparatively less strong than the negative associations of the two variables for the other seasons. While NO₂ had a significant positive association with AREDV in all seasons except for spring, tree pollen was positively associated with AREDV only in the spring season. Finally, AREDV was found to be negatively associated with temperature in the spring and fall seasons and had a significant positive association with humidity in the winter season (Table 4).

Discussion

This study investigated the association between changes in daily pollutant values, temperature, humidity, and daily AREDV values from 2001–2008. Our previous research found a correlation between increased spring tree pollen counts and increased AREDV [14]. In this study, tree pollen levels peaked in the spring as well as an overall significant increase in spring tree pollen levels from 2001–2004 to 2005–2008. This is accompanied by an overall statistically significant overall decrease in AREDV values from 2001–2004 to 2005–2008. When comparing AREDV to other environmental factors, other statistically significant changes during the time period were discovered. From 2001–2004 to 2005–2008, there were significant decreases in SO₂, NO₂, and CO, along with decreases in humidity. The only significant increase across the time period, aside from tree pollen, was an increase in O₃ values.

Similar associations between the air pollutants and AREDV values have been previously reported in other studies [15]. Guo et al. reported an increase in AREDV values in Shanghai, China that correlated to an increase in SO₂, CO and NO₂ values, as well as a decrease in O₃ values [8]. Decreases in SO₂, CO and NO₂ values, and an increase in O₃ values, which associated with a decrease in AREDV values were found in this study as well. Prunicki et al. reported that exposure to high CO and NO₂ air pollutant levels resulted in DNA methylation of Foxp3 promoter regions within

genes, which is associated to an increased prevalence of asthma [16]. A decrease in CO and NO₂ values was also found to be associated with a decrease in AREDV values in this study. Mazenq et al. reported that exposure to high levels of NO₂ have significant correlations to AREDV [17]. Evans et al. reported that there is an inverse association between AREDV and O₃ levels in the environment [18]. Both of these studies support the increase in AREDV being associated to increased levels of NO₂ and decreased levels of O₃. However, some studies have reported a significant positive association between AREDV/asthma exacerbation and O₃ [10,19]. While an increase in O₃ did not have a direct association to an increase in AREDV in our study, this does not mean that O₃ is a pollutant that should be inhaled. These results only suggest that O₃ and AREDV levels are not associated; however, O₃ has been reported to have associations with other diseases [20,21].

Our study has several limitations. While daily values collected for each of the variables were used in the study, there were some variables that had missing or incomplete data, such as for PM_{2.5} and PM₁₀. Thus, the effect of these pollutants on AREDV could not be accurately assessed and reported. Another limitation is the small number of stations through which our data were obtained (an NCDC-Bronx station for weather and pollutant variables and an Armonk station for pollen values), which would not give as accurate of a representation of the pollutant levels in the Bronx, NY as more stations would. The number of hospitals (two) that were used to collect our AREDV data is another limitation. A larger sample size that spanned a greater radius of location would provide a better, more balanced set of results. In addition, the AREDV data did not account for other triggers of asthma requiring ED visits, such as home environmental triggers (mold, rodents) and viral respiratory infections. Thus, there is no way to entirely know that the change in pollutant levels are the only factors associated with the change in AREDV over time. Regarding the data collected, individual level data

Table 4. Simple linear regression assessing the association between AREDV and pollutants/Environmental factors.

Pollutant/ Environmental Factor	Spring				Summer				Fall				Winter			
	Unstandardized Coefficient	p-value ^a	95% Confidence Interval	Unstandardized Coefficient	p-value ^a	95% Confidence Interval	Unstandardized Coefficient	p-value ^a	Unstandardized Coefficient	p-value ^a	95% Confidence Interval	Unstandardized Coefficient	p-value ^a	Unstandardized Coefficient	p-value ^a	95% Confidence Interval
SO ₂ (ppb)	0.157	<0.001	0.085, 0.230	0.085	0.001	0.036, 0.135	0.104	<0.001	0.061, 0.147	0.001	0.061, 0.147	0.092	0.001	0.039, 0.144	0.001	0.039, 0.144
CO (ppm)	4.539	<0.001	2.084, 6.993	4.619	<0.001	2.885, 6.352	2.229	0.013	0.472, 3.985	<0.001	0.472, 3.985	6.855	<0.001	4.631, 9.079	<0.001	4.631, 9.079
O ₃ (ppm)	–96.000	<0.001	–149.106, –42.894	27.487	0.007	7.655, 47.320	–127.350	<0.001	–183.198, –71.502	<0.001	–183.198, –71.502	–199.638	<0.001	–263.860, –135.415	<0.001	–263.860, –135.415
NO ₂ (ppb)	0.016	0.437	–0.024, 0.055	0.037	0.003	0.012, 0.062	0.080	0.001	0.031, 0.129	0.001	0.031, 0.129	0.079	0.020	0.013, 0.146	0.020	0.013, 0.146
Tree Pollen (grains/m ³)	0.002	0.001	0.001, 0.002	0.011	0.822	–0.087, 0.109	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Temperature (°F)	–0.082	0.001	–0.131, –0.034	–0.001	0.971	–0.063, 0.061	–0.076	<0.001	–0.115, –0.037	<0.001	–0.115, –0.037	0.037	0.267	–0.028, 0.103	0.267	–0.028, 0.103
Humidity (%)	0.027	0.067	–0.002, 0.056	0.016	0.211	–0.009, 0.040	0.001	0.935	–0.030, 0.032	0.935	–0.030, 0.032	0.041	0.032	0.004, 0.079	0.032	0.004, 0.079

SO₂: sulfur dioxide; CO: carbon monoxide; O₃: ozone; NO₂: nitrogen dioxide; AREDV: asthma-related emergency department visits; PPB: parts per billion; PPM: parts per million.

Spring: 20 March to 20 June; Summer: 21 June to 21 September; Fall: 22 September to 20 December; Winter: 21 December to 19 March.

^ap-values obtained through simple linear regression analysis using SPSS v.25.0.

Significance was assessed if p values were ≤ 0.05.

The simple linear regression model considers AREDV as the dependent variable and only one pollutant/environmental factor as the independent variable.

were not able to be obtained, which consequently did not allow for multivariate analysis or analysis by factors such as age, gender, disease severity or treatment. Instead, simple linear regression analysis was used to assess associations between pollutant values and AREDV. Future studies including individual level data, such as age and gender, could examine possible effects of these variables on study outcomes. Lastly, this study described data collected retrospectively over the eight-year period in the Bronx, NY. Future studies collecting prospective data in other regions of the USA are needed, as these eight years potentially may not reflect the present-day pollutant levels and environmental factors found in the USA.

Conclusion

This study revealed an association between decreased AREDV and decreased NO₂, CO, and SO₂ values in the Bronx. There was also a statistically significant association between decreased AREDV and increased O₃ values, which shows that although O₃ is a pollutant that should not be inhaled, it does not have a positive association with AREDV. There may be a link between the decrease in humidity and in AREDV that was seen across all seasons throughout the eight-year time period; however, simple linear regression confirmed a significant positive association in the winter season only. By tracking and predicting future environmental and air pollutant changes, efforts can be made to notify the public, adjust clinical practice accordingly, and reduce asthma-related ED visits.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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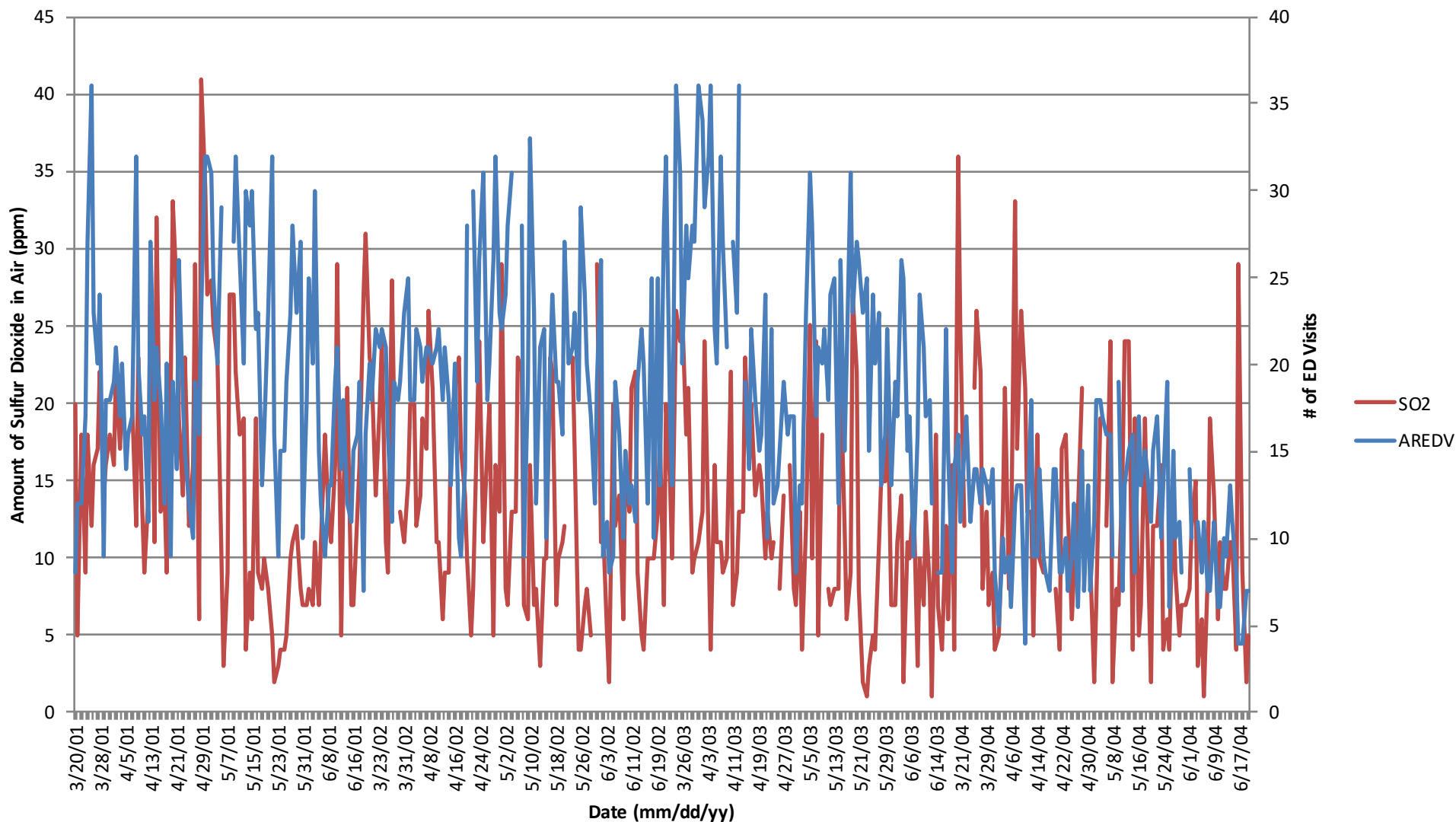
Marina Reznik  <http://orcid.org/0000-0001-7645-1260>

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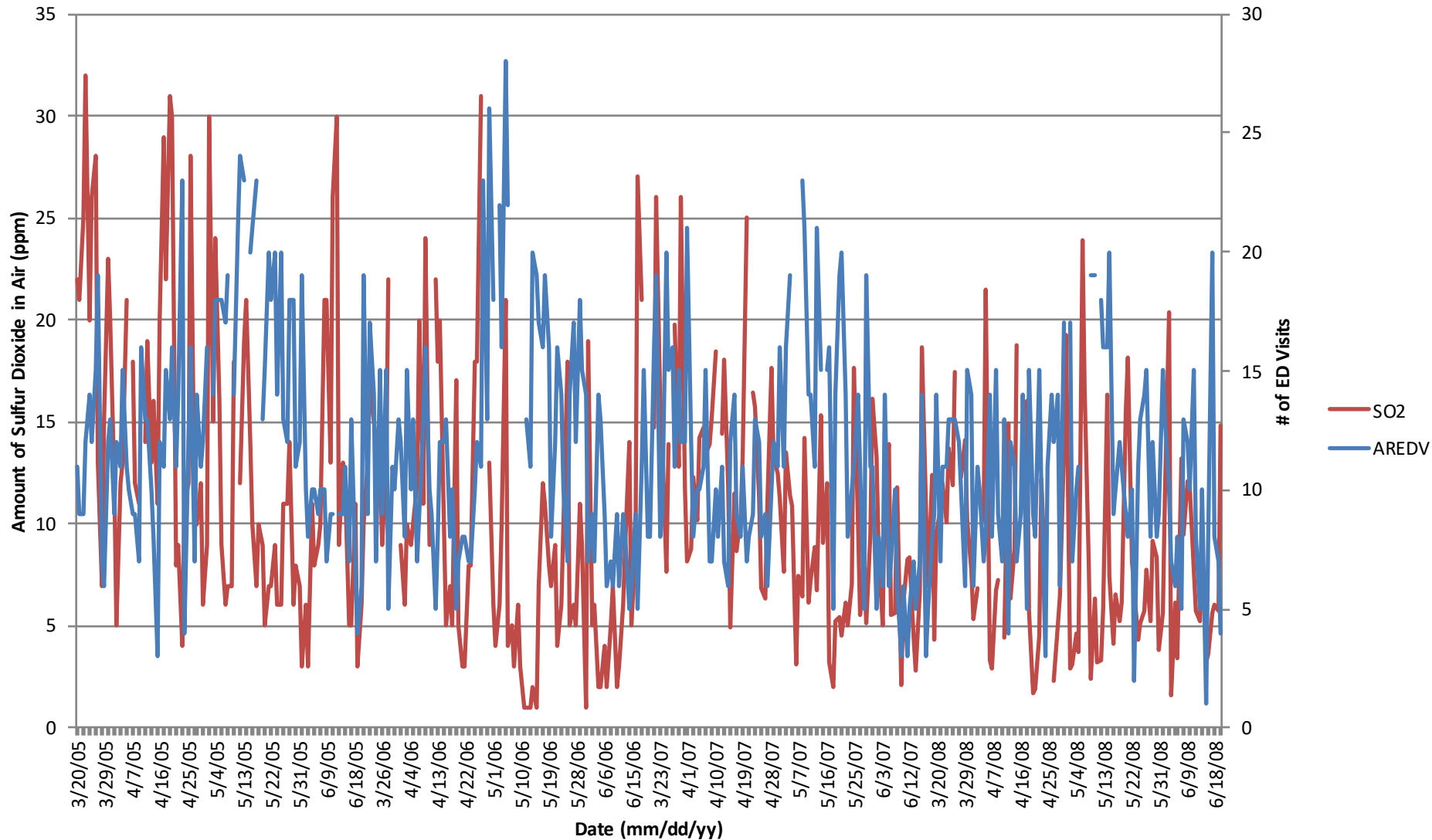
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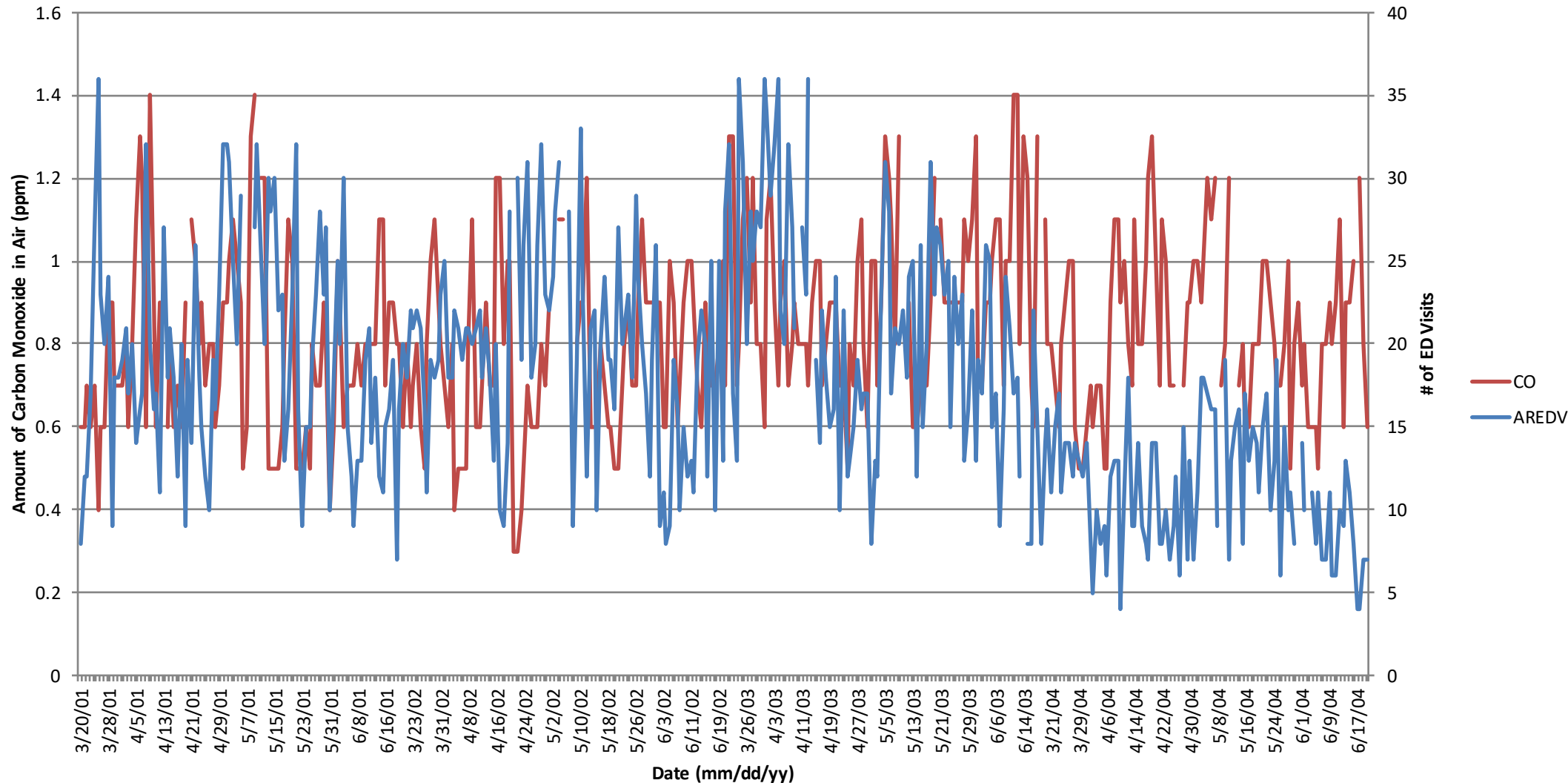
Supplemental Figure 1. Spring SO₂ (ppb) and asthma-related emergency department visits (AREDV) from 2001 to 2004.



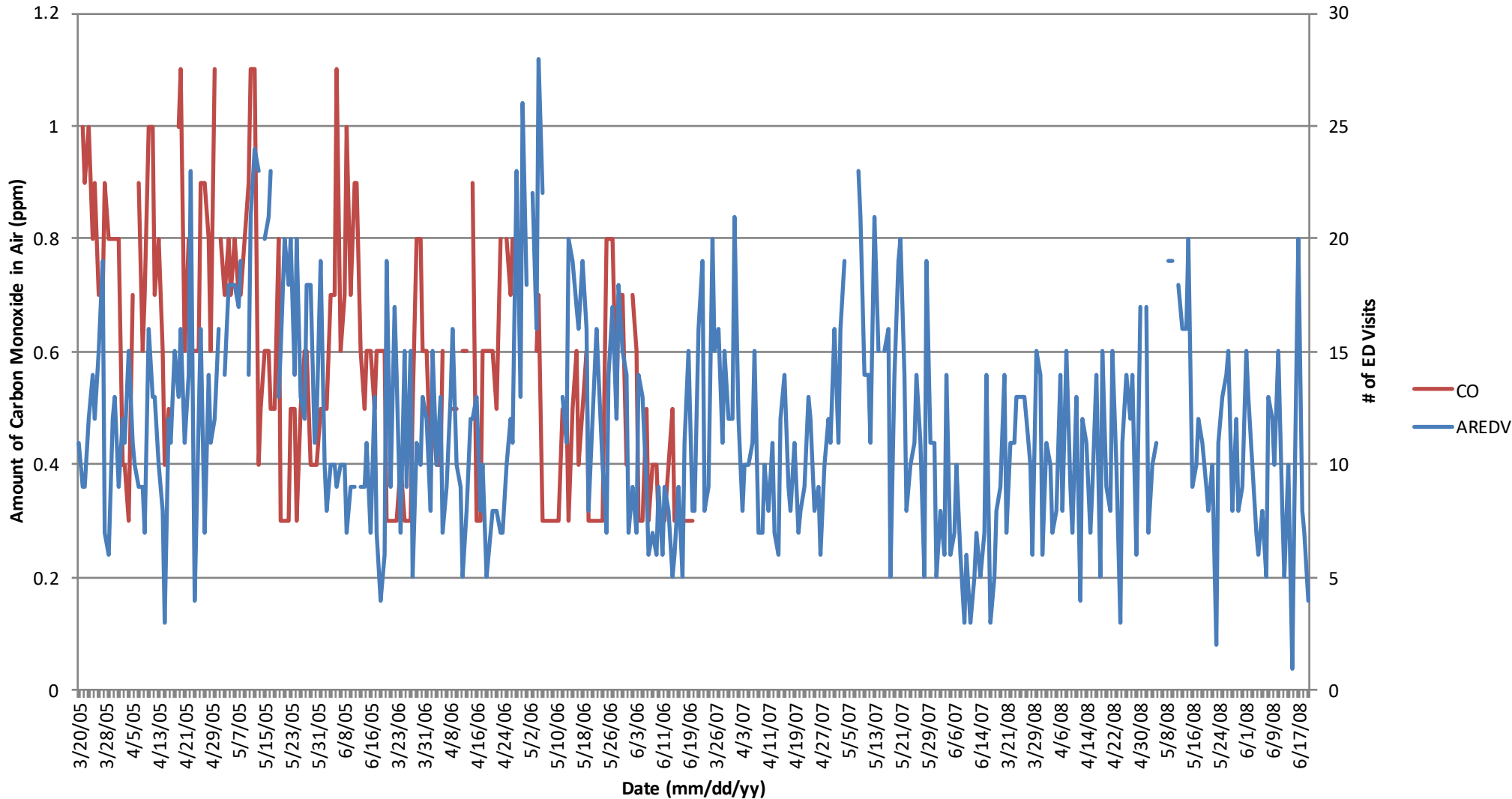
Supplemental Figure 2. Spring SO₂ (ppb) and asthma-related emergency department visits (AREDV) from 2005 to 2008.



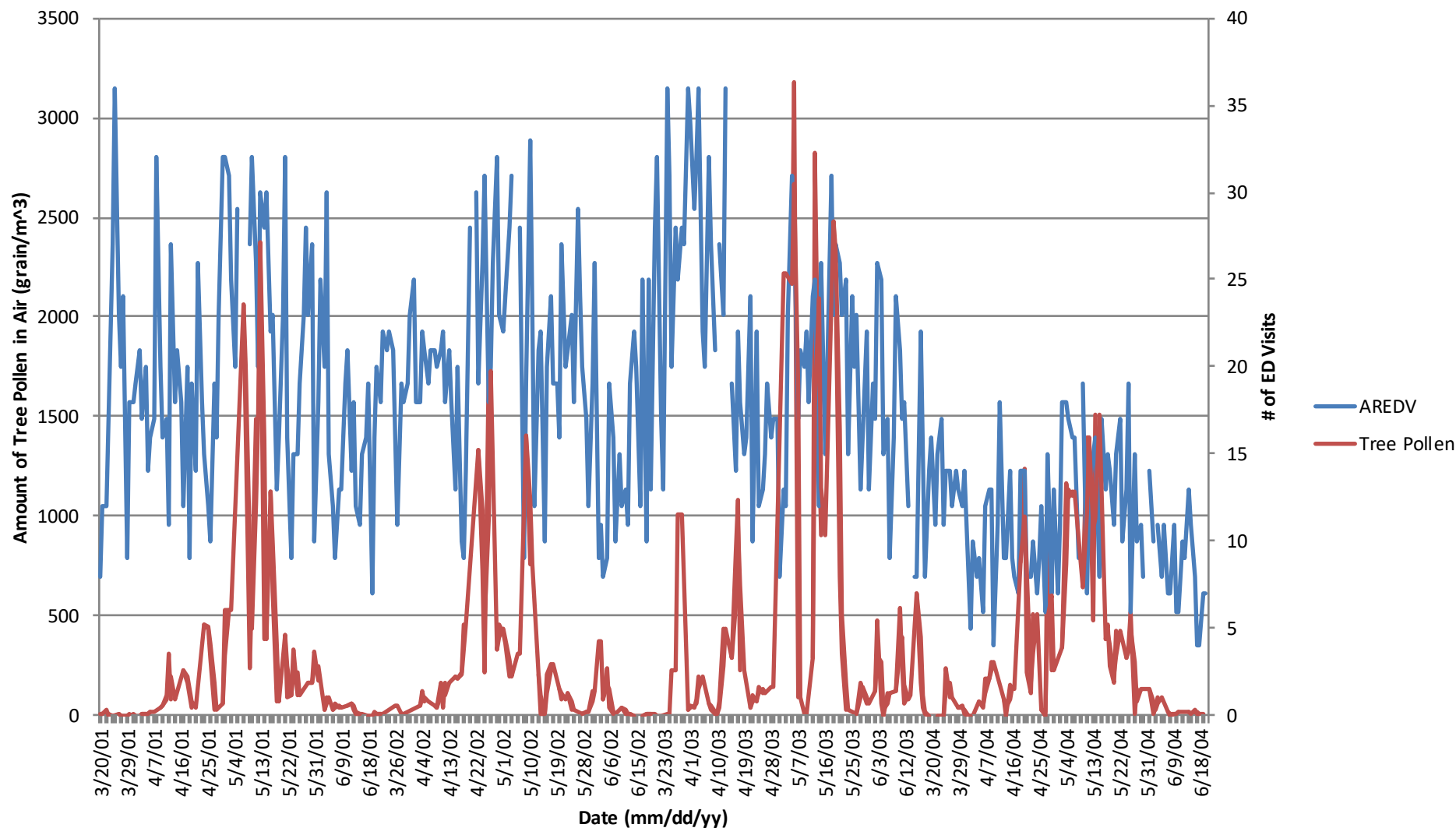
Supplemental Figure 3. Spring CO (ppm) and asthma-related emergency department visits (AREDV) from 2001 to 2004.



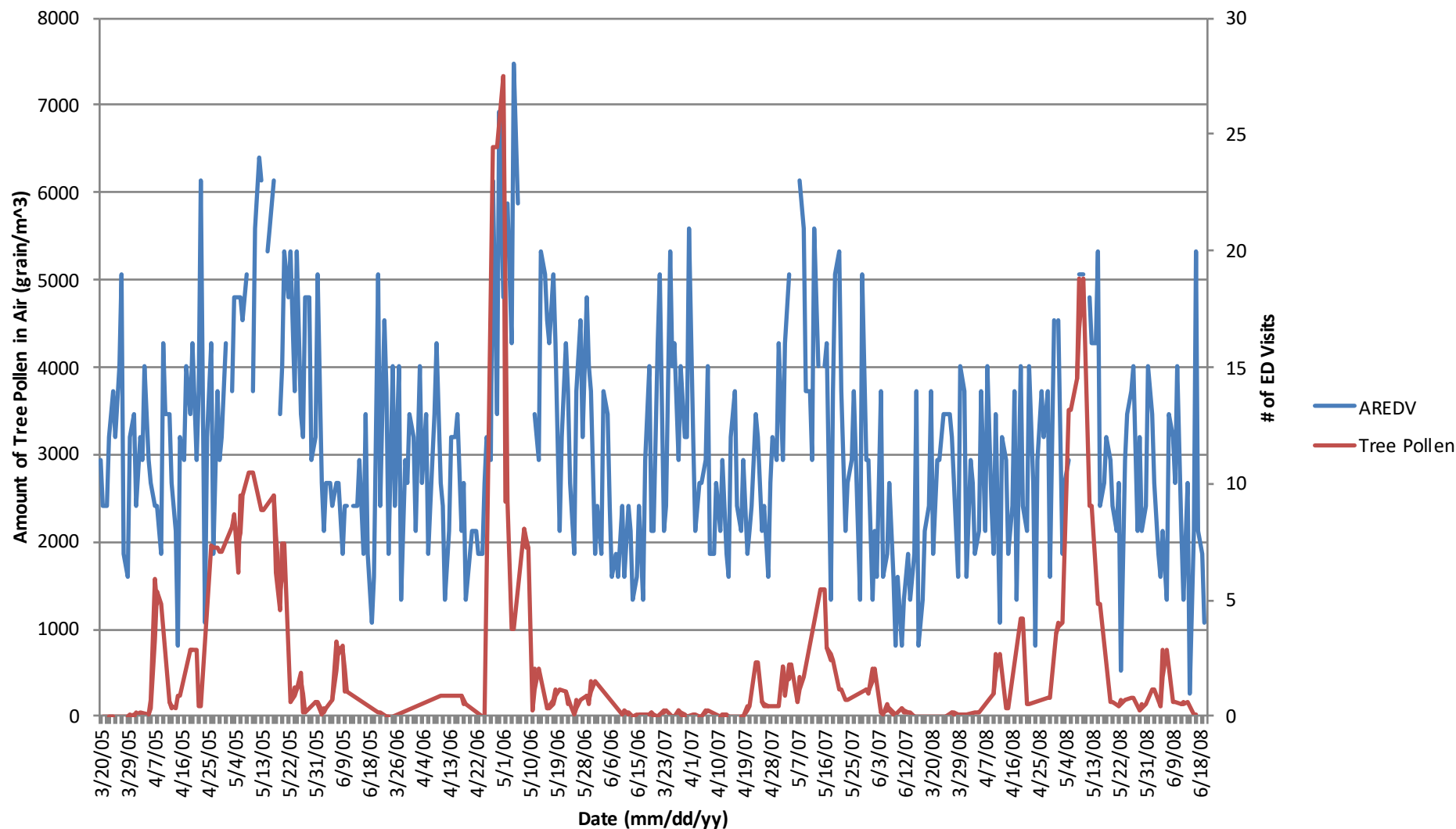
Supplemental Figure 4. Spring CO (ppm) and asthma-related emergency department visits (AREDV) from 2005 to 2008.



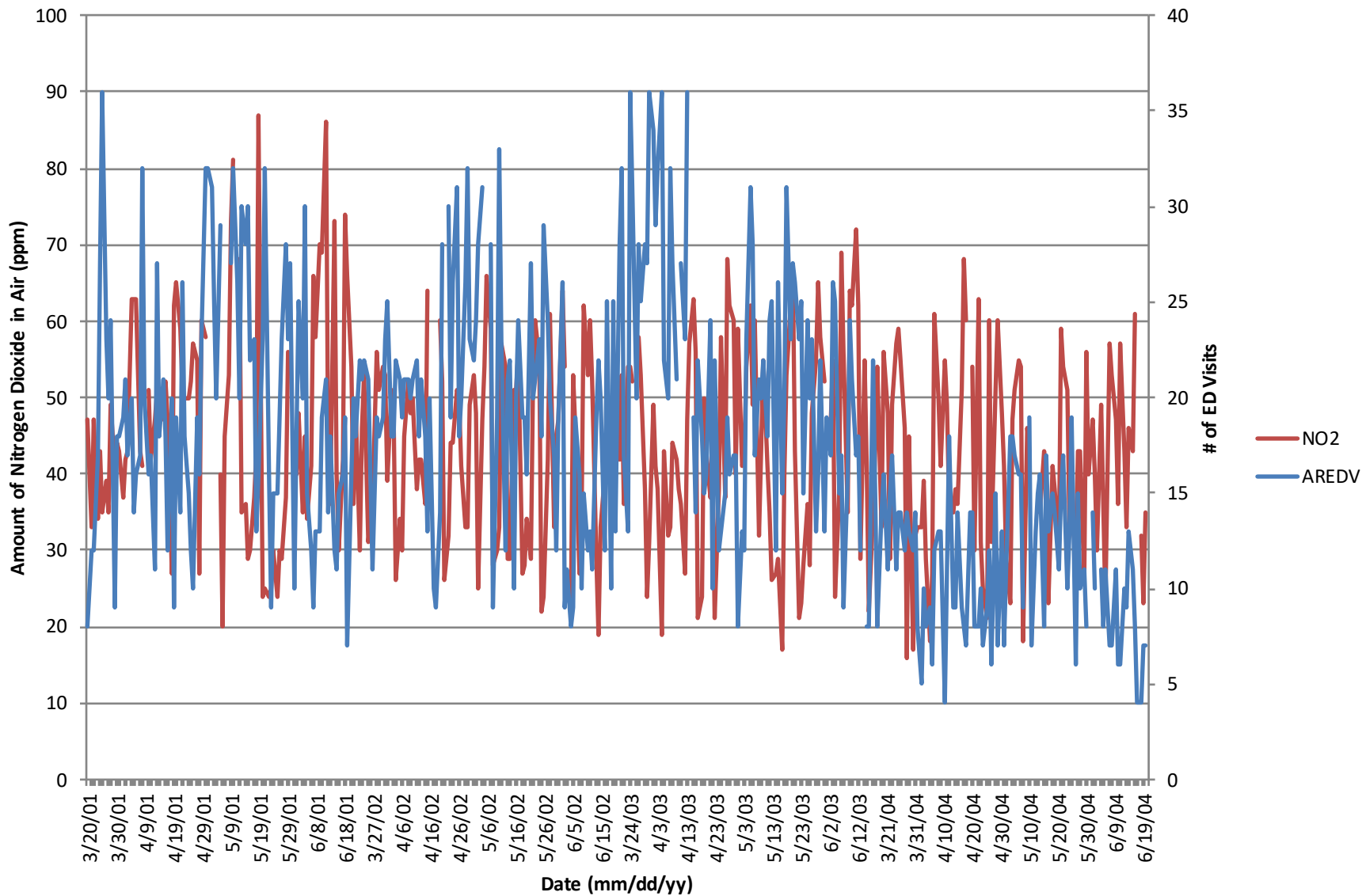
Supplemental Figure 5. Spring Tree Pollen (grains/m³) and asthma-related emergency department visits (AREDV) from 2001 to 2004.



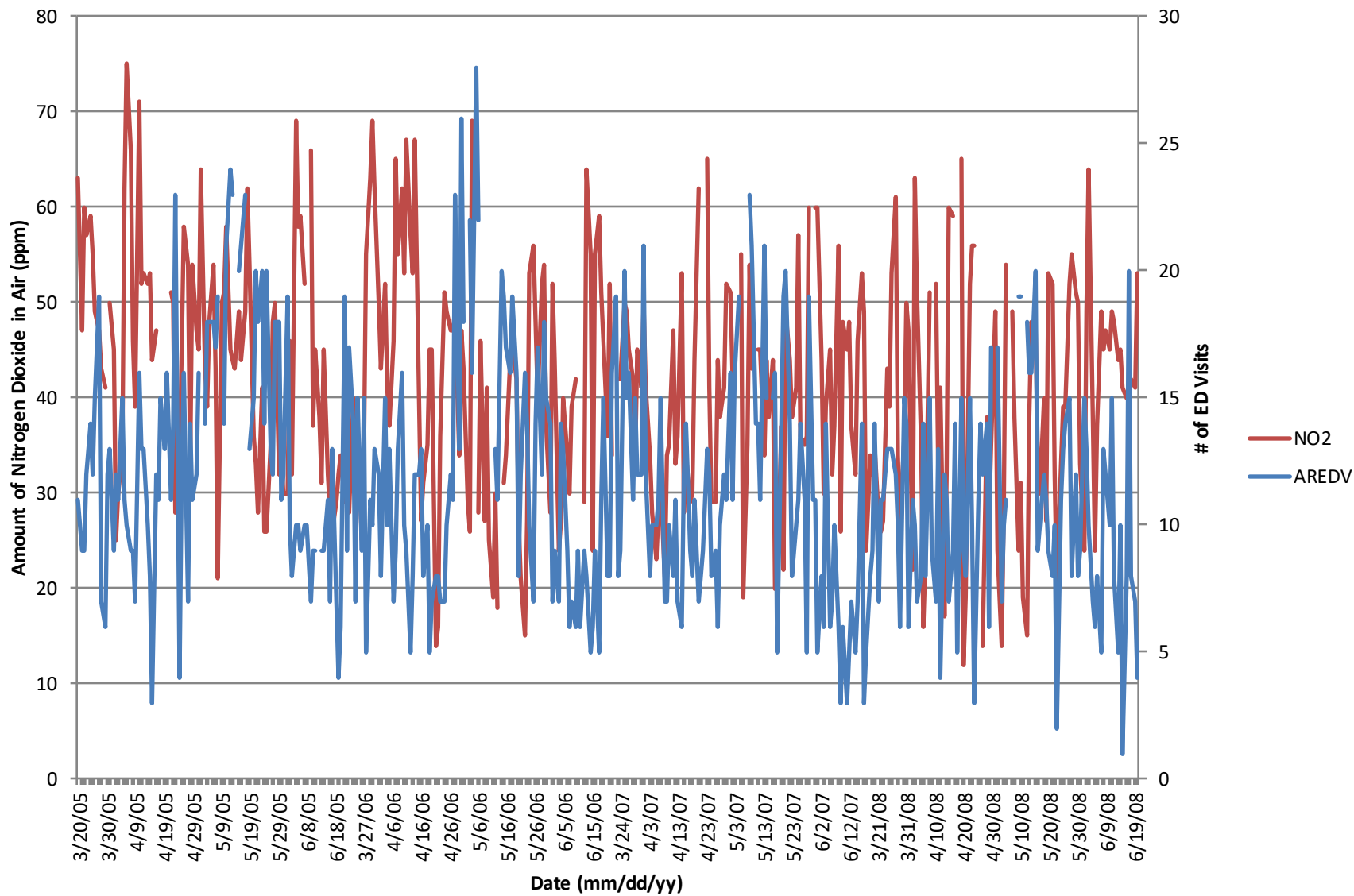
Supplemental Figure 6. Spring Tree Pollen (grains/m³) and asthma-related emergency department visits (AREDV) from 2005 to 2008.



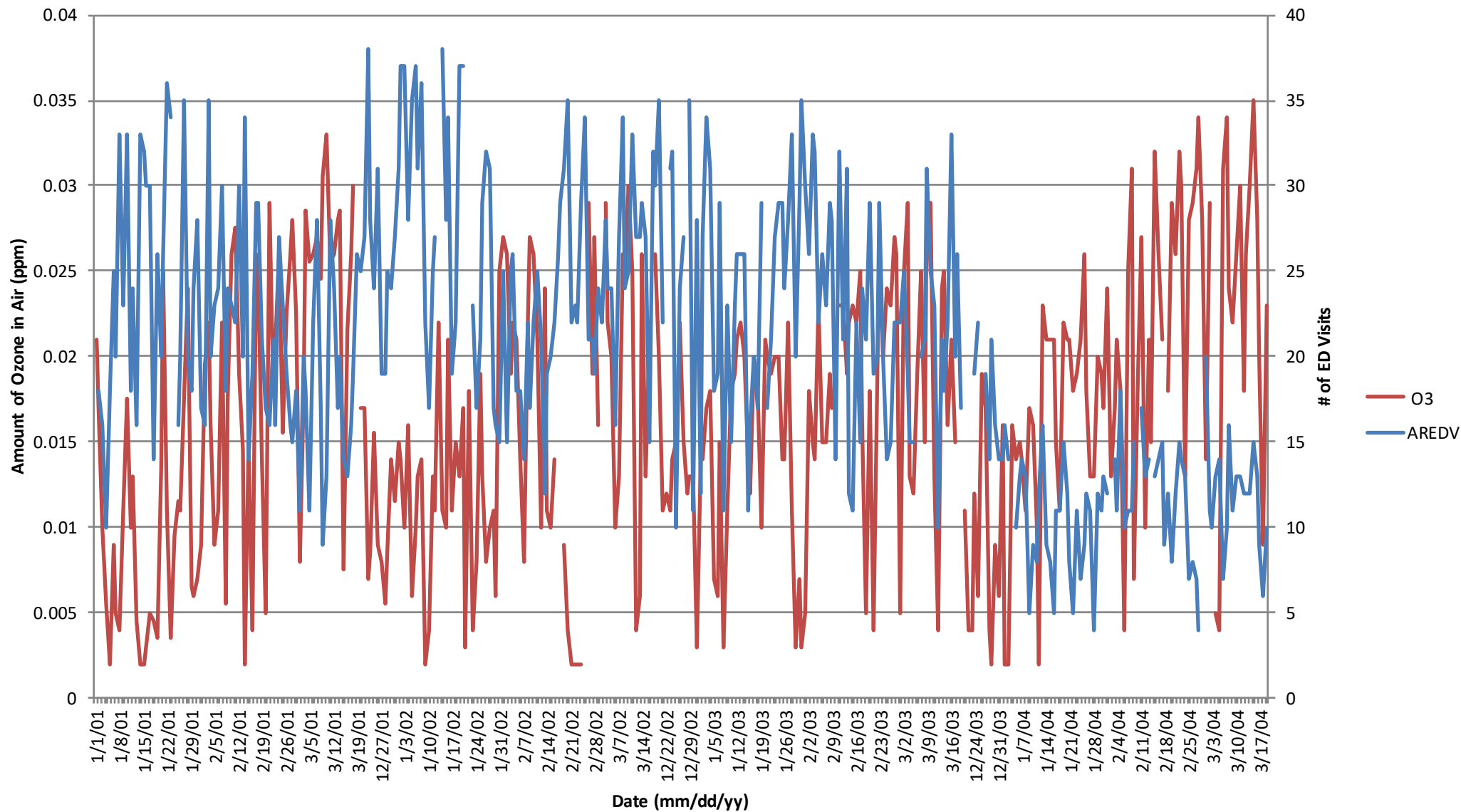
Supplemental Figure 7. Spring NO₂ (ppb) and asthma-related emergency department visits (AREDV) from 2001 to 2004.



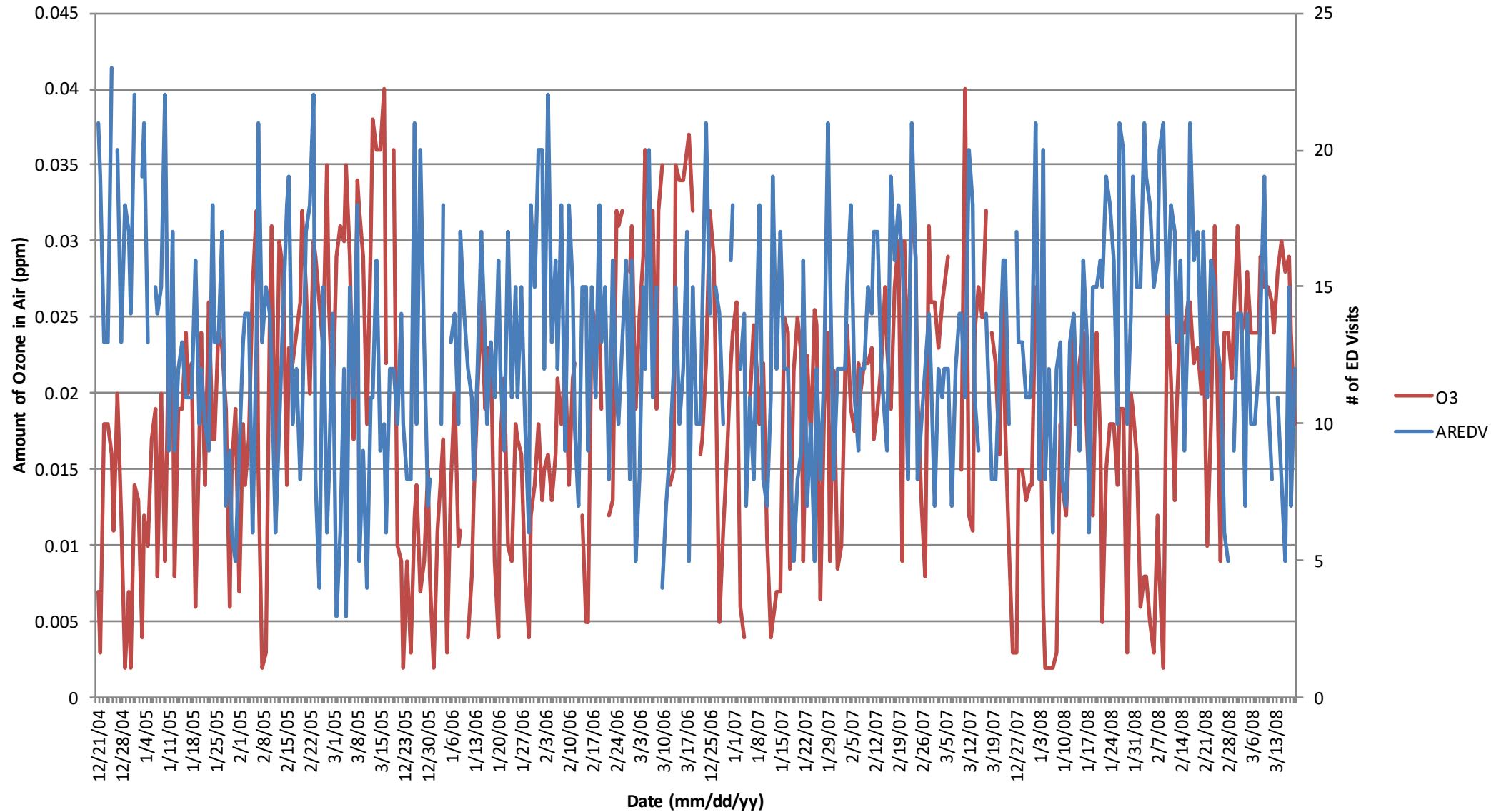
Supplemental Figure 8. Spring NO₂ (ppb) and asthma-related emergency department visits (AREDV) from 2005 to 2008.



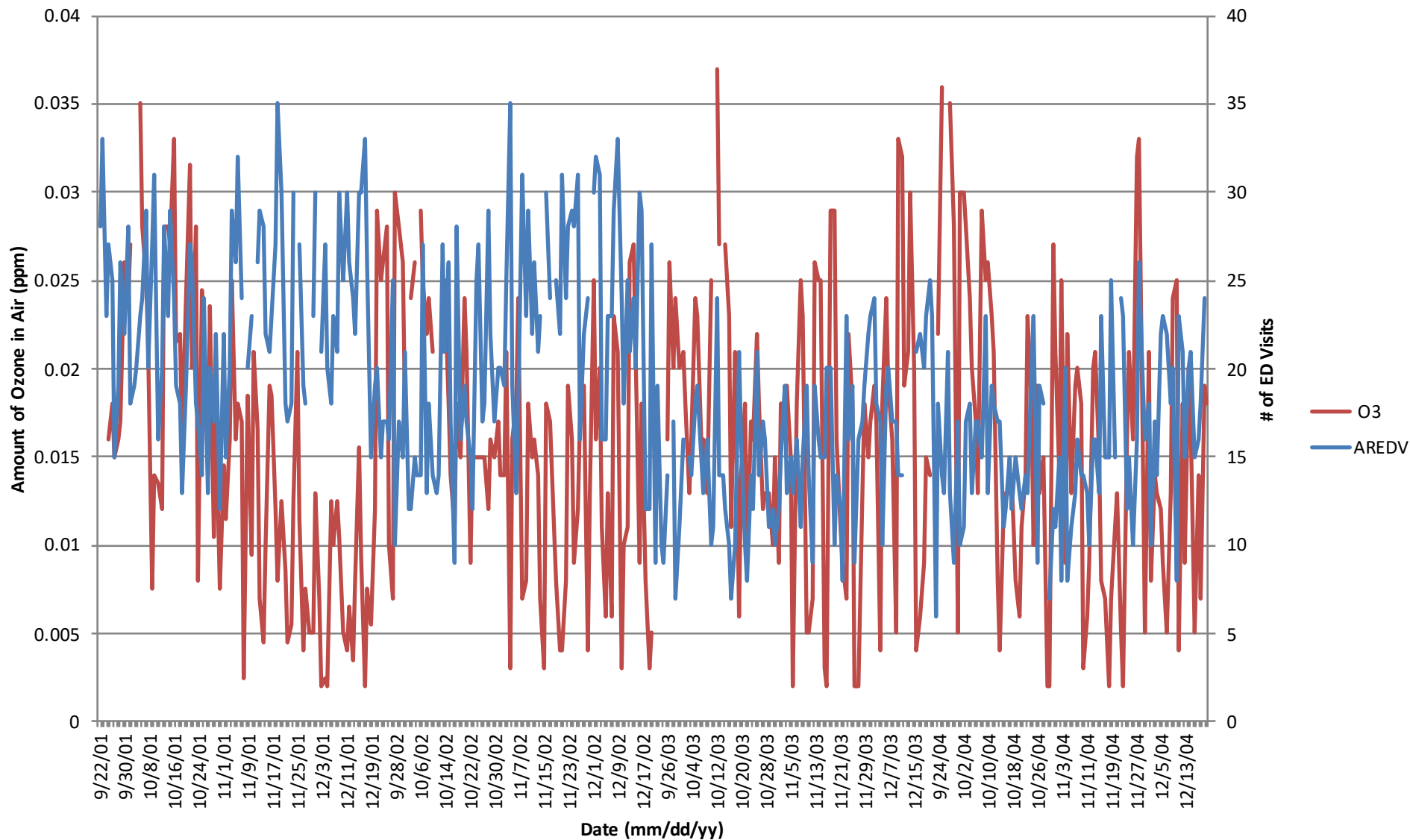
Supplemental Figure 9. Winter O₃ (ppm) and asthma-related emergency department visits (AREDV) from 2001 to 2004.



Supplemental Figure 10. Winter O₃ (ppm) and asthma-related emergency department visits (AREDV) from 2005 to 2008.



Supplemental Figure 11. Fall O₃ (ppm) and asthma-related emergency department visits (AREDV) from 2001 to 2004.



Supplemental Figure 12. Fall O₃ (ppm) and asthma-related emergency department visits (AREDV) from 2005 to 2008.

