COLORADO

Air Pollution Control Division

Department of Public Health & Environment

Technical Services Program

Final Report: Exploratory Analysis of Ozone Dynamics in the Pueblo Region during Summer 2015

July 19, 2016

FINAL REPORT:
OZONE SPECIAL STUDY
PUEBLO, COLORADO
SUMMER 2015

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Executive Summary

During the period of April 27th to October 1st of 2015, the Air Pollution Control Division (APCD) of the Colorado Department of Public Health and Environment (CDPHE) operated five short-term ozone monitoring sites in and around the area of Pueblo, Colorado and obtained data from another two industrial monitoring sites in the same area. The purpose of this study was to identify specific locations that would be appropriate for the siting of a permanent ozone monitoring station in Pueblo, where enhanced monitoring is desirable from a public health perspective due to the large number of people residing in the region, as well as to the proximity of emission sources.

Average ozone concentrations were typically below the National Ambient Air Quality Standard (NAAQS) level of 70 parts per billion (measured as the fourth-highest daily maximum 8-hour average concentration) throughout the study. Average daily maximum 8-hr ozone values ranged between 48.2 ppb and 57.9 ppb at the seven monitoring locations. Only one of these sites recorded a fourth-highest daily maximum 8-hr value in excess of the current NAAQS, although five of the seven sites recorded at least one 8-hr average value above this threshold. Concentrations were consistently higher in the suburban and rural fringe outlying Pueblo city limits, presumably due to the titration of ozone by NO emissions within the central Pueblo area where modeling studies suggest that nitrogen oxide concentrations should reach their regional maximum based on the proximity of major roads and industrial emission sources. Daily maximum 8-hr ozone concentrations in Pueblo (mean = 54.3) were similar to those measured at two permanent APCD ozone monitoring sites in Colorado Springs (mean = 51.7). Considering that the Colorado Springs sites have both exceeded the NAAQS threshold of 70 ppb in three of the last five years, this comparison suggests that sites in Pueblo are also likely to exceed the standard and thus enhanced monitoring may be warranted in this region.

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Glossary of Terms

APCD	Air Pollution Control Division
CDPHE	Colorado Department of Public Health and Environment
CFR	Code of Federal Regulations
EPA	U.S. Environmental Protection Agency
NAAQS	National Ambient Air Quality Standards
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Reactive nitrogen oxides
O_3	Ozone
ppb	Parts per billion (one part in 10^9)
ppm	Parts per million (one part in 10^6)
QA/QC	Quality Assurance/Quality Control
VOC	Volatile Organic Compound

1

Introduction

Ground-level ozone (the primary constituent of smog) is the most complex, difficult to control, and pervasive of the six principal air pollutants. Unlike other pollutants, ozone is not usually emitted directly into the air, but at ground-level is formed via photochemical reactions among NO_x and volatile organic compounds (VOCs) in the presence of sunlight. There are thousands of types of sources of these ozone precursor gases. Some of the most common sources include gasoline vapors, chemical solvents, combustion products of fuels, and consumer products. Emissions of NO_x and VOCs from motor vehicles and stationary sources can be carried hundreds of miles from their origins and result in high ozone concentrations over very large regions.[1]

Scientific evidence indicates that ground-level ozone not only affects people with impaired respiratory systems (such as asthmatics), but healthy adults and children as well.[2] Exposure to ozone for 6 to 7 hours, even at relatively low concentrations, significantly reduces lung function and induces respiratory inflammation in normal, healthy people during periods of moderate exercise. It can be accompanied by symptoms such as chest pain, coughing, nausea, and pulmonary congestion. Recent studies provide evidence of an association between elevated ozone levels and increases in hospital admissions for respiratory problems in several U.S. cities.[3] Results from animal studies indicate that repeated exposure to high levels of ozone for several months or more can produce permanent structural damage in the lungs. In addition to its effects on human health, ozone can damage plant life and is responsible for approximately one to two billion dollars of agricultural crop yield loss in the U.S. each year. Ozone also negatively impacts natural vegetation and ecosystems, leading to reduced growth and survivability of tree seedlings, and increased plant susceptibility to disease, pests, and other environmental stressors (e.g., harsh weather).[4] In long-lived species, these effects may become evident only after several years or even decades and may result in long-term effects on forest ecosystems. Ground level ozone injury to trees and plants can thus lead to a decrease in the natural beauty of our national parks and recreation areas.

Sunlight and warm weather facilitate the ozone formation process and can lead to high concentrations. Ozone is therefore considered to be primarily a summertime pollutant, with an "ozone season" being active in Colorado from March to September, when hot summer days provide the conditions for precursor chemicals to react and form ozone. Of the 20 permanent ozone monitoring sites operated by the APCD, 16 exceeded the National Ambient Air Quality Standard (NAAQS) for ozone in the summer of 2013, while 6 exceeded the standard in the summer of 2014. In 2015, based on a U.S. Environmental Protection Agency (EPA) review of the air quality criteria for ozone and related photochemical oxidants, EPA revised the level of the NAAQS design value from 0.075 to 0.070 parts per million (measured as the fourth-highest daily maximum 8-hour average concentration, averaged across three consecutive years). It is anticipated that most current APCD ozone monitoring sites will exceed this new strengthened standard in the years to come. Ozone pollution control and monitoring will thus be an ongoing concern in Colorado for the foreseeable future.

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[1] Sillman, S. (1999). The relation between ozone, NO_x and hydrocarbons in urban and polluted rural environments. Atmospheric Environment, 33(12), 1821-1845.

[2] Lippmann, M. (1989). Health effects of ozone: a critical review. Journal of the Air Pollution Control Association, 39(5), 672-695.

[3] Medina-Ramon, M., Zanobetti, A., Schwartz, J. (2006). The effect of ozone and PM_{10} on hospital admissions for pneumonia and chronic obstructive pulmonary disease: a national multicity study. American Journal of Epidemiology, 163(6), 579-588.

[4] Ashmore, M. R. (2005). Assessing the future global impacts of ozone on vegetation. Plant, Cell and Environment, 28(8), 949-964.

1.1 Study Purpose

During the period of April 27th to October 1st of 2015, the Air Pollution Control Division (APCD) of the Colorado Department of Public Health and Environment (CDPHE) operated five short-term ozone monitoring sites in and around the area of Pueblo, Colorado. Four of these sites were equipped with meteorological instrumentation measuring temperature, wind speed, and wind direction, and additional meteorological and air quality data were obtained from two other sites in central Pueblo. This data has been analyzed in the following report with the goal of identifying areas in Pueblo that are most likely to exceed National Ambient Air Quality Standards (NAAQS) for ozone (O_3). This report will be useful to air quality managers within the APCD in the planning of future monitoring activities, particularly in the establishment of a permanent O_3 site in Pueblo, where enhanced monitoring is desirable from a public health perspective due to the large number of people residing in the region (approximately 160,000 according to the 2010 U.S. Census), as well as to the proximity of emission sources; however, this document should also serve as an informative resource for air quality scientists, stakeholders, and Colorado citizens.

1.2 Site Descriptions

Figure 1.1 is a map of Colorado showing the topography of the state and the locations of the permanent ozone monitoring sites currently operated by the APCD. An inset map provides a detailed overview of the Pike's Peak and Pueblo regions. There are two major cities in this area: Pueblo, the focus of the present report, and Colorado Springs, which is located approximately 70 kilometers north of Pueblo and is home to over 645,000 people, according to the 2010 U.S. Census. The APCD currently operates only two ozone monitoring sites in this area, one in Colorado Springs and one in the nearby community of Manitou Springs. As of 2014, these two sites possess ozone design values of 69 ppb and 71 ppb, respectively, both values close to the new NAAQS of 70 ppb.

Figure 1.2 is an overview map of the Pueblo region showing the location of the seven ozone monitoring sites discussed in this report. Five of these sites (Pueblo West, Pueblo Reservoir, PAGS, Vineland, and Huerfano) were temporary solar-powered monitoring stations operated by the APCD during the study period, while the other two sites (Rocky Mountain Steel and Rocky Mountain Steel - Reservoir) were operated by a local steel plant during the study period for regulatory purposes. The locations of the five APCD-operated sites were chosen based on an analysis of meteorological data by the APCD air quality modeling staff, which suggested that ozone accumulation hot-spots were most likely to exist in the rural, agricultural, and suburban areas outside of Pueblo city limits.

Table 1.1: Ozone monitoring sites discussed in this report.

Site Name	Latitude	Longitude	Elevation (Feet)
Huerfano	38.1394	-104.4859	4901
Pueblo Airport Generating Station (PAGS)	38.3186	-104.5376	4862
Pueblo Reservoir	38.2672	-104.7052	4815
Rocky Mountain Steel	38.2429	-104.5990	4746
Vineland	38.2179	-104.4778	4770
Pueblo West	38.4045	-104.7226	5289
Rocky Mountain Steel (Reservoir)	38.1825	-104.6456	4908

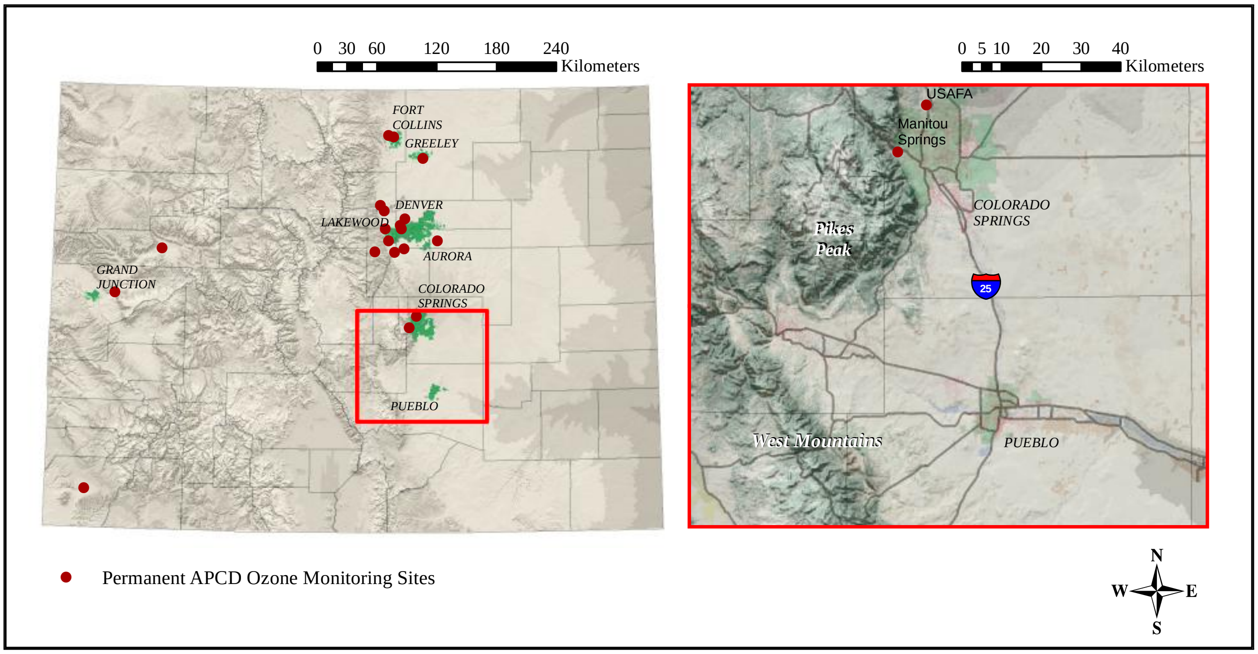

Figure 1.1: Map of Colorado with inset map showing the Pikes Peak region, including the cities of Colorado Springs and Pueblo.

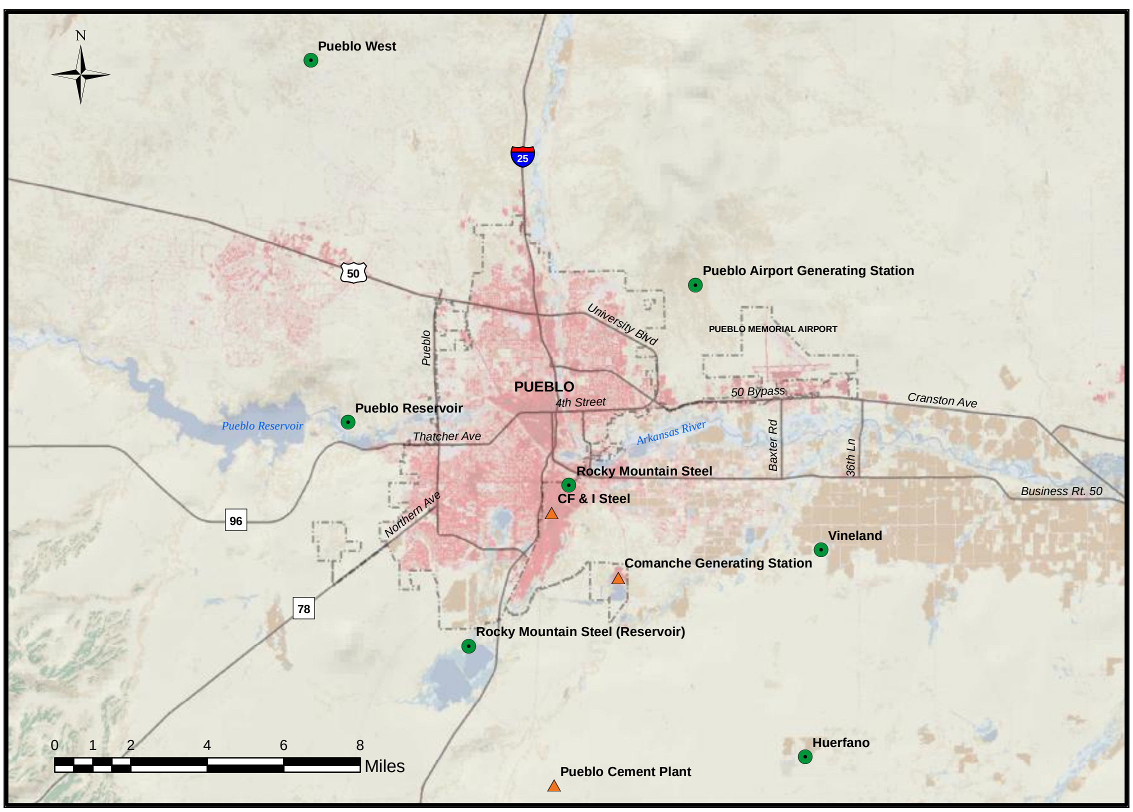

Figure 1.2: Map of ozone monitoring sites (green circles) in the Pueblo region during the study period. Major emission sources are indicated with orange triangles. The urbanized region around Pueblo is shown in light red and agricultural areas around the Arkansas River are shown in light brown. Pueblo city limits are indicated with a broken line.

1.3 Monitoring Equipment

Ozone was measured continuously at the five APCD-operated sites using 2B Technologies (2BTech) Model 205 ozone monitors, which are designed to enable accurate and precise measurements of ozone with a precision of 0.0010 ppm (1.0 ppb). The 2BTech Model 205 is light weight and has a low power consumption relative to conventional instruments and is therefore well suited for long-term monitoring at remote locations where power is limited or unavailable. For this reason, the 2BTech has become *de facto* standard instrumentation in studies of ozone in remote regions of the Rocky Mountains by the U.S. Forest Service and other governmental agencies.[5] The portable monitors were transported to the monitoring locations and operated from a standard 12-V battery charged by a 90-W solar panel. Analyzers were programmed to sample at 1-minute intervals and all data were stored on a data logger (Campbell Scientific) that also recorded air and instrument temperature and battery power. The monitor, battery, and data logger were enclosed in weather-proof instrument shelters mounted along with the solar panels between two T-posts, which were installed about 80 cm apart. Sample inlets, which consisted of Teflon particle filters and $\frac{1}{4}''$ Teflon tubing, were located 2 meters above the ground surface. A 2BTech Model 306 ozone source was used to calibrate the instruments during their installation and sites were visited monthly throughout the study period for calibration checks and routine maintenance. Additionally, the instruments were field audited twice during the study period by APCD quality assurance staff. The Huerfano and Pueblo West monitoring sites are pictured below (**??**) and a detailed schematic of the monitoring equipment is shown on the following page (Figure 1.4).

Figure 1.3: Photographs of the area surrounding the Pueblo West (top) and Huerfano (bottom) sampling sites prior to the installation of the monitoring equipment.

In addition to the ozone measurements, each APCD monitoring site was equipped with a Argent weather station, including a cup anemometer and wind vane, which recorded average wind speed and direction on 1-minute intervals throughout the study. The weather sensor equipment at PAGS was damaged early in the study and became inoperable, so wind speed and direction data were not recorded at this site during the majority of the study.

[5] Musselman, Robert C., and John L. Korfmacher. Ozone in remote areas of the Southern Rocky Mountains. Atmospheric Environment 82 (2014): 383-390.

Figure 1.4: Top left: APCD monitoring equipment at the Huerfano site, including a solar-powered ozone monitor and met tower. Top right: Schematic of the monitoring system showing the location of the sampling inlet and instrument shelter. Bottom: Detailed schematic of the instrument shelter showing the location of the 2B Tech instrument, battery, data logger, and other miscellaneous features.

2

Data Analysis

2.1 Meteorology

Wind roses for monitoring stations in the Pueblo region during the study period are shown below. Wind roses are plotted based on the direction that the wind is blowing from. Another way of visualizing a wind rose is to picture yourself standing in the center of the plot and facing into the wind. The wind direction is divided into 12 cardinal directions. The wind speed is divided into five ranges. The roses below use 0-1 ms^{-1}, 1-2 ms^{-1}, 2-3 ms^{-1}, 3-4 ms^{-1}, 4-5 ms^{-1}, 6-7 ms^{-1}, and greater than 7 ms^{-1}. The length of each arm of the wind rose represents the percentage of time the wind was blowing from that direction at that speed. The longer the arm, the greater the percentage of time the wind is blowing from that direction.

Wind regimes at the Peublo monitoring sites during the study period were dominated by easterly and westerly winds associated with thermally-driven upslope flows during the day and downvalley slope and drainage flows at night (Figure 2.1). The highest speed winds (> 5 ms^{-1}) were observed during the afternoon arriving from an easterly direction. Particularly strong upslope winds were observed at the Pueblo Reservoir site, which is located directly in the Arkansas River drainage. Nighttime westerly drainage flows were associated with lower wind speeds, typically in the range of 1-3 ms^{-1}.

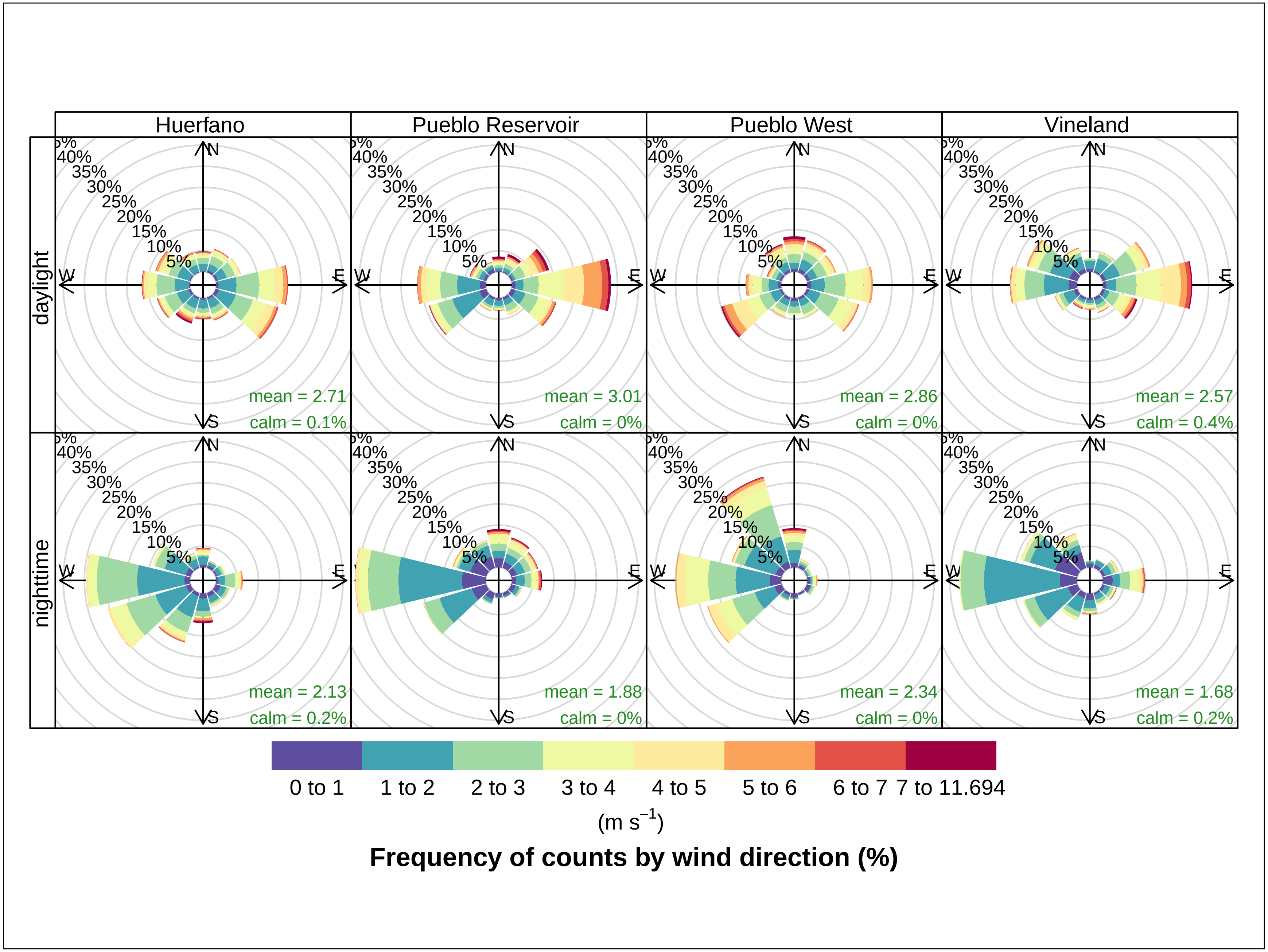

Figure 2.1: Wind roses for Pueblo monitoring sites during the study period showing the frequency of counts from each of the 12 cardinal directions for both daylight hours (top) and nighttime (bottom). Note that meteorological data is not available for the PAGS site.

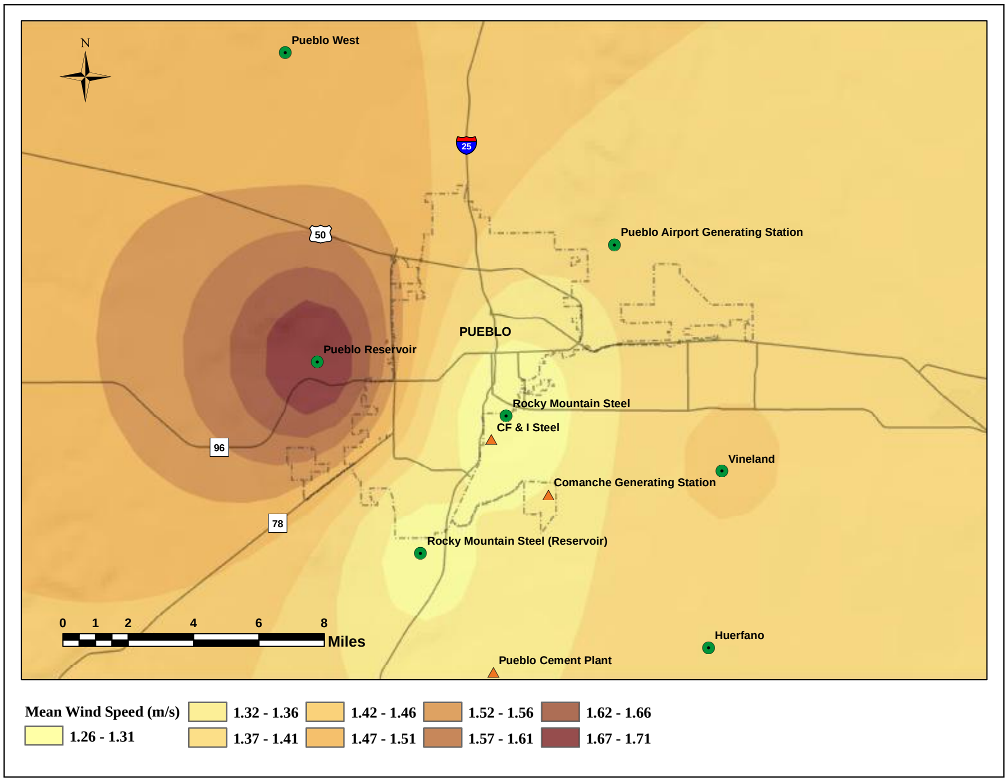

Figure 2.2: Countour plot showing an interpolation of average wind speeds (in ms^{-1}) over the Pueblo region. Note that meteorological data is not available for the PAGS site.

2.2 Ozone

Table 2.1 presents summary statistics for the 1-hr and 8-hr average ozone concentrations measured at each site during the study, while detailed time series of 24-hr average concentrations are shown in Figure 2.3 for each site. As expected, ozone concentrations within central Pueblo (Rocky Mountain Steel and Rocky Mountain Steel - Reservoir) were significantly lower (1-hr mean = 36.0 ppb and 36.4 ppb, respectively) than those observed at the sites outside of Pueblo city limits, where 1-hr mean ozone concentrations ranged between 41.0 ppb and 46.5 ppb. This observation is presumably attributable to the scavenging (i.e., titration) of ozone by primary NO emissions within the central Pueblo area, where modeling studies suggest that nitrogen oxide concentrations should reach their regional maximum based on the proximity of major roads and industrial emission sources (see Figure 2.4).[1] Average daily maximum 8-hr ozone values ranged between 48.2 ppb and 57.9 ppb at the seven sites (Figure 2.5). Only one of these sites (PAGS) recorded a fourth-highest daily maximum 8-hr value in excess of the current NAAQS (70 ppb), although all sites except Rocky Mountain Steel and Rocky Mountain Steel - Reservoir recorded at least one 8-hr average value above this threshold. In Figure 2.7 the daily maximum 8-hr values measured at permanent APCD ozone monitoring sites in Colorado Springs during the study period are compared to those observed in Pueblo. Daily maximum 8-hr ozone concentrations in Pueblo (mean = 54.3) were slightly higher and more variable compared to those measured in Colorado Springs (mean = 51.7); however, a t-test indicates that the difference between the two means is not statistically significant (p = 0.57), suggesting that the likelihood of high concentration events is similar in the two regions. Considering that the Colorado Springs sites have both exceeded the NAAQS threshold of 70 ppb in three of the last five years, this comparison suggests that sites in Pueblo are also likely to exceed the standard.

[1]Novotny, E. V., Bechle, M. J., Millet, D. B., Marshall, J. D. (2011). National satellite-based land-use regression: NO_2 in the United States. Environmental Science and Technology, 45(10), 4407-4414.

Table 2.1: Summary statistics for ozone data collected during the study period.

Site Name	Ozone (ppb)					
	1-Hour		Daily Maximum 8-Hour			
	Mean	Std. Dev.	Mean	Std. Dev.	1st Highest	4th Highest
Huerfano	42.8	13.3	55.1	7.3	75.7	67.1
Pueblo Airport Generating Station (PAGS)	46.5	12.8	57.9	6.9	79.2	70.3
Pueblo Reservoir	43.6	13.5	55.9	7.0	73.6	66.1
Rocky Mountain Steel	36.0	13.5	48.2	6.3	59.4	58.0
Vineland	41.0	13.7	53.1	7.1	71.5	63.7
Pueblo West	45.4	10.8	54.3	7.1	74.2	66.3
Rocky Mountain Steel (Reservoir)	36.4	12.6	48.4	6.4	60.8	58.4

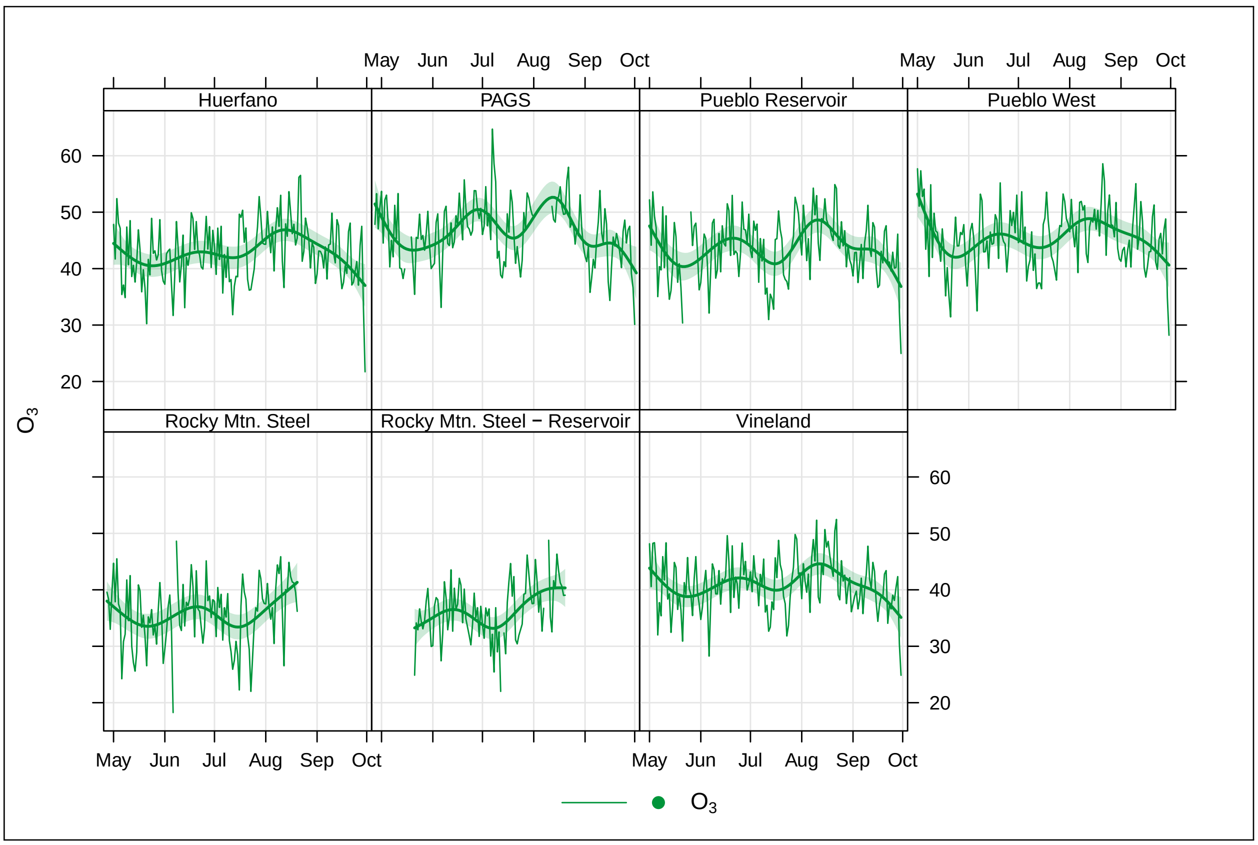

Figure 2.3: Time series of 24-hour average ozone concentrations at each monitoring site during the study. The mean trend and 95% confidence interval obtained using a generalized additive model is shown as a green line.

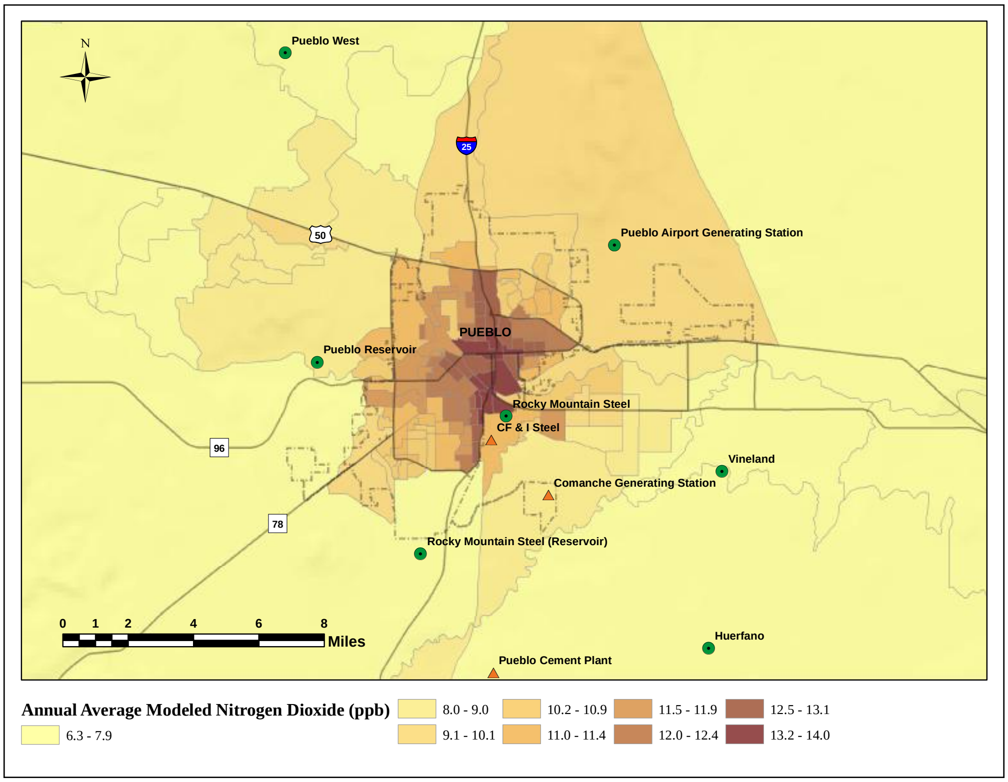

Figure 2.4: Plot showing average annual NO_2 values derived from land-use regression modeling for each census tract in the Pueblo region. Maximum values are predicted to occur over central Pueblo near major highways and industries.

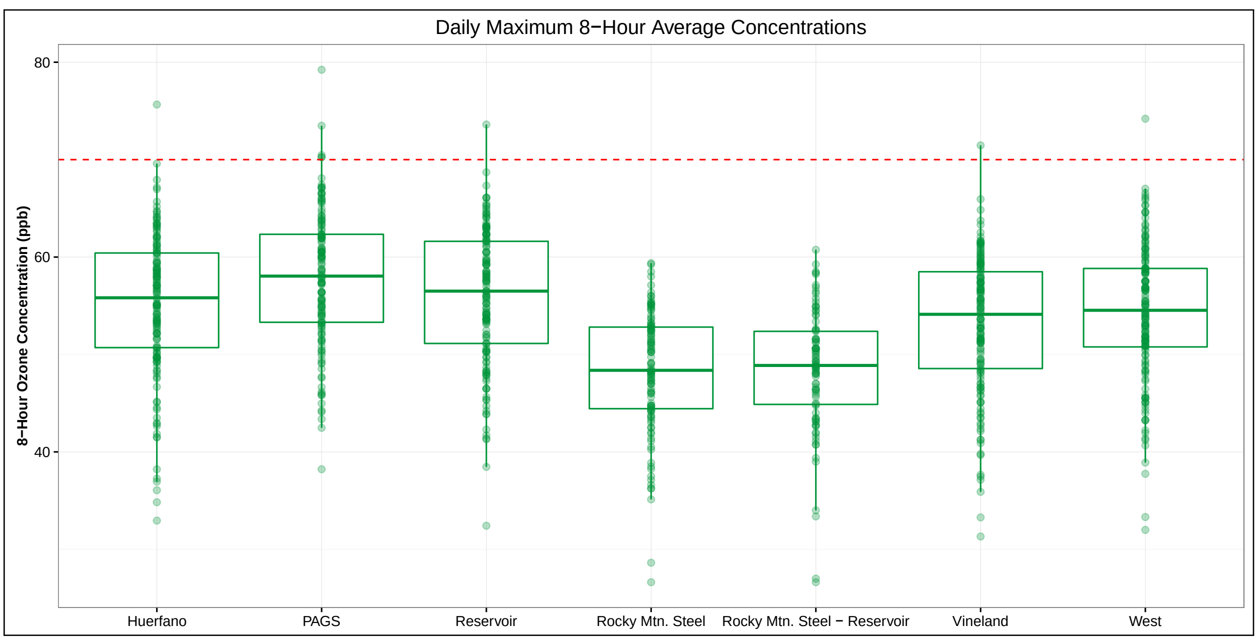

Figure 2.5: Box plot summarizing the daily maximum 8-hour ozone concentrations observed at each site during the study period. The box plot shows the median 8-hour max at each site, as well as the interquartile range (box) of values observed and the minimum and maximum values. Outliers are indicated by black points.

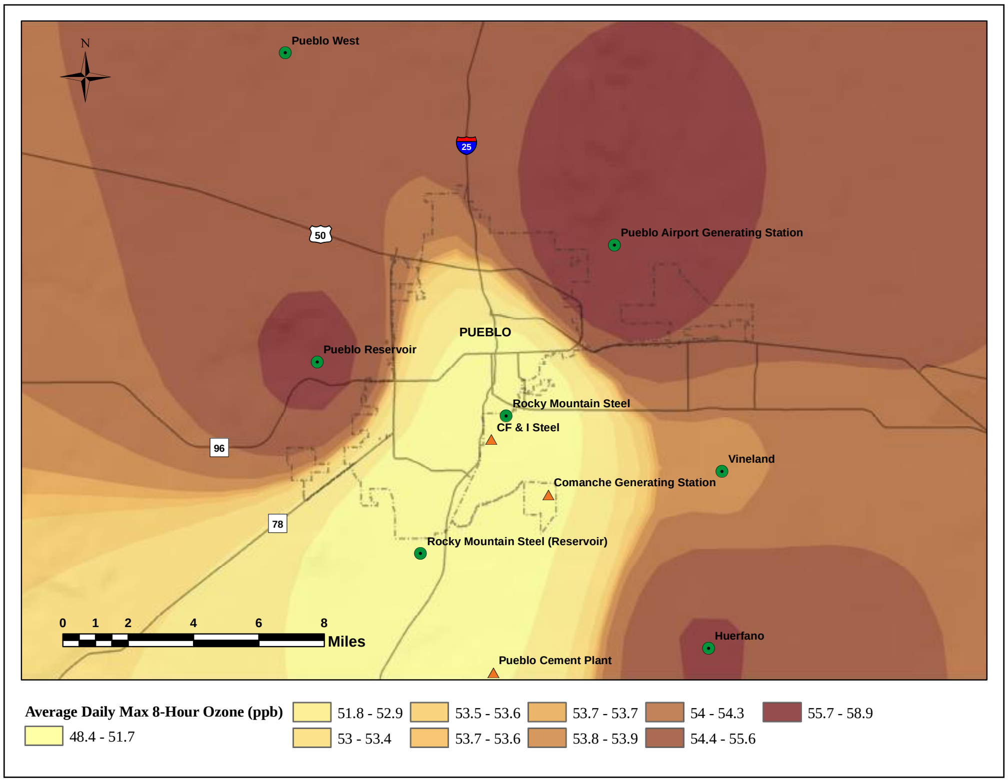

Figure 2.6: Countour plot showing an interpolation of average daily maximum 8-hour ozone concentrations over the Pueblo region. Only periods having data from all sites were considered in the production of this plot.

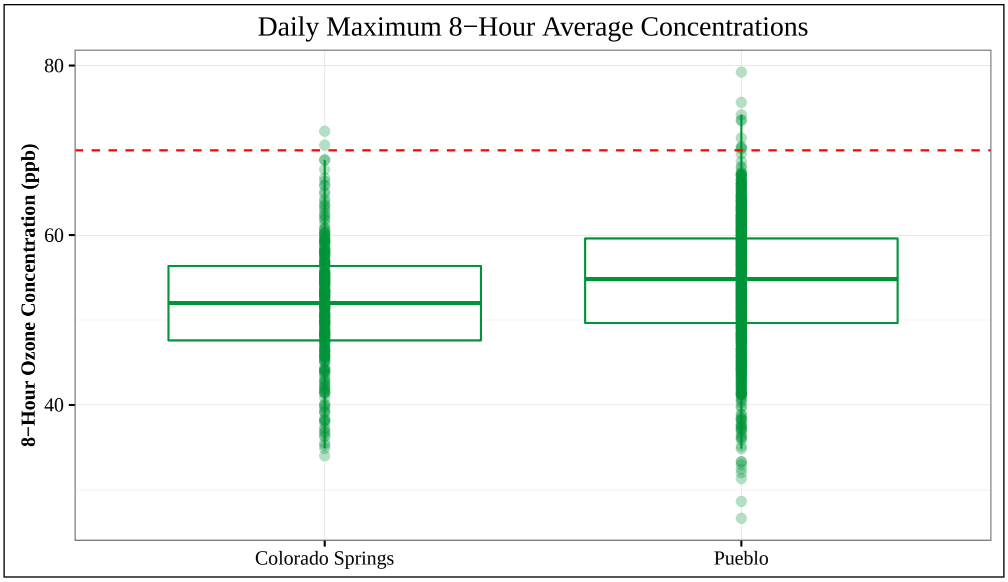

Figure 2.7: Box plot comparing the daily maximum 8-hr ozone concentrations observed at permanent APCD monitoring sites in Colorado Springs with those measured at the temporary monitoring sites in Pueblo during the study period. The box plot shows the median 8-hour max for each region, as well as the interquartile range (box) of values observed and the minimum and maximum values. The NAAQS (70 ppb) is shown as a broken red line.

2.2.1 Variations by Month

Figure 2.8 summarizes the daily maximum 8-hr ozone values observed at all Pueblo sites by month. Maximum values in excess of the 70 ppb standard were observed only during July and August, with significantly higher values being observed in August compared to the other months. Figure 2.9 shows the maximum 8-hour ozone concentration observed at the Pueblo Reservoir site for each day of the study period. Although the Pueblo Reservoir monitor only recorded one exceedance of the 70 ppb standard (on August 21st), daily maximum 8-hr values in excess of 60 ppb were common throughout the study period, particularly during August, when 8-hr values greater than or equal to 65 ppb were observed on 9 of 31 days.

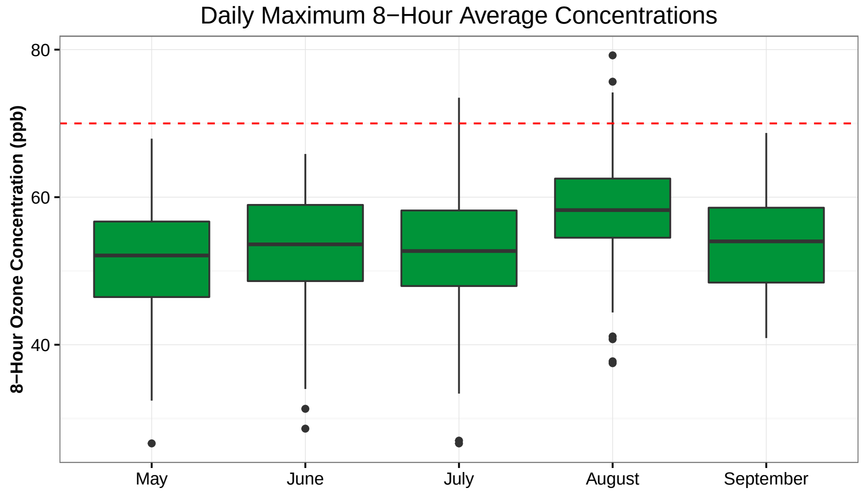

Figure 2.8: Box plot summarizing the daily maximum 8-hour ozone concentrations observed during each month of the study period. The box plot shows the median 8-hour maximum, as well as the interquartile range (box) of values observed and the minimum and maximum values. Outliers are indicated by black points.

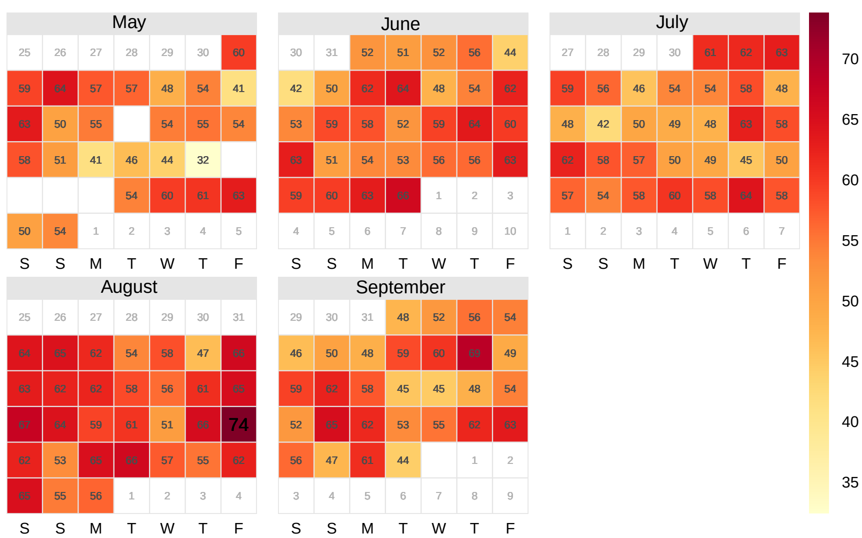

Figure 2.9: Calendar showing the maximum 8-hour ozone concentration observed at the Pueblo Reservoir site for each day of the study period. Values in excess of the 70 ppb standard are shown in bold.

2.2.2 Diurnal Variations

Figure 2.10 presents plots of diurnally averaged trends for ozone, wind direction, and wind speed at the Pueblo Reservoir and Vineland sites, which are largely representative of the six monitoring sites in the study area. From inspection of this plot, it is clear that ozone displayed a strong diurnal trend that was consistent throughout the study period. Maximum values were observed in the afternoon between 12:00 and 15:00, concurrent with vigorous afternoon upslope flow from the east (approximately 90 degrees), while nighttime drainage flows from the west (approximately 270 degrees) were associated with lower ozone concentrations and wind speeds. The quadratic relationships observed between wind speed and ozone for these two sites are shown in Figure 2.11. From an inspection of this plot, it is clear that increases in wind speeds between 1-6 ms^{-1} were associated with increasing ozone concentrations, with decreasing ozone concentrations accompanying wind speeds higher than 6 ms^{-1}.

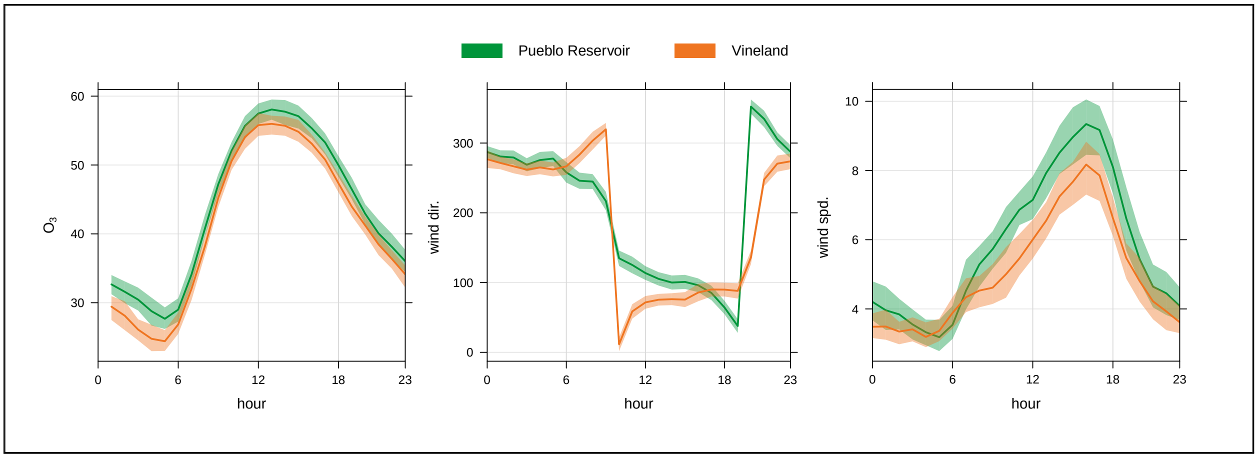

Figure 2.10: Plots summarizing diurnal variations in ozone (ppb), wind direction (degrees), and wind speed (ms^{-1}) at the Pueblo Reservoir and Vineland sites. The 99% confidence interval for the mean is shown as a shaded area around each line.

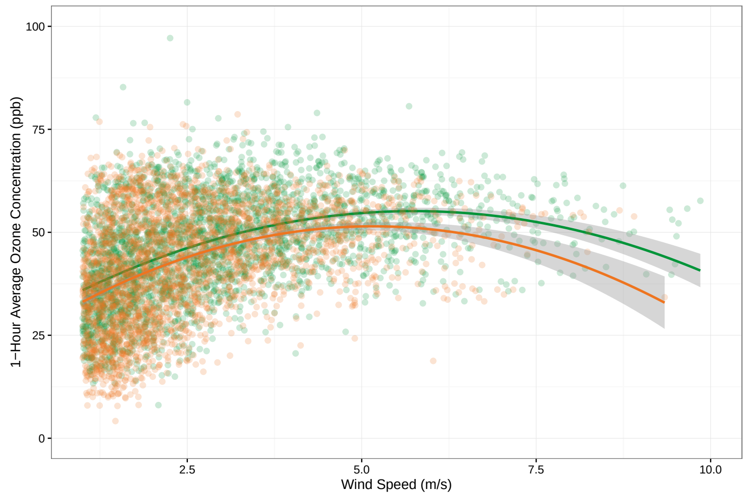

Figure 2.11: Scatterplot showing the quadratic relationship between wind speed and ozone at the Pueblo Reservoir and Vineland sites. Data is shown only for periods with wind speeds exceeding 1 ms^{-1}.

2.2.3 Wind Direction Dependency of Ozone Concentrations

Pollution roses for monitoring stations in the Pueblo region during the study period are shown below. These plots are similar to the wind roses shown previously; however, here ozone is plotted as a function of wind direction, with 1-hr ozone concentration divided into seven ranges (the highest range includes all values in excess of the 8-hr NAAQS of 70 ppb). The length of each arm of the pollution rose represents the percentage of time the wind was blowing from that direction at a given ozone concentration range. The longer the arm, the greater the percentage of time the wind is blowing from that direction.

As can be seen from the plot, daytime maxima in ozone concentration were most frequently associated with easterly upslope flow, particularly at the Pueblo Reservoir and Huerfano sites. Downslope flow during the night was associated with lower concentrations at all sites. In Figure 2.13, Conditional Probability Function (CPF) plots are shown for ozone at the Pueblo Reservoir, Huerfano, Vineland, and Pueblo West sites. The CPFs have been generated by dividing the number of samples in each wind sector with concentrations greater than the 99^{th} percentile concentration (66-70 ppb, depending on the site) by the total number of samples in the same wind sector.[2] From inspection of this plot it is clear that ozone concentrations in excess of 70 ppb at the Pueblo Reservoir and Pueblo West sites are almost exclusively associated with winds from due east in the range of 2-5 ms^{-1}. In comparison, concentrations exceeding the 99^{th} percentile have a higher probability of arriving at the Vineland site from the northeasterly direction, while high concentrations at the Huerfano site are most closely associated with southwesterly winds in excess of 6 ms^{-1}.

[2]Ashbaugh, L. L., Malm, W. C., Sadeh, W. Z. (1985). A residence time probability analysis of sulfur concentrations at Grand Canyon National Park. Atmospheric Environment (1967), 19(8), 1263-1270.

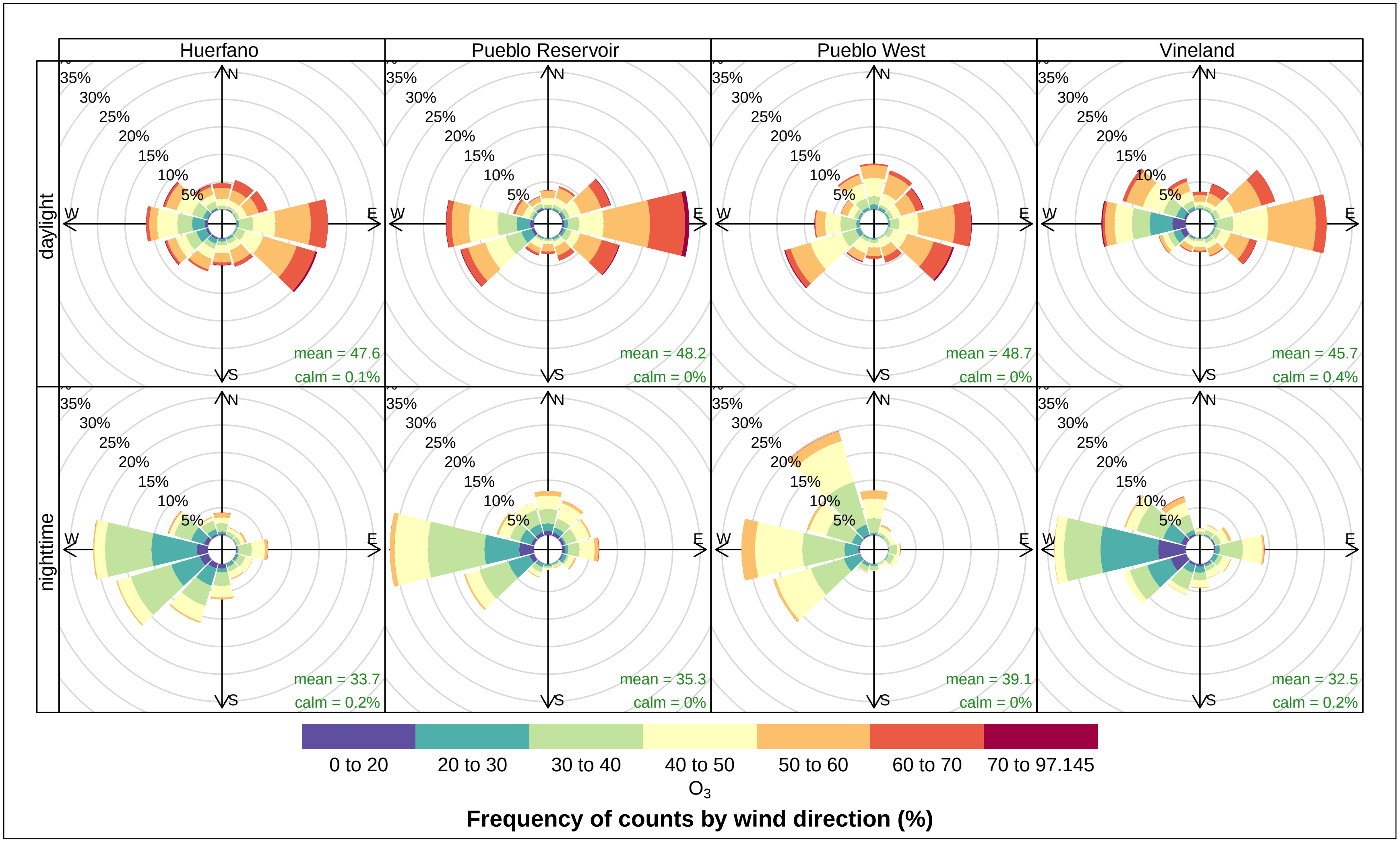

Figure 2.12: Ozone roses for Pueblo monitoring sites during the study period showing the frequency of counts from each of the 12 cardinal directions for both daylight hours (top) and nighttime (bottom). Note that meteorological data is not available for the PAGS site.

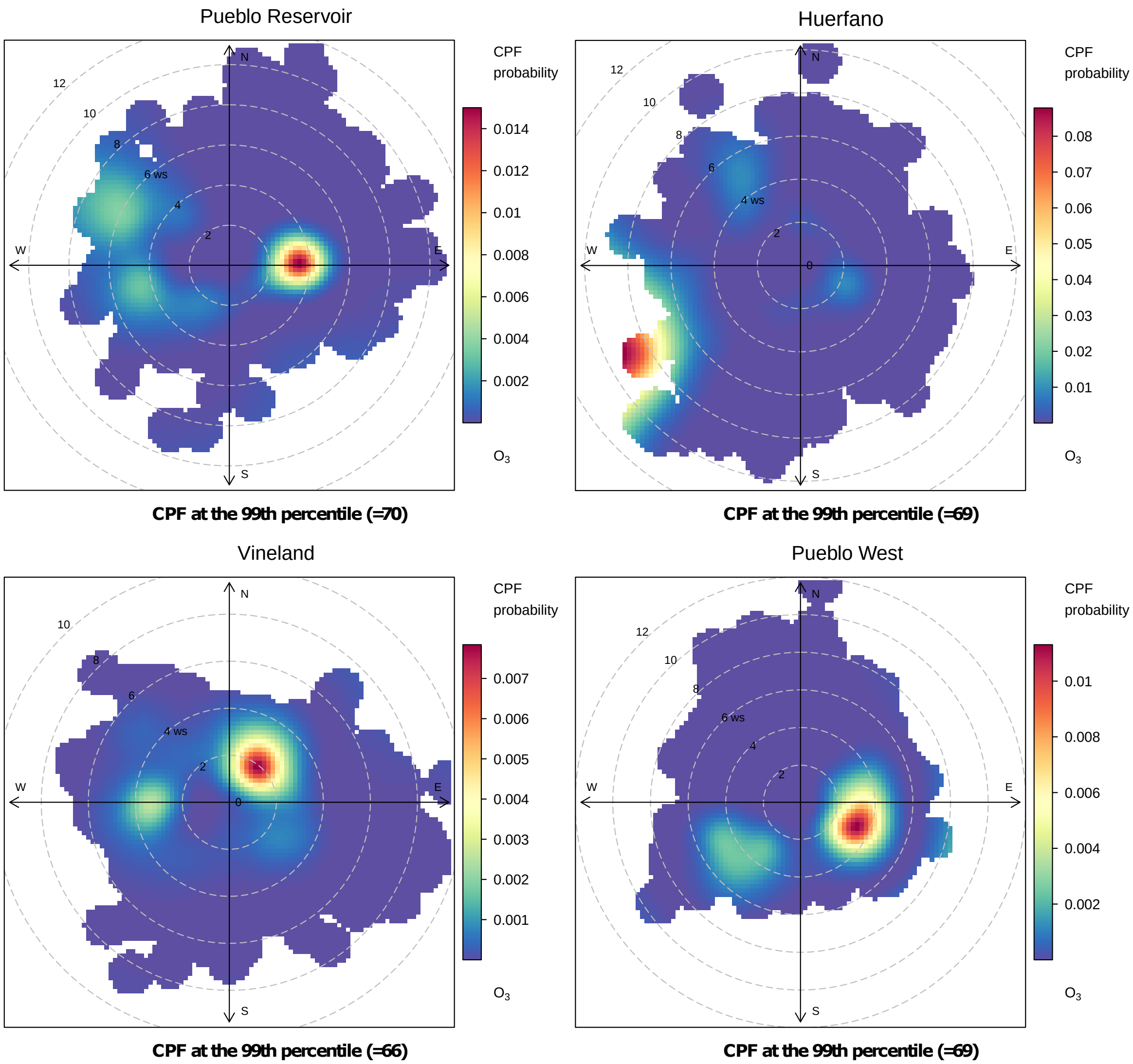

Figure 2.13: Conditional Probability Function (CPF) plots for ozone.

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Air Mass Back Trajectory (AMBT) Analysis

Here we describe the results of Air Mass Back Trajectory (AMBT) analysis, which has been conducted using the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model developed by the U.S. National Oceanic and Atmospheric Administration (NOAA).[1] The HYSPLIT model is a complete system for computing simple air parcel trajectories, as well as complex transport, dispersion, chemical transformation, and deposition simulations. A common application of this model is a back trajectory analysis to determine the origin of air masses and establish source-receptor relationships. AMBT analysis has been applied in this study to determine air mass origins and potential source regions of ozone for the Pueblo area throughout the study period.

Four-day (96-hour) AMBT simulations were computed for the Pueblo region for every three hours of the study period using the Global NOAA-NCEP/NCAR reanalysis data archives, which are provided on a 2.5 degree longitude-latitude grid. The trajectories were started at ground-level (10 meters) at the longitude and latitude of the Pueblo Reservoir site and propagated backward in time. A summary of the AMBT simulations can be found in Figure 3.1 below. This plot shows a hexagonal binning of trajectory points (i.e., a point every three hours along each back trajectory), which were computed by counting the number of trajectory intersections over each grid point and dividing by the total number of trajectories. This plot illustrates the dominant atmospheric transport patterns during the study period, which were primarily oriented in a north-south direction along the Rocky Mountains. Air masses over the Pueblo region arrived primarily from two main source regions: the east/northeast (Great Plains states) and south/southwest (Four Corners region). Less frequent transport pathways from the southeast were associated with the summer monsoon, which brings moist air into southern Colorado from the Gulf of Mexico. Westerly transport from the mountainous regions of the U.S West (California, Nevada, Utah, Wyoming, Montana, etc.) was much less common during the study period.

Ozone data from the Pueblo Reservoir site was combined with the HYSPLIT data by matching each AMBT with the ozone concentration observed at its time of arrival. Concentrations observed under different transport regimes were then compared in order to identify the most significant ozone source regions. In this analysis, trajectories where the associated ozone concentration was greater than the 90^{th} percentile of all values observed at the Pueblo Reservoir site were compared with the the full set of trajectories to understand the differences in frequencies of the origin of air masses. The comparison is made by comparing the percentage change in gridded frequencies as is shown in Figure 3.2. From inspection of this plot it can be seen that high ozone concentrations were most often associated with transport from the east/northeast or east/southeast, while transport from the south/southwest was associated with lower concentrations. This observation agrees with the observed dependence of ozone concentration on the surface wind data (i.e., highest ozone concentrations were observed under a easterly, upslope transport regime).

[1]Stein, A. F., Draxler, R. R., Rolph, G. D., Stunder, B. J. B., Cohen, M. D., Ngan, F. (2015). NOAA's HYSPLIT atmospheric transport and dispersion modeling system. Bulletin of the American Meteorological Society, 96(12), 2059-2077.

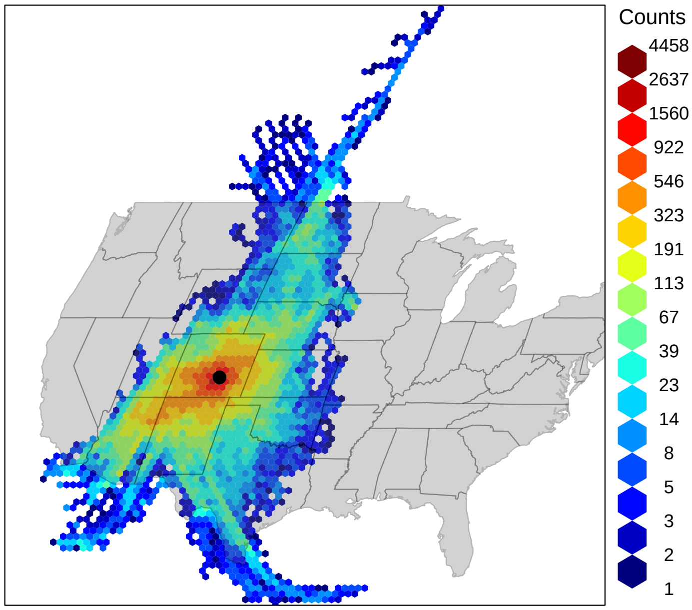

Figure 3.1: Summary of AMBT simulations for the Pueblo area during the study period.

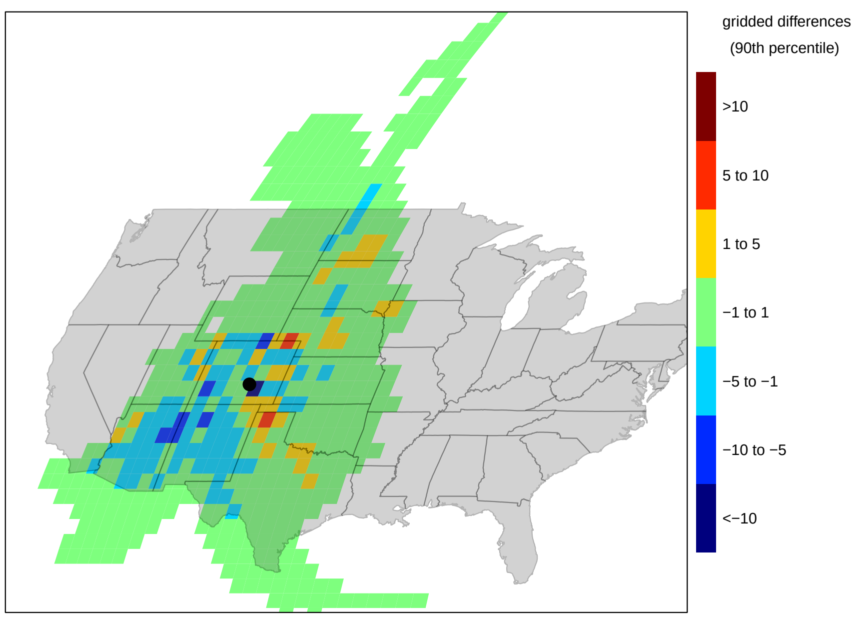

Figure 3.2: Difference plot comparing percentage change in gridded frequencies for AMBTs associated with ozone concentrations over the 90th percentile.

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Conclusion

This report summarizes ozone and meteorological data obtained during a special study in Pueblo, Colorado during the summer of 2015. The purpose of this study was to identify specific locations that would be appropriate for the siting of a permanent ozone monitoring station in Pueblo, where enhanced monitoring is desirable from a public health perspective due to the large number of people residing in the region, as well as to the proximity of emission sources.

Seven monitoring sites were employed in the study. Five of these sites were located in the rural areas outside of Pueblo city limits, and two sites were located in Pueblo's industrial area along the I-25 corridor. Monitoring was conducted at the five rural sites from April 27^{th} to October 1^{st}, while shorter time series were obtained from the two I-25 sites. Six of these sites were equipped with meteorological instrumentation measuring wind speed and wind direction, allowing for an analysis of the dependence of ozone concentrations on surface winds.

Wind regimes at the Peublo monitoring sites during the study period were dominated by easterly and westerly winds associated with thermally-driven upslope flows during the day and downvalley slope and drainage flows at night (Figure 2.1). The highest speed winds (> 5 ms^{-1}) were observed during the afternoon arriving from an easterly direction. Nighttime westerly drainage flows were associated with lower wind speeds, typically in the range of 1-3 ms^{-1}. Maximum ozone concentrations were most frequently associated with easterly upslope flow, while downslope flow during the night was associated with lower concentrations at all sites. Similarly, air mass back trajectory simulations suggest that high ozone concentrations were most often associated with transport from the east/northeast, while transport from the south/southwest was associated with lower concentrations.

Average ozone concentrations were typically below the National Ambient Air Quality Standard (NAAQS) level of 70 parts per billion (measured as the fourth-highest daily maximum 8-hour average concentration) throughout the study. Average daily maximum 8-hr ozone values ranged between 48.2 ppb and 57.9 ppb at the seven monitoring locations. Only one of these sites recorded a fourth-highest daily maximum 8-hr value in excess of the current NAAQS, although five of the seven sites recorded at least one 8-hr average value above this threshold. Concentrations were consistently higher in the suburban and rural fringe outlying Pueblo city limits, presumably due to the titration of ozone by NO emissions within the central Pueblo area where modeling studies suggest that nitrogen oxide concentrations should reach their regional maximum based on the proximity of major roads and industrial emission sources. Daily maximum 8-hr ozone concentrations in Pueblo (mean = 54.3) were similar to those measured at two permanent APCD ozone monitoring sites in Colorado Springs (mean = 51.7). Considering that the Colorado Springs sites have both exceeded the NAAQS threshold of 70 ppb in three of the last five years, this comparison suggests that sites in Pueblo are also likely to exceed the standard and thus enhanced monitoring may be warranted in this region.