UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

November 20, 2014

OFFICE OF
AIR QUALITY PLANNING
AND STANDARDS

MEMORANDUM

SUBJECT: Comparison of Ozone Metrics Considered in the Current NAAQS Review

FROM: Benjamin Wells (EPA, OAQPS)

TO: Ozone NAAQS Review Docket (EPA-HQ-OAR-2008-0699)

Overview

The final policy assessment for the current review of the national ambient air quality standards (NAAQS) for ozone (O_3) (U.S. EPA, 2014) identifies two metrics that are appropriate for consideration of the secondary standard. One metric is identical to the form and averaging time for the current primary and secondary O_3 standards: the annual 4th highest daily maximum 8-hour O_3 concentration, averaged over three consecutive years, in parts per billion (ppb). For convenience, this metric is hereafter referred to as the "4th max" metric. The other metric identified for the secondary standard is the annual W126 index, averaged over three consecutive years, in parts per million-hours (ppm-hrs), hereafter referred to as the "W126" metric.

This memo provides the results of a technical analysis which examines the relationship between the 4th max metric and the W126 metric based on ambient air quality data from 2001 to 2013. The analysis focuses on levels of 75, 70, 65, and 60 ppb for the 4th max metric, with particular emphasis on 70 and 65 ppb, and levels of 17, 15, 13, 11, and 7 ppm-hrs for the W126 metric, with particular emphasis on 17, 15, and 13 ppm-hrs. These particular levels were chosen for evaluation based on EPA staff recommendations in the final policy assessment.

Data Handling

Hourly O_3 concentration data were retrieved from EPA's Air Quality System (AQS) database for 1,849 O_3 monitors which operated between 2001 and 2013. These data were used to calculate 4th max and W126 values for each 3-year period from 2001-2003 to 2011-2013. Before calculating these values, some initial processing was done on the hourly data. First, data collected using monitoring methods other than federal reference or equivalent methods, and data collected from monitoring sites not meeting EPA's quality assurance or siting criteria in 40 CFR part 58 were removed. Second, data collected by multiple monitoring instruments operating at the same site were combined by selecting the monitor with the most hourly observations each year, then filling

in missing hourly concentration values using data collected from the remaining monitors at the site. Finally, data were combined across 62 pairs of monitoring sites approved by the appropriate EPA regional offices, in order to maintain a continuous data record when these sites were replaced or relocated a short distance away. The final dataset consisted of hourly O_3 concentration data for 1,657 monitoring sites.

The 4th max values were calculated according to the data handling in the proposed rulemaking notice for the O_3 NAAQS (Appendix U to 40 CFR part 50). First, moving 8-hour averages were calculated from the hourly O_3 concentration data for each site. For each 8-hour period, an 8-hour average value was calculated if there were at least 6 hourly O_3 concentrations available, and stored in the first hour of the period. Daily maximum 8-hour average values were found using the 8-hour periods beginning from 7:00 AM to 11:00 PM each day. These daily maximum values were used if at least 13 of the 17 possible 8-hour averages were available, or if the daily maximum value was greater than the 4th max level being evaluated. Finally, the annual 4th highest daily maximum value was found for each year, then averaged across each consecutive 3-year period to obtain the final set of 4th max values. The annual 4th highest daily maximum 8-hour values and the 3-year average values were truncated to the next lowest unit ppb for applications requiring direct comparison to a 4th max level, otherwise, all decimal digits were retained in the calculations. The 4th max values were considered valid if daily maximum values were available for at least 90% of the days in the O_3 monitoring season (defined in Appendix D to 40 CFR part 58) on average across the three years, with a minimum of 75% of the days in the O_3 monitoring season in any single year. In addition, 4th max values were considered valid if they were greater than the 4th max levels to which they were being compared.

To calculate the W126 values, the hourly O_3 concentration values (in parts per million) for daytime hours (defined as the 12-hour period from 8:00 AM to 8:00 PM each day) at each site were weighted using the following equation:

$$\text{Weighted } O_3 = O_3 / (1 + 4403*\exp(-126 * O_3))$$

These weighted values were summed over each calendar month, then adjusted for missing data (e.g.; if 80% of the daytime hourly concentrations were available, the sum would be multiplied by 1/0.8 = 1.25) to obtain the monthly W126 index values. Monthly W126 index values were not calculated for months where fewer than 75% of the possible daytime hourly concentrations were available. Next, moving 3-month sums were calculated from the monthly index values, and the highest of these 3-month sums was determined as the annual W126 index. Three-month periods spanning multiple years (e.g., November to January, December to February) were not considered in these calculations. The annual W126 index values were averaged across each consecutive 3-year period to obtain the final W126 values, with units in parts per million-hours (ppm-hrs). The annual W126 index values and the 3-year average values were truncated to the next lowest unit ppm-hour for applications requiring direct comparison to a W126 level, otherwise, all decimal digits were retained in the calculations. The W126 values were considered valid if hourly O_3 concentration values were available for at least 90% of the daytime hours during the O_3 monitoring season on average across the three years, with a minimum of 75% of the daytime hours during the O_3 monitoring season in any single year. In addition, W126 values were considered valid if they were greater than the W126 levels to which they were being compared.

In the final dataset, 1,419 of the 1,657 O_3 monitoring sites had sufficient data to calculate valid 4th max and W126 values for at least one 3-year period between 2001-2003 and 2011-2013. The number of sites with valid 4th max and W126 values ranged from 1,023 in 2001-2003 to 1,104 in 2011-2013, and 729 sites had valid 4th max and W126 values for all eleven 3-year periods.

Analysis

The analysis based on the 4th max and W126 values consisted of three parts. The first part focused on the metric values for the most recent period, 2011-2013, to determine how many sites had values greater than the various 4th max and W126 levels of interest, and to gain a sense of how the 4th max and W126 metrics relate to one another based on observed air quality data. The second part of the analysis focused on trends in the 4th max and W126 values from 2001-2003 to 2011-2013, to examine how those values have changed over time. The final part of the analysis focused on the relative changes in the 4th max and W126 values from 2001-2003 to 2011-2013, to assess how those values have responded to changes in precursor emissions, and to gain a sense of how future control programs designed to meet a revised primary O_3 standard could impact both 4th max and W126 values.

Recent Air Quality Data

The first portion of the analysis focused on the 4th max and W126 values for the most recent 3-year period, 2011-2013. Figures 1 and 2 below show maps of the 4th max and W126 values based on 2011-2013 data. These values were compared to the various 4th max and W126 levels of interest in order to determine the number of sites with values greater than each level. Table 1 shows the number of sites with 4th max values greater than each 4th max level, and Table 2 shows the number of sites with W126 values greater than each W126 level.

The number of sites with 4th max values greater than 70 ppb was approximately double the number of sites with 4th max values greater than 75 ppb, and the number of sites with 4th max values greater than 65 ppb was approximately triple the number of sites with 4th max values greater than 75 ppb. In general, given similar points within the range of levels being considered, there were fewer sites exceeding the W126 levels than the 4th max levels

The 4th max and W126 values were also compared to each combination of 4th max and W126 levels of interest based on 2011-2013 data. First, Table 3 shows the number of sites with 4th max values greater than each 4th max level, and W126 values less than or equal to each W126 level (e.g., 305 sites had 4th max values greater than 70 ppb and W126 values less than or equal to 13 ppm-hrs). Next, Table 4 shows the number of sites with 4th max values less than or equal to each 4th max level, and W126 values greater than each W126 level (e.g., 16 sites had 4th max values less than or equal to 70 ppb and W126 values greater than 13 ppm-hrs). Finally, Table 5 shows the number of sites with 4th max values greater than each 4th max level, and W126 values greater than each W126 level (e.g., 244 sites had 4th max values greater than 70 ppb and W126 values greater than 13 ppm-hrs).

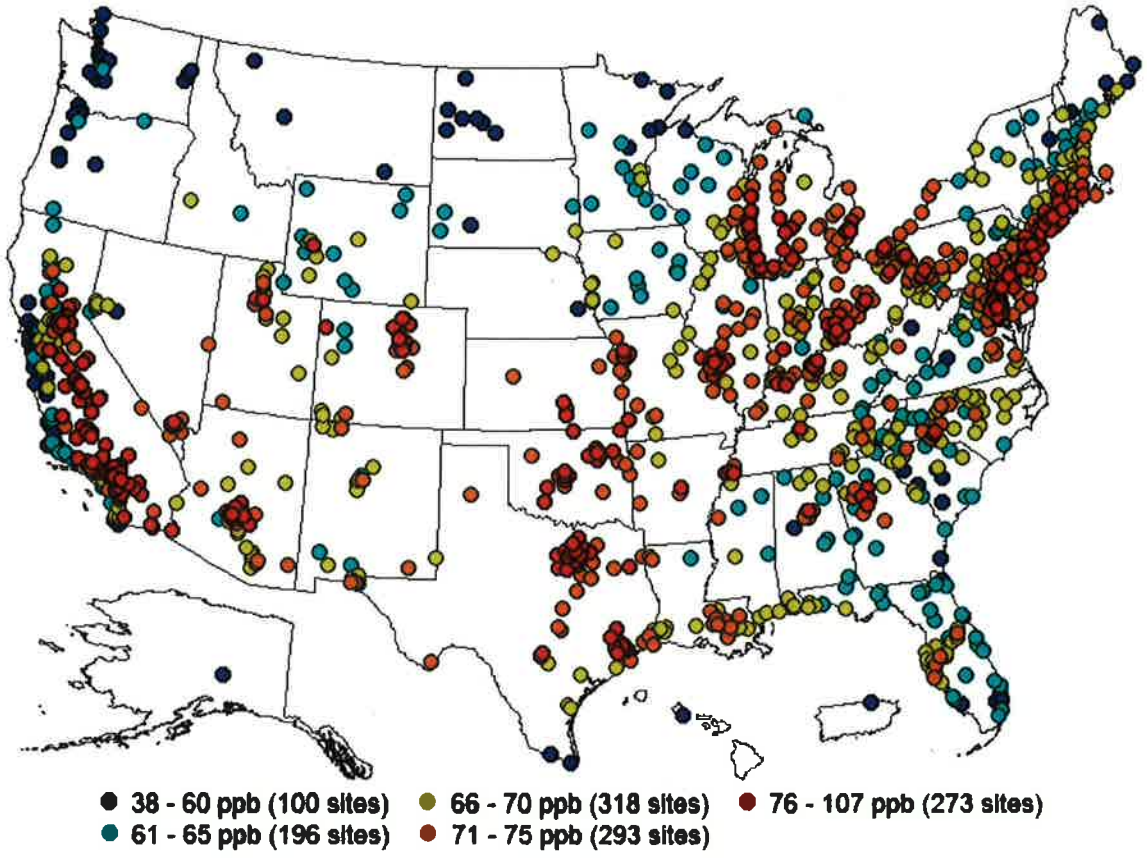

Figure 1. Map of 4th max values based on 2011-2013 data

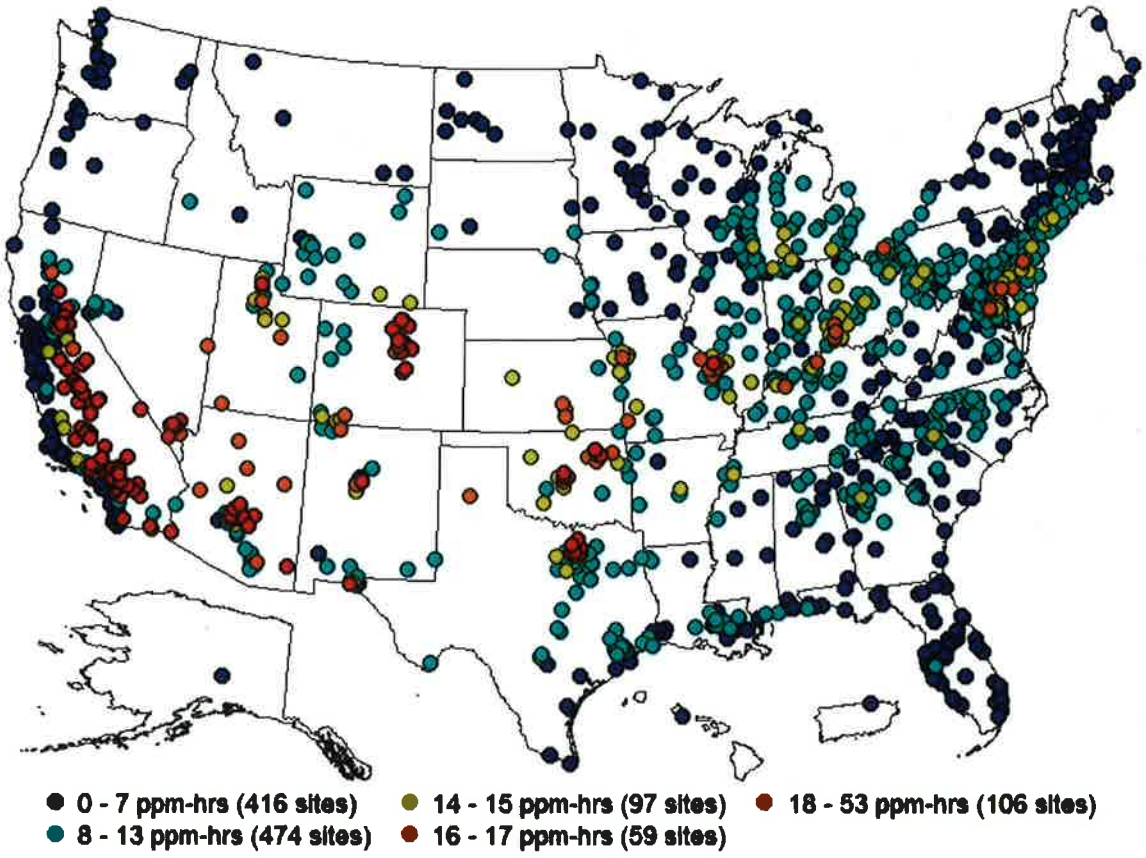

Figure 2. Map of W126 values based on 2011-2013 data

Table 1. Number of sites with 4th max values greater than various 4th max levels of interest based on 2011-2013 data

4th Max Level (ppb)	75	70	65	60
# of Sites Exceeding Level[1]	273	566	884	1080

Table 2. Number of sites with W126 values greater than various W126 levels of interest based on 2011-2013 data

W126 Level (ppm-hrs)	17	15	13	11	7
# of Sites Exceeding Level[2]	106	165	262	381	736

Table 3. Number of sites with 4th max values greater than various 4th max levels of interest and W126 values less than or equal to various W126 levels of interest based on 2011-2013 data

# of Sites Exceeding Only 4th Max Level		W126 Level (ppm-hrs)				
		17	15	13	11	7
4th Max Level (ppb)	75	176	139	86	41	2
	70	439	386	305	206	28
	65	726	669	576	463	150
	60	903	846	753	640	312

Table 4. Number of sites with 4th max values less than or equal to various 4th max levels of interest and W126 values greater than various W126 levels of interest based on 2011-2013 data

# of Sites Exceeding Only W126 Level		W126 Level (ppm-hrs)				
		17	15	13	11	7
4th Max Level (ppb)	75	15	35	75	143	433
	70	0	4	16	30	178
	65	0	0	0	0	15
	60	0	0	0	0	0

[1] There were 1,180 sites with sufficient 2011-2013 data to calculate a valid 4th max value.
[2] There were 1,152 sites with sufficient 2011-2013 data to calculate a valid W126 value.

Table 5. Number of sites with 4th max values greater than various 4th max levels of interest and W126 values greater than various W126 levels of interest based on 2011-2013 data

# of Sites Exceeding Both Levels		W126 Level (ppm-hrs)				
		17	15	13	11	7
4th Max Level (ppb)	75	89	127	182	230	269
	70	106	161	244	348	534
	65	106	165	262	381	715
	60	106	165	262	381	735

According to Table 4, there were no sites with 4th max values less than or equal to 70 ppb and W126 values greater than 17 ppm-hrs, and there were no sites with 4th max values less than or equal to 65 ppb and W126 values greater than 11 ppm-hrs. Figure 3a shows the locations of the 35 sites with 4th max values less than or equal to 75 ppb and W126 values greater than 15 ppm-hrs, as well as the 16 sites with 4th max values less than or equal to 70 ppb and W126 values greater than 13 ppm-hrs. All of these sites are located in the Southwestern U.S. (i.e., the region bounded by the red border in Figure 3a), which indicates that there may be regional differences in the relationship between the 4th max and W126 metrics. Figure 3b shows an enlarged version of the same map focused on the Southwestern U.S.

In order to examine these differences, many of the further analyses were stratified into the nine NOAA climate regions (Karl and Koss, 1984), which are shown in Figure 4. Note that since the NOAA climate regions only cover the contiguous U.S., Alaska was added to the Northwest region, Hawaii was added to the West region, and Puerto Rico was added to the Southeast region.

Figure 5a shows a scatter plot comparing the 4th max (x-axis) and W126 (y-axis) values based on 2011-2013 data, with points colored by region, while Figure 5b shows an enlarged version of the same scatter plot with emphasis on the region containing the 4th max and W126 levels of interest. These figures indicate that there is a strong, positive, non-linear relationship between the 4th max and W126 metrics. The amount of variability in the relationship between the 4th max and W126 metrics appears to increase as the metric values themselves increase. The relationship between the 4th max and W126 metrics also appears to vary across regions. In particular, the Southwest and West regions (i.e., the southwestern U.S.) appear to have higher W126 values relative to their respective 4th max values than the rest of the U.S.

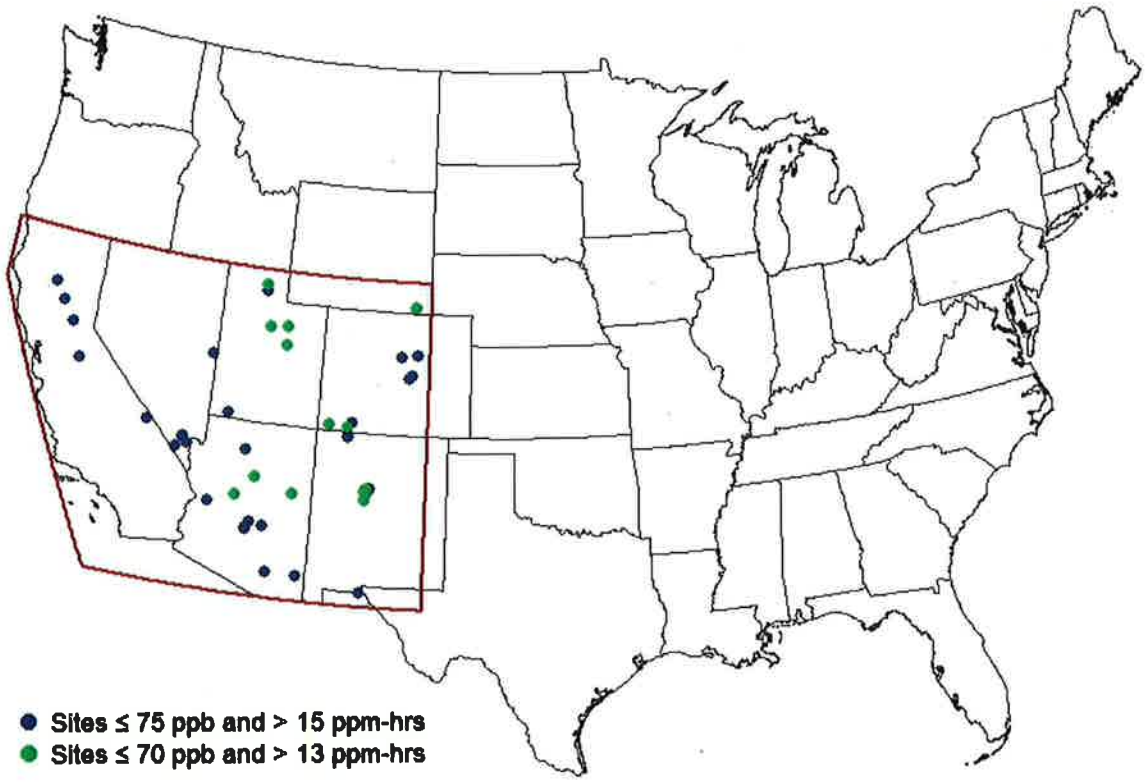

Figure 3a. Map of sites with 4th max values less than or equal to 75 ppb and W126 values greater than 15 ppm-hrs, and sites with 4th max values less than or equal to 70 ppb and W126 values greater than 13 ppm-hrs. The red border indicates the Southwestern U.S. region enlarged in the figure below.

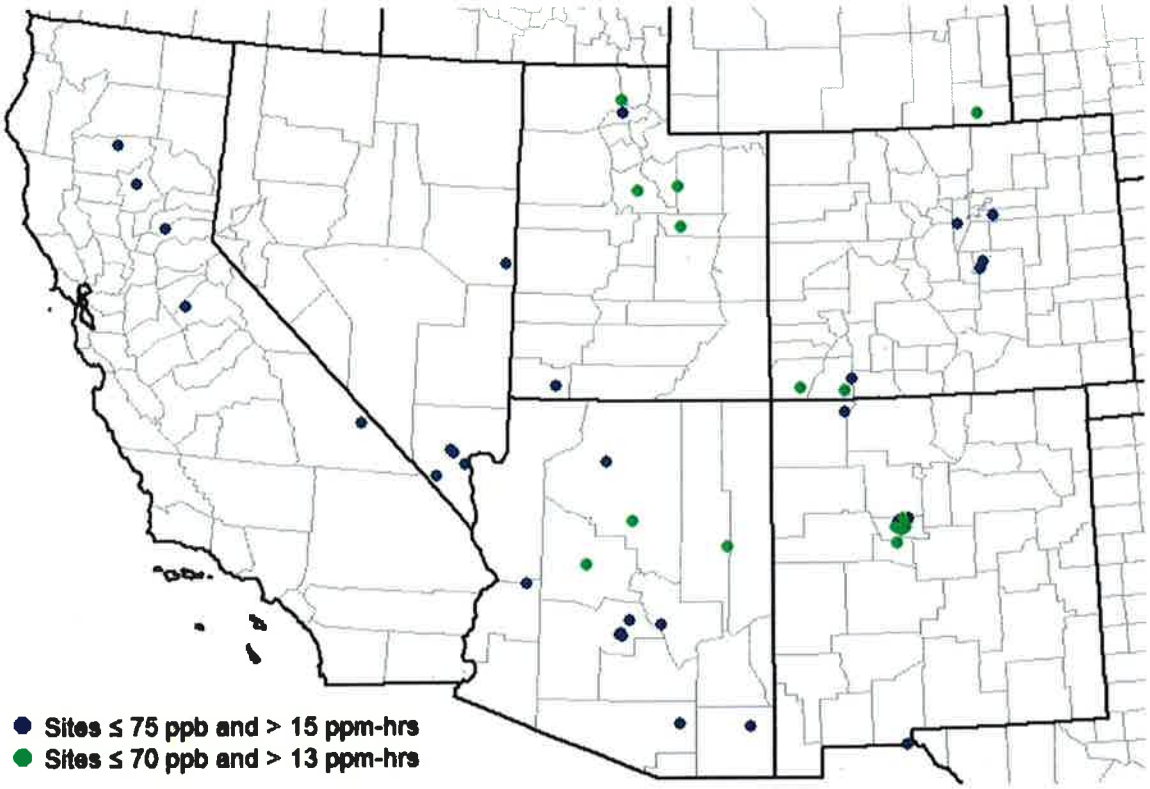

Figure 3b. Map of sites with 4th max values less than or equal to 75 ppb and W126 values greater than 15 ppm-hrs, and sites with 4th max values less than or equal to 70 ppb and W126 values greater than 13 ppm-hrs, enlarged for emphasis on the Southwestern U.S. region.

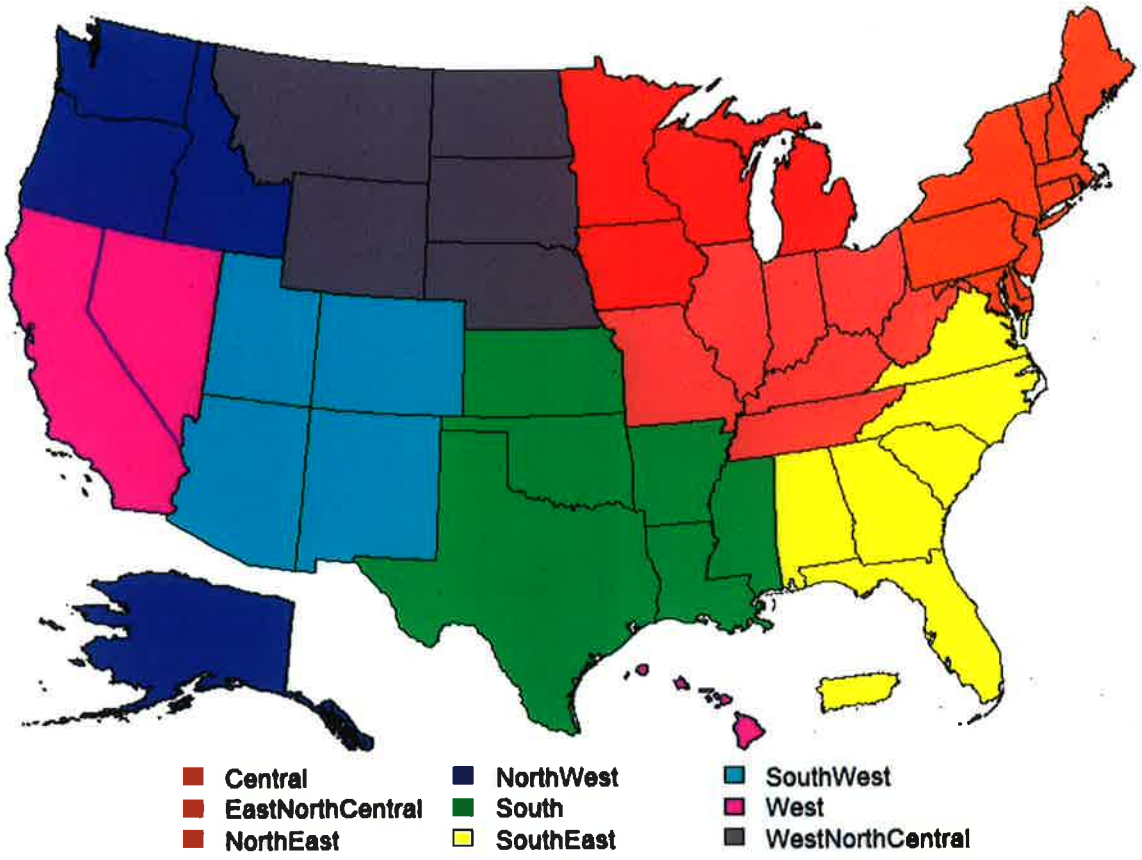

Figure 4. Map of the nine NOAA climate regions

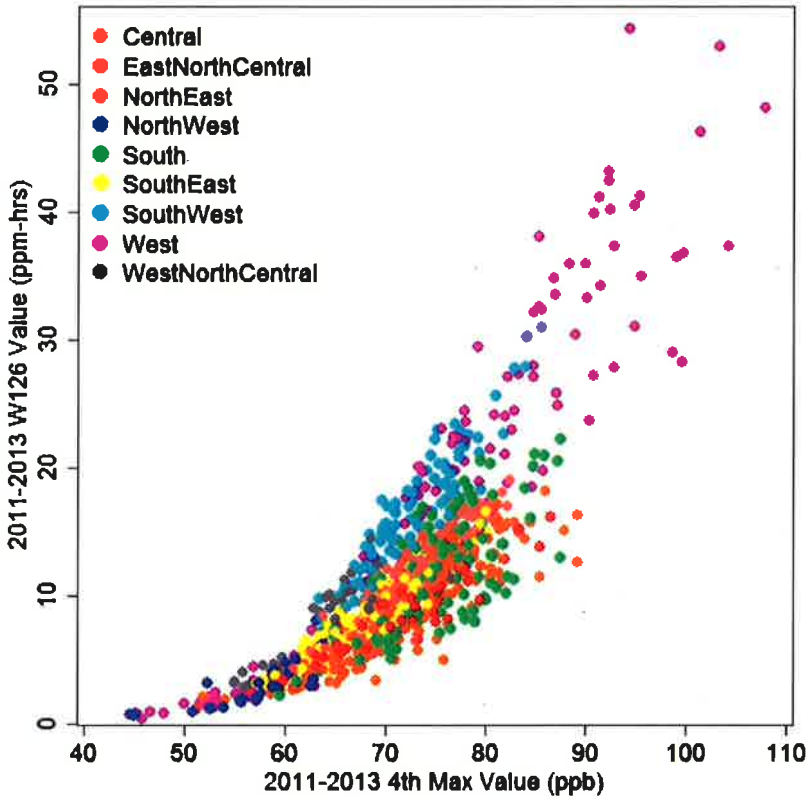

Figure 5a. Scatter plot comparing the 4th max (x-axis) and W126 (y-axis) values based on 2011-2013 data

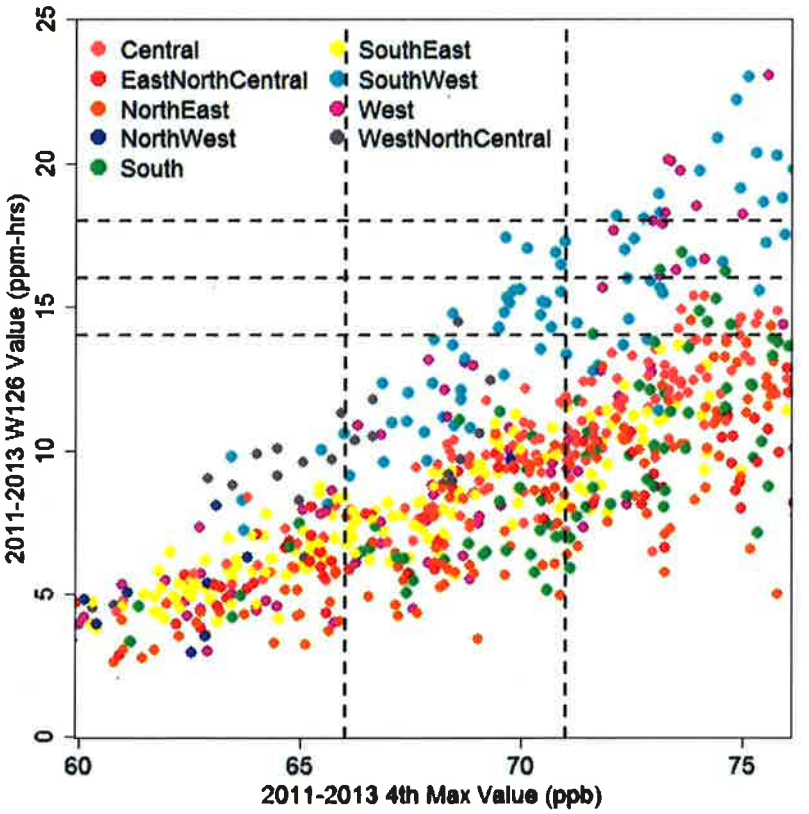

Figure 5b. Scatter plot comparing the 4th max (x-axis) and W126 (y-axis) values based on 2011-2013 data, enlarged to emphasize points within the range of 4th max and W126 levels of interest. Dotted lines mark cutoffs for meeting 4th max levels of 65 and 70 ppb, and meeting W126 levels of 13, 15, and 17 ppm-hrs.

Air Quality Trends

The second portion of the analysis focuses on trends in the 4th max and W126 values from 2001-2003 to 2011-2013. Figure 6 shows the trend in the 4th max values, and Figure 7 shows the trend in the W126 values based on the 729 sites which collected sufficient data to calculate valid 4th max and W126 values for all eleven 3-year periods. In general, the trends in both the 4th max and W126 values were decreasing. The amount of variability in the 4th max and W126 values also tended to decrease over time (i.e., the 90th percentile values decreased more quickly than the 10th percentile values), especially for the W126 values.

Next, Figure 8 compares sites based on their 4th max values relative to 70 ppb, and their W126 values relative to 13 ppm-hrs. This combination of levels was chosen because it has the highest potential within the levels of greatest interest (e.g., 65 to 70 ppb, 13 to 17 ppm-hrs) for sites with 4th max values less than or equal to the 4th max level to also have W126 values greater than the W126 level. Figure 8 uses four panels to group these trends: the top left panel shows the trend in the number of sites with 4th max values less than or equal to 70 ppb and W126 values greater than 13 ppm-hrs; the top right panel shows the trend in the number of sites with 4th max values greater than 70 ppb and W126 values greater than 13 ppm-hrs; the bottom left panel shows the trend in the number of sites with 4th max values less than or equal to 70 ppb and W126 values less than or equal to 13 ppm-hrs; and the bottom right panel shows the trend in the number of sites with 4th max values greater than 70 ppb and W126 values less than or equal to 13 ppm-hrs. The bars in each panel are colored to show the number of sites located within each NOAA climate region for each 3-year period.

Figure 8 shows that fewer than 20 sites would have 4th max values less than or equal to 70 ppb and W126 values greater than 13 ppm-hrs in any 3-year period, and that these sites are predominately located in the Southwest region. The number of sites with 4th max values less than or equal to 70 ppb and W126 values less than or equal to 13 ppm-hrs has increased over time, while the number of sites with 4th max values greater than 70 ppb and W126 values greater than 13 ppm-hrs has decreased by a similar amount. The number of sites with 4th max values greater than 70 ppb and W126 values less than or equal to 13 ppm-hrs has remained relatively constant over the past decade.

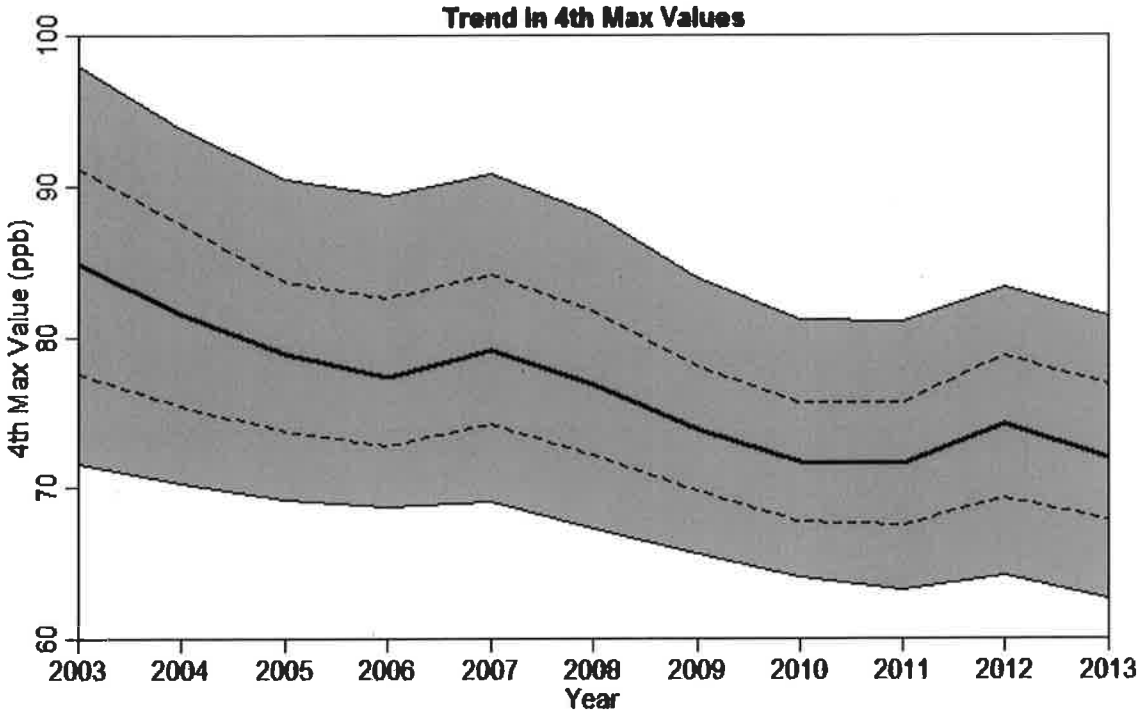

Figure 6. Trend in 4th max values, 2001-2003 to 2011-2013. The bold center lines show median values, the dotted lines show 25th and 75th percentile values, and the outer lines containing the shaded area show 10th and 90th percentile values.

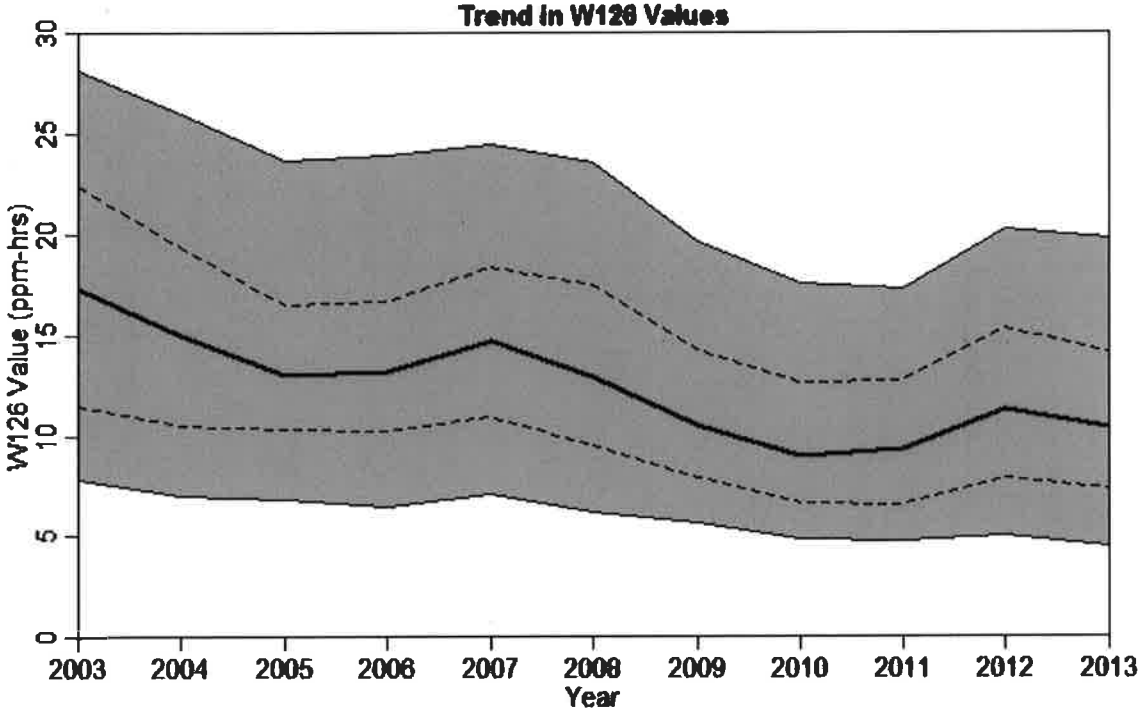

Figure 7. Trend in W126 values, 2001-2003 to 2011-2013. The bold center lines show median values, the dotted lines show 25th and 75th percentile values, and the outer lines containing the shaded area show 10th and 90th percentile values.

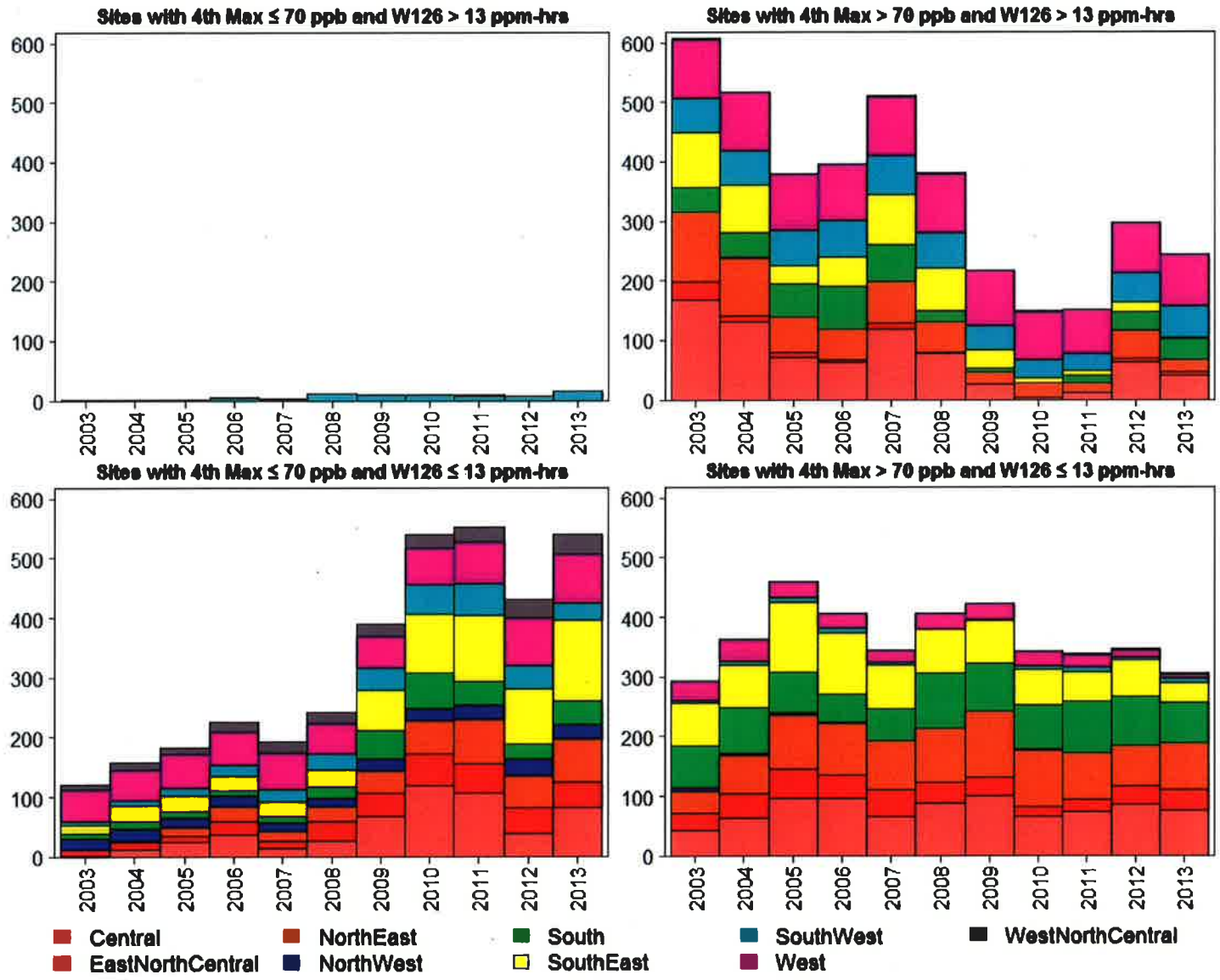

Figure 8. Trends in the number of sites with 4th max values less than or equal to 70 ppb and W126 values greater than 13 ppm-hrs (top left panel); the number of sites with 4th max values greater than 70 ppb and W126 values greater than 13 ppm-hrs (top right panel); the number of sites with 4th max values less than or equal to 70 ppb and W126 values less than or equal to 13 ppm-hrs (bottom left panel); and the number of sites with 4th max values greater than 70 ppb and W126 values less than or equal to 13 ppm-hrs (bottom right panel). Bars are colored to show the number of sites located within each NOAA climate region for the 3-year period ending with the year shown on the x-axis.

Relative Changes in 4th Max and W126 Values

The final portion of the analysis compared the respective 4th max and W126 values from 2001-2003 to those from 2011-2013 for the 777 sites with valid 4th max and W126 values in both periods. Figure 9 shows a map of the changes in the 4th max values, while Figure 10 shows a map of the changes in the W126 values. Most sites in the Eastern U.S. and California saw large, widespread decreases in both 4th max and W126 values over the past decade as a result of regional and national NOx control programs, such as the NOx SIP Call and Federal mobile source emissions standards. In the inter-mountain West, where NOx control programs have been more localized, the decreases observed in the 4th max and W126 values were typically much smaller in magnitude, and a few sites even showed increases.

Figure 11 shows a scatter plot comparing the changes in 4th max (x-axis, ppb) and W126 (y-axis, ppm-hrs) values from 2001-2003 to 2011-2013. The relationship between the changes in the 4th max and W126 metrics was fairly linear and positive (Pearson correlation coefficient R = 0.80). The regression line shown in Figure 11 indicates that, on average, there was a change of approximately 0.7 ppm-hr in the W126 values per unit ppb change in the 4th max values. Similar to the direct comparison between the 4th max and W126 metrics based on 2011-2013 data, the amount of variability in the relative changes between these two metrics generally increased with the magnitude of the changes, and regional differences were apparent.

Figure 12 shows scatter plots of the changes in 4th max (x-axis) and W126 (y-axis) values from 2001-2003 to 2011-2013 in each NOAA climate region and the associated regression lines fit using the sites within each region. Table 6 provides some summary statistics based on the regional analyses. Figure 12 and Table 6 show that the positive, linear relationship between the changes in the 4th max and W126 values persists within each region, with Pearson correlation coefficients ranging from 0.57 to 0.92. The regression lines shown in Figure 12 with slopes listed in Table 6 indicate that the Southwest and West regions, which had the greatest potential for sites having 4th max values less than or equal to the various 4th max levels of interest and W126 values greater than the various W126 levels of interest, also exhibited the greatest response in W126 values per unit change in 4th max values.

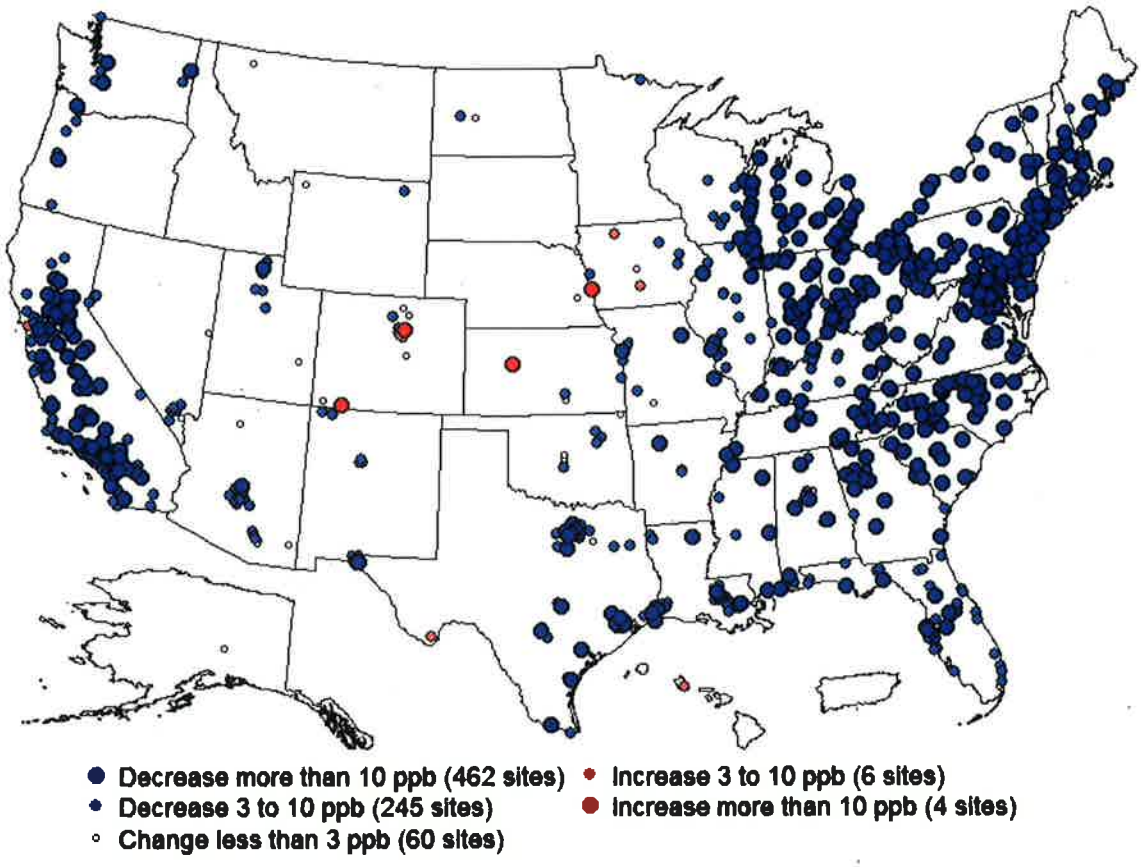

Figure 9. Map of changes in 4th max values from 2001-2003 to 2011-2013

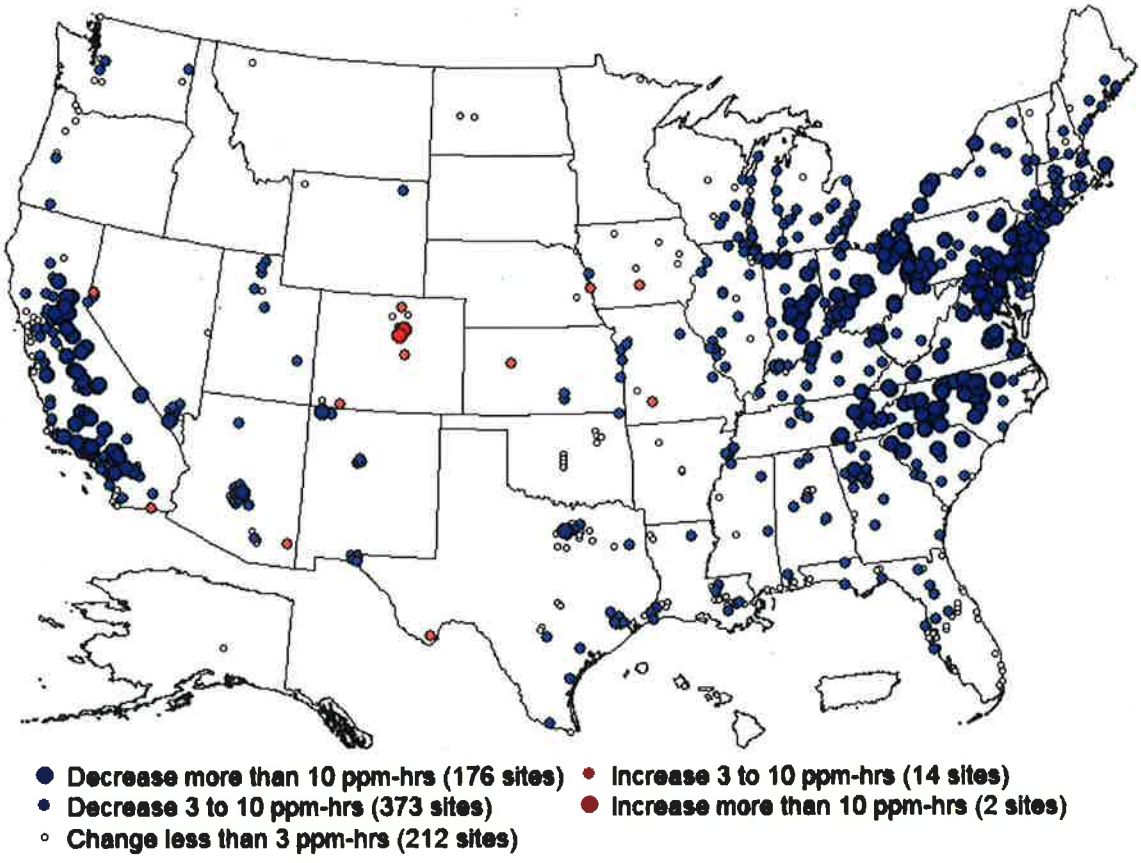

Figure 10. Map of changes in W126 values from 2001-2003 to 2011-2013

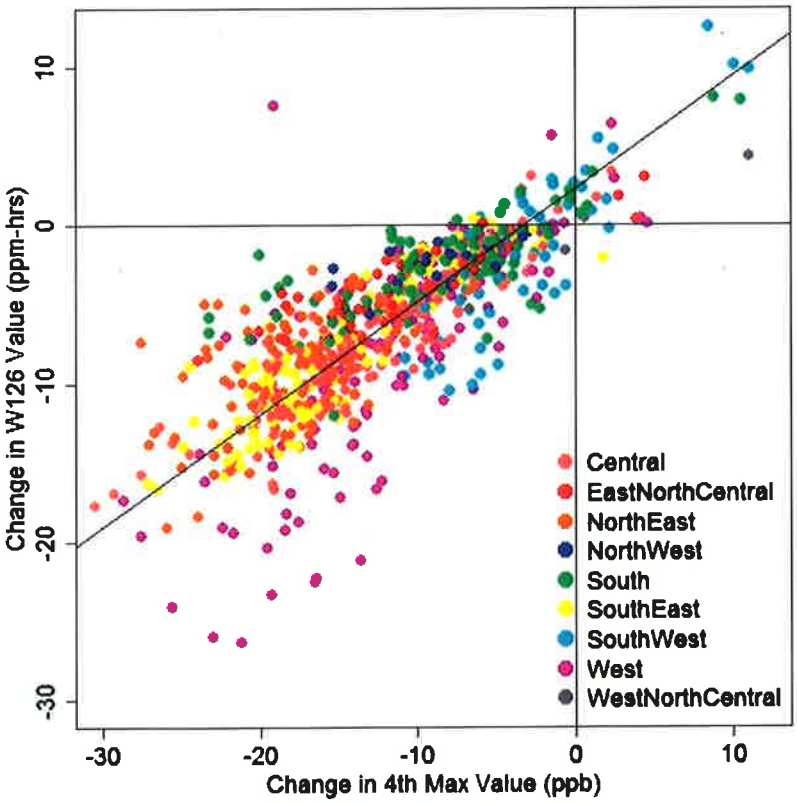

Figure 11. Scatter plot comparing the changes in 4th max (x-axis) and W126 (y-axis) values from 2001-2003 to 2011-2013.

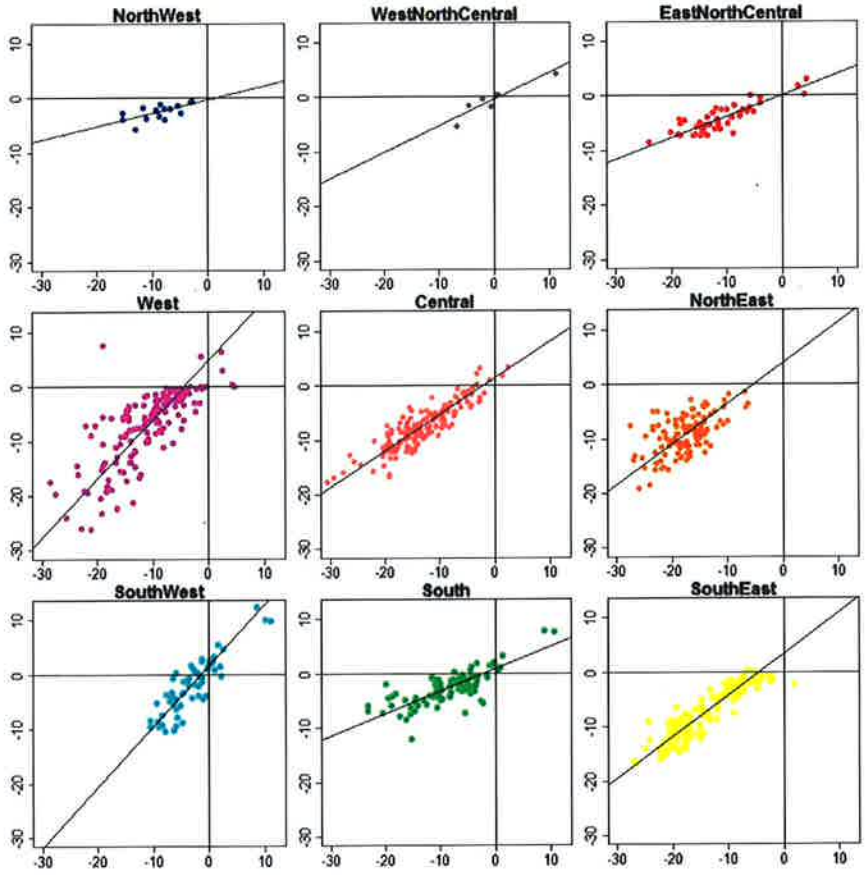

Figure 12. Scatter plots showing the changes in 4th max (x-axis, ppb) and W126 (y-axis, ppm-hrs) values for sites within each of the nine NOAA climate regions.

Table 6. Summary statistics based on regional analysis of changes in 4th max and W126 values from 2001-2003 to 2011-2013

NOAA Climate Region	Number of O_3 Sites	Mean Change in 4th Max Value (ppb)	Mean Change in W126 Value (ppm-hrs)	Regression Slope	Pearson Correlation Coefficient
Central	158	-13.0	-7.4	0.67	0.89
East North Central	49	-11.4	-4.3	0.39	0.85
Northeast	120	-17.6	-9.1	0.75	0.57
Northwest	16	-8.9	-2.5	0.24	0.63
South	94	-8.5	-2.6	0.41	0.75
Southeast	134	-13.7	-7.0	0.76	0.91
Southwest	57	-3.3	-1.9	1.12	0.87
West	142	-11.3	-7.4	1.09	0.75
West North Central	7	-0.3	-0.5	0.49	0.92
National	777	-12.0	-6.3	0.71	0.80

Summary

The analysis based on 2011-2013 data showed that nearly one quarter of U.S. O_3 sites had 4th max values greater than 75 ppb, nearly half of U.S. O_3 sites had 4th max values greater than 70 ppb, and roughly three quarters of U.S. O_3 sites had 4th max values greater than 65 ppb. In contrast, less than 10 percent of U.S. O_3 sites had W126 values greater than 17 ppm-hrs, and less than one quarter of U.S. O_3 sites had W126 values greater than 13 ppm-hrs.

When examining both metrics in combination, the 2011-2013 data showed that there were 35 sites with 4th max values less than or equal to 75 ppb and W126 values greater than 15 ppm-hrs, and 15 of these sites also had W126 values greater than 17 ppm-hrs. These sites were located exclusively in the Southwestern U.S (i.e., the West and Southwest climate regions). There were no sites with 4th max values less than or equal to 70 ppb and W126 values greater than 17 ppm-hrs. There were 16 sites with 4th max values less than or equal to 70 ppb and W126 values greater than 13 ppm-hrs, and 4 of these sites also had W126 values greater than 15 ppm-hrs. These sites were also located exclusively in the Southwestern U.S. There were no sites with 4th max values less than or equal to 65 ppb and W126 values greater than 11 ppm-hrs.

The trends analysis showed that 4th max and W126 values have generally decreased over the past decade. The number of sites with 4th max values less than or equal to 70 ppb and W126 values less than or equal to 13 ppm-hrs has increased substantially, while the number of sites with 4th max values greater than 70 ppb and W126 values greater than 13 ppm-hrs has decreased by a similar amount. The number of sites with 4th max values greater than 70 ppb and W126 values less than or equal to 13 ppm-hrs has remained relatively constant over the past decade, while sites with 4th max values less than or equal to 70 ppb and W126 values greater than 13 ppm-hrs have consistently been limited to a few locations in the Southwestern U.S.

Finally, the analysis of the relative changes in the 4th max and W126 values from 2001-2003 to 2011-2013 showed that there was a positive, linear relationship between the changes in the 4th max and W126 metrics. Nationally, the W126 values decreased by approximately 0.7 ppm-hr per

unit ppb decrease in the 4th max values over this period. This relationship varied across the NOAA climate regions, and the Southwest and West regions which showed the greatest potential for exceeding only the W126 levels of interest also showed the greatest improvement in the W126 values per unit decrease in 4th max values.

In conclusion, the ambient data analyses showed that the 4th max and W126 metrics were highly correlated, and so were the relative changes in these two metrics over the past decade. Thus, it is expected that future control programs designed to help meet a primary O_3 standard based on the 3-year average of the 4th highest daily maximum 8-hour concentration would provide similar improvements in terms of the 3-year average of the annual W126 metric.

References

Karl, T. R.; Koss, W. J. (1984). "Regional and National Monthly, Seasonal, and Annual Temperature Weighted by Area, 1895-1983." *Historical Climatology Series*, 4-3, National Climatic Data Center, Asheville, NC, 38 pp.

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