## Technical Basis for the EPA's Development of the Significant Impact Thresholds for PM2.5 and Ozone

Technical Basis for the EPA's Development of the Significant Impact Thresholds for PM2.5 and Ozone
U.S. Environmental Protection Agency Office of Air Quality Planning and Standards

Air Quality Assessment Division
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## 1 Bootstrap examples

Bootstrap examples from selects $\mathrm{PM}_{2.5}$ sites for the $2008-2010$ DV period. Top left, top right, and middle left plots show the distribution of daily PM concentrations for 2008, 2009, and 2010, respectively. The vertical red line shows the annual mean and the vertical blue line shows the annual 98 th percentile. Middle left plots show sample distributions of resampled data from 2008 , along with the annual mean and the 98th percentile from each resample. The bottom left plots show the distribution of the annual DVs from the 20,000 resampled DV periods (2008-2010). The bottom right plots show the distribution of the $24-\mathrm{hr}$ DVs from the 20,000 resampled DV periods (2008-2010)


Figure 1: Example from site 10732003.


Figure 2: Example from site 21700008.


Figure 3: Example from site 60195001.


Figure 4: Example from site 481410053.


Figure 5: Example from site 560210001.

## 2 Ozone results

Bootstrap results for ozone data from the years 2000-2013. Each section containts a single DV period,e.g., the results for 2015 include data from 2013-2015.

### 2.1 2013-2015 ozone bootstrap results



Figure 6: Bootstrap results for the ozone 2015 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.


Figure 7: Bootstrap results from the $50 \%$ CIs for the 2015 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2015 ozone DV at each site.
$2.2 \quad 2012-2014$ ozone bootstrap results


Figure 8: Bootstrap results for the ozone 2014 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

## 2014 bootstrap 50th percentile uncert



2014 bootstrap 50th percentile uncert



Figure 9: Bootstrap results from the $50 \%$ CIs for the 2014 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2014 ozone DV at each site.
$2.3 \quad$ 2011-2013 ozone bootstrap results


Figure 10: Bootstrap results for the ozone 2013 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

## 2013 bootstrap 50th percentile uncert



Figure 11: Bootstrap results from the $50 \%$ CIs for the 2013 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2013 ozone DV at each site.
$2.4 \quad 2010-2012$ ozone bootstrap results


Figure 12: Bootstrap results for the ozone 2012 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

## 2012 bootstrap 50th percentile uncert



Figure 13: Bootstrap results from the $50 \%$ CIs for the 2012 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2012 ozone DV at each site.
$2.5 \quad 2009-2011$ ozone bootstrap results


Figure 14: Bootstrap results for the ozone 2011 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

2011 bootstrap 50th percentile uncert


2011 bootstrap 50th percentile uncert



Figure 15: Bootstrap results from the $50 \%$ CIs for the 2011 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2011 ozone DV at each site.
$2.6 \quad 2008-2010$ ozone bootstrap results




- $68 \% \mathrm{Cl}$

- $95 \% \mathrm{Cl}$
- max/min
- median

Cl limits
- $50 \% \mathrm{Cl}$
- $68 \% \mathrm{Cl}$
- $75 \% \mathrm{Cl}$
- $95 \% \mathrm{Cl}$
- max/min
- median


Figure 16: Bootstrap results for the ozone 2010 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

2010 bootstrap 50th percentile uncert


Figure 17: Bootstrap results from the $50 \%$ CIs for the 2010 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2010 ozone DV at each site.
2.7 2007-2009 ozone bootstrap results


Figure 18: Bootstrap results for the ozone 2009 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

## 2009 bootstrap 50th percentile uncert



Figure 19: Bootstrap results from the $50 \%$ CIs for the 2009 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2009 ozone DV at each site.
$2.8 \quad 2006-2008$ ozone bootstrap results


Figure 20: Bootstrap results for the ozone 2008 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

## 2008 bootstrap 50th percentile uncert



Figure 21: Bootstrap results from the $50 \%$ CIs for the 2008 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2008 ozone DV at each site.
$2.9 \quad 2005-2007$ ozone bootstrap results


Figure 22: Bootstrap results for the ozone 2007 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

## 2007 bootstrap 50th percentile uncert



Figure 23: Bootstrap results from the $50 \%$ CIs for the 2007 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2007 ozone DV at each site.
$2.10 \quad 2004-2006$ ozone bootstrap results


Figure 24: Bootstrap results for the ozone 2006 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

2006 bootstrap 50th percentile uncert


Figure 25: Bootstrap results from the $50 \%$ CIs for the 2006 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2006 ozone DV at each site.
2.11 2003-2005 ozone bootstrap results


Figure 26: Bootstrap results for the ozone 2005 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

2005 bootstrap 50th percentile uncert


2005 bootstrap 50th percentile uncert


Figure 27: Bootstrap results from the $50 \%$ CIs for the 2005 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2005 ozone DV at each site.
$2.12 \quad$ 2002-2004 ozone bootstrap results


Figure 28: Bootstrap results for the ozone 2004 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

2004 bootstrap 50th percentile uncert


2004 bootstrap 50th percentile uncert


Figure 29: Bootstrap results from the $50 \%$ CIs for the 2004 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2004 ozone DV at each site.
2.13 2001-2003 ozone bootstrap results


Figure 30: Bootstrap results for the ozone 2003 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

2003 bootstrap 50th percentile uncert


2003 bootstrap 50th percentile uncert


Figure 31: Bootstrap results from the $50 \%$ CIs for the 2003 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2003 ozone DV at each site.
$2.14 \quad 2000-2002$ ozone bootstrap results


Figure 32: Bootstrap results for the ozone 2002 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

2002 bootstrap 50th percentile uncert


2002 bootstrap 50th percentile uncert


Figure 33: Bootstrap results from the $50 \%$ CIs for the 2002 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2002 ozone DV at each site.

## 3 Air quality variability results for years 2002-2013 for $\mathrm{PM}_{2.5}$

Bootstrap results for $\mathrm{PM}_{2.5}$ data from the years 2000-2015. Each section containts a single DV period,e.g., the results for 2015 include data from 2013-2015.

### 3.1 2013-2015 $\mathrm{PM}_{2.5}$ bootstrap results



Figure 34: Bootstrap results for the $2015 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 35: Bootstrap results for the $2015 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 36: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 37: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2015 \mathrm{PM}_{2.5}$ DVs.

## $3.2 \quad$ 2012-2014 $\mathrm{PM}_{2.5}$ bootstrap results



Figure 38: Bootstrap results for the $2014 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 39: Bootstrap results for the $2014 \mathrm{PM}_{2.5}$ DVs, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 40: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 41: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2014 \mathrm{PM}_{2.5}$ DVs.

### 3.3 2011-2013 $\mathrm{PM}_{2.5}$ bootstrap results



Figure 42: Bootstrap results for the $2013 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 43: Bootstrap results for the $2013 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 44: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 45: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2013 \mathrm{PM}_{2.5}$ DVs.

## $3.4 \quad 2010-2012 \mathrm{PM}_{2.5}$ bootstrap results



Figure 46: Bootstrap results for the $2012 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 47: Bootstrap results for the $2012 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 48: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 49: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2012 \mathrm{PM}_{2.5}$ DVs.

## $3.5 \quad$ 2009-2011 $\mathrm{PM}_{2.5}$ bootstrap results



Figure 50: Bootstrap results for the $2011 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 51: Bootstrap results for the $2011 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 52: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 53: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2011 \mathrm{PM}_{2.5}$ DVs.

## $3.6 \quad 2008-2010 \mathrm{PM}_{2.5}$ bootstrap results



Figure 54: Bootstrap results for the $2010 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


24-hr NAAQS bootstrap summary


Figure 55: Bootstrap results for the $2010 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.


Figure 56: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 57: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2010 \mathrm{PM}_{2.5}$ DVs.

### 3.7 2007-2009 $\mathrm{PM}_{2.5}$ bootstrap results



Figure 58: Bootstrap results for the $2009 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 59: Bootstrap results for the $2009 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 60: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 61: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2009 \mathrm{PM}_{2.5}$ DVs.

## $3.8 \quad 2006-2008 \mathrm{PM}_{2.5}$ bootstrap results



Figure 62: Bootstrap results for the $2008 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 63: Bootstrap results for the $2008 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 64: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 65: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2008 \mathrm{PM}_{2.5}$ DVs.
$3.9 \quad 2005-2007 \mathrm{PM}_{2.5}$ bootstrap results


Figure 66: Bootstrap results for the $2007 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 67: Bootstrap results for the $2007 \mathrm{PM}_{2.5}$ DVs, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 68: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 69: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2007 \mathrm{PM}_{2.5}$ DVs.
$3.10 \quad$ 2004-2006 $\mathrm{PM}_{2.5}$ bootstrap results


Figure 70: Bootstrap results for the $2006 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 71: Bootstrap results for the $2006 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 72: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 73: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2006 \mathrm{PM}_{2.5}$ DVs.
3.11 2003-2005 $\mathrm{PM}_{2.5}$ bootstrap results


Figure 74: Bootstrap results for the $2005 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 75: Bootstrap results for the $2005 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 76: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 77: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2005 \mathrm{PM}_{2.5}$ DVs.

## $3.12 \quad$ 2002-2004 $\mathrm{PM}_{2.5}$ bootstrap results



Figure 78: Bootstrap results for the $2004 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 79: Bootstrap results for the $2004 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 80: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 81: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2004 \mathrm{PM}_{2.5}$ DVs.

### 3.13 2001-2003 $\mathrm{PM}_{2.5}$ bootstrap results



Figure 82: Bootstrap results for the $2003 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 83: Bootstrap results for the $2003 \mathrm{PM}_{2.5} \mathrm{DVs}$, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.
boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites

boot 50th percentile uncert, all sites


Figure 84: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 85: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2003 \mathrm{PM}_{2.5}$ DVs.

## $3.14 \quad 2000-2002 \mathrm{PM}_{2.5}$ bootstrap results



Figure 86: Bootstrap results for the $2002 \mathrm{PM}_{2.5}$ DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top two panels show the values for the DVs at the various CIs, while the bottom two panels show the relative difference between the CI and the actual DV.

Annual NAAQS bootstrap summary


## 24-hr NAAQS bootstrap summary



Figure 87: Bootstrap results for the $2002 \mathrm{PM}_{2.5}$ DVs, showing distribution of the relative differences between the bootstrap DVs and the actual DV at the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean, median, maximum, minimum, standard deviations of the relative differences.


Figure 88: Bootstrap results from the $50 \%$ CIs for $\mathrm{PM}_{2.5}$ DVs. The top two panels show the relative difference between the CI and the actual DV and the bottom two panels show the absolute difference between the values for the DVs at each site and the CI.

Annual NAAQS, rel uncert (\%), all sites


24-hr NAAQS, rel uncert (\%), all sites


Figure 89: Spatial distribution of the relative difference between the CI and the actual DV from the $50 \%$ CIs for the $2002 \mathrm{PM}_{2.5}$ DVs.

## 4 Comparison plots of nearby sites

Comparison of $\mathrm{PM}_{2.5}$ data for paired, nearby sites for the spatial analysis conducted in Section 3.1.2.

County 1: Honolulu State 1: Hawaii
Sites: 150031001 \& 150031004


## Site_ID

- 150031001
- 150031004


Figure 90: Comparison of $\mathrm{PM}_{2.5}$ data for sites 150031001 and 150031001 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with2あata points are colored by month.

County 1: Clark State 1: Indiana Sites: 180190006 \& 211110067

delta 9.256 km


Figure 91: Comparison of $\mathrm{PM}_{2.5}$ data for sites 180190006 and 180190006. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll2あata points are colored by month.

County 1: Marion State 1: Indiana Sites: 180970078 \& 180970081

delta 8.915 km


Figure 92: Comparison of $\mathrm{PM}_{2.5}$ data for sites 180970078 and 180970078. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll2tata points are colored by month.

County 1: Clinton State 1: Iowa Sites: 190450019 \& 190450021



Figure 93: Comparison of $\mathrm{PM}_{2.5}$ data for sites 190450019 and 190450019. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with2\$ata points are colored by month.


Figure 94: Comparison of $\mathrm{PM}_{2.5}$ data for sites 220330009 and 220330009. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with $2 \Phi$ ata points are colored by month.

## County 1: Washington State 1: Minnesota

 Sites: 271630447 \& 271630448


Figure 95: Comparison of $\mathrm{PM}_{2.5}$ data for sites 271630447 and 271630447. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with3data points are colored by month.


Figure 96: Comparison of $\mathrm{PM}_{2.5}$ data for sites 320310016 and 320310016. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll3data points are colored by month.

## County 1: Bernalillo State 1: New Mexico

## Sites: 350010023 \& 350010024




Figure 97: Comparison of $\mathrm{PM}_{2.5}$ data for sites 350010023 and 350010023 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with3łata points are colored by month.

## County 1: Northampton State 1: Pennsylvania Sites: 420950025 \& 420950027


delta 5.702 km


Figure 98: Comparison of $\mathrm{PM}_{2.5}$ data for sites 420950025 and 420950025 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll33ata points are colored by month.

## County 1: Philadelphia State 1: Pennsylvania

 Sites: 421010047 \& 421010057


Figure 99: Comparison of $\mathrm{PM}_{2.5}$ data for sites 421010047 and 421010047 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with3dlata points are colored by month.

## County 1: Philadelphia State 1: Pennsylvania

 Sites: 421010055 \& 421010047
delta 3.052 km


Figure 100: Comparison of $\mathrm{PM}_{2.5}$ data for sites 421010055 and 421010055 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witlledata points are colored by month.

## County 1: Providence State 1: Rhode Island

 Sites: 440070022 \& 440071010
delta 5.871 km


Figure 101: Comparison of $\mathrm{PM}_{2.5}$ data for sites 440070022 and 440070022 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with36ata points are colored by month.

## County 1: Salt Lake State 1: Utah

Sites: 490353006 \& 490353010

delta 7.274 km


Figure 102: Comparison of $\mathrm{PM}_{2.5}$ data for sites 490353006 and 490353006. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witllyむata points are colored by month.

## County 1: New Castle State 1: Delaware

 Sites: 100032004 \& 420450002
delta 19.141 km


Figure 103: Comparison of $\mathrm{PM}_{2.5}$ data for sites 100032004 and 100032004. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with3\$ata points are colored by month.


Figure 104: Comparison of $\mathrm{PM}_{2.5}$ data for sites 110010043 and 110010043. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll $3 \$$ ata points are colored by month.


Figure 105: Comparison of $\mathrm{PM}_{2.5}$ data for sites 130670003 and 130670003. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll4(1)ata points are colored by month.

County 1: Hawaii State 1: Hawaii
Sites: 150011006 \& 150012023



Figure 106: Comparison of $\mathrm{PM}_{2.5}$ data for sites 150011006 and 150011006. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witllhdata points are colored by month.

County 1: Hawaii State 1: Hawaii Sites: 150011012 \& 150012020


## Site_ID

- 150011012
- 150012020


Figure 107: Comparison of $\mathrm{PM}_{2.5}$ data for sites 150011012 and 150011012. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll\$ata points are colored by month.


Figure 108: Comparison of $\mathrm{PM}_{2.5}$ data for sites 150012016 and 150012014. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll 4 $\mathrm{B}_{\text {ata }}$ points are colored by month.

County 1: Honolulu State 1: Hawaii
Sites: 150031001 \& 150031004


## Site_ID

- 150031001
- 150031004


Figure 109: Comparison of $\mathrm{PM}_{2.5}$ data for sites 150031001 and 150031001. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witllddlata points are colored by month.


Figure 110: Comparison of $\mathrm{PM}_{2.5}$ data for sites 150032004 and 150032004. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witllあぁata points are colored by month.

County 1: Clark State 1: Indiana Sites: 180190006 \& 211110067

delta 9.256 km


Figure 111: Comparison of $\mathrm{PM}_{2.5}$ data for sites 180190006 and 180190006. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll $4 \$$ ata points are colored by month.

County 1: Marion State 1: Indiana Sites: 180970078 \& 180970081

delta 8.915 km


Figure 112: Comparison of $\mathrm{PM}_{2.5}$ data for sites 180970078 and 180970078. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll4むata points are colored by month.

County 1: Clinton State 1: Iowa Sites: 190450019 \& 190450021



Figure 113: Comparison of $\mathrm{PM}_{2.5}$ data for sites 190450019 and 190450019. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll $4 \$ a t a$ points are colored by month.


Figure 114: Comparison of $\mathrm{PM}_{2.5}$ data for sites 191032001 and 191032001. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witlh4ata points are colored by month.


Figure 115: Comparison of $\mathrm{PM}_{2.5}$ data for sites 191390015 and 191390015. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with5(llata points are colored by month.

## County 1: Jefferson State 1: Kentucky

Sites: 211110051 \& 180190006



Figure 116: Comparison of $\mathrm{PM}_{2.5}$ data for sites 211110051 and 211110051. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll 5data points are colored by month.


Figure 117: Comparison of $\mathrm{PM}_{2.5}$ data for sites 220330009 and 220330009. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll $5 \$$ ata points are colored by month.


Figure 118: Comparison of $\mathrm{PM}_{2.5}$ data for sites 240150003 and 240150003. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll\$\$ata points are colored by month.


Figure 119: Comparison of $\mathrm{PM}_{2.5}$ data for sites 240251001 and 240251001. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll5data points are colored by month.

County 1: Kent State 1: Maryland Sites: 240290002 \& 240150003

delta 44.457 km


Figure 120: Comparison of $\mathrm{PM}_{2.5}$ data for sites 240290002 and 240290002. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll 5 ( $\ddagger$ ata points are colored by month.

## County 1: Montgomery State 1: Maryland

 Sites: 240313001 \& 240330030


Figure 121: Comparison of $\mathrm{PM}_{2.5}$ data for sites 240313001 and 240313001 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with5 6 ( 6 ata points are colored by month.

## County 1: Prince George's State 1: Maryland

 Sites: 240330030 \& 110010043
delta 18.887 km


Figure 122: Comparison of $\mathrm{PM}_{2.5}$ data for sites 240330030 and 240330030. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll 5 $\ddagger$ ata points are colored by month.

County 1: Wayne State 1: Michigan
Sites: 261630001 \& 261630039

delta 15.608 km


Figure 123: Comparison of $\mathrm{PM}_{2.5}$ data for sites 261630001 and 261630001. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll 5 \$ata points are colored by month.

County 1: Anoka State 1: Minnesota
Sites: 270031002 \& 270530963



Figure 124: Comparison of $\mathrm{PM}_{2.5}$ data for sites 270031002 and 270031002 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witlh5\$ata points are colored by month.

## County 1: Hennepin State 1: Minnesota

 Sites: 270530963 \& 271230871
delta 17.526 km


Figure 125: Comparison of $\mathrm{PM}_{2.5}$ data for sites 270530963 and 270530963. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with601ata points are colored by month.

## County 1: Washington State 1: Minnesota

 Sites: 271630447 \& 271630448


Figure 126: Comparison of $\mathrm{PM}_{2.5}$ data for sites 271630447 and 271630447. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with6data points are colored by month.


Figure 127: Comparison of $\mathrm{PM}_{2.5}$ data for sites 290370003 and 290370003. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witlh6\$ata points are colored by month.

## County 1: Clay State 1: Missouri

 Sites: 290470005 \& 290950034
delta 27.712 km


Figure 128: Comparison of $\mathrm{PM}_{2.5}$ data for sites 290470005 and 290470005. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll66ata points are colored by month.

County 1: Jefferson State 1: Missouri
Sites: 290990019 \& 295100007

delta 15.725 km


Figure 129: Comparison of $\mathrm{PM}_{2.5}$ data for sites 290990019 and 290990019. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witlh6dlata points are colored by month.

## County 1: Saint Louis State 1: Missouri

Sites: 291893001 \& 295100085



Figure 130: Comparison of $\mathrm{PM}_{2.5}$ data for sites 291893001 and 291893001. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witlh6あata points are colored by month.

## County 1: St. Louis City State 1: Missouri

 Sites: 295100007 \& 295100085


Figure 131: Comparison of $\mathrm{PM}_{2.5}$ data for sites 295100007 and 295100007. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with66ata points are colored by month.

## County 1: Lewis and Clark State 1: Montana Sites: 300490004 \& 300490026


delta 21.435 km


Figure 132: Comparison of $\mathrm{PM}_{2.5}$ data for sites 300490004 and 300490004 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with6\#ata points are colored by month.

County 1: Missoula State 1: Montana
Sites: 300630024 \& 300630037



Figure 133: Comparison of $\mathrm{PM}_{2.5}$ data for sites 300630024 and 300630024 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witlh6\$ata points are colored by month.

County 1: Douglas State 1: Nebraska Sites: 310550019 \& 311530007


## Site_ID

- 310550019
- 311530007
delta 12.791 km


Figure 134: Comparison of $\mathrm{PM}_{2.5}$ data for sites 310550019 and 310550019. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witlh6\$ata points are colored by month.


Figure 135: Comparison of $\mathrm{PM}_{2.5}$ data for sites 320310016 and 320310016. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll 7 7 Data points are colored by month.


Figure 136: Comparison of $\mathrm{PM}_{2.5}$ data for sites 330050007 and 330050007 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll 7 data points are colored by month.

County 1: Rockingham State 1: New Hampshire Sites: 330150018 \& 330115001


## Site_ID

- 330115001
- 330150018


Figure 137: Comparison of $\mathrm{PM}_{2.5}$ data for sites 330150018 and 330150018 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll $7 \$$ ata points are colored by month.

## County 1: Hudson State 1: New Jersey

 Sites: 340171003 \& 340390004
delta 16.157 km


Figure 138: Comparison of $\mathrm{PM}_{2.5}$ data for sites 340171003 and 340171003 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll 7 Bata points are colored by month.

## County 1: Mercer State 1: New Jersey

Sites: 340210008 \& 420170012

delta 16.34 km


Figure 139: Comparison of $\mathrm{PM}_{2.5}$ data for sites 340210008 and 340210008 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witllydata points are colored by month.

## County 1: Bernalillo State 1: New Mexico

## Sites: 350010023 \& 350010024




Figure 140: Comparison of $\mathrm{PM}_{2.5}$ data for sites 350010023 and 350010023. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll7 7 7 ata points are colored by month.

County 1: Queens State 1: New York Sites: 360810124 \& 340171003

delta 19.502 km


Figure 141: Comparison of $\mathrm{PM}_{2.5}$ data for sites 360810124 and 360810124 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll 7\$ata points are colored by month.

## County 1: Mercer State 1: North Dakota

 Sites: 380570004 \& 380650002
delta 28.522 km


Figure 142: Comparison of $\mathrm{PM}_{2.5}$ data for sites 380570004 and 380570004 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the


## County 1: Adams State 1: Pennsylvania

 Sites: 420010001 \& 420410101
delta 37.824 km


Figure 143: Comparison of $\mathrm{PM}_{2.5}$ data for sites 420010001 and 420010001 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll $7 \$$ ata points are colored by month.

## County 1: Allegheny State 1: Pennsylvania

 Sites: 420030008 \& 420030064


Figure 144: Comparison of $\mathrm{PM}_{2.5}$ data for sites 420030008 and 420030008 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll $7 \Phi$ ata points are colored by month.

## County 1: Beaver State 1: Pennsylvania

 Sites: 420070014 \& 421255001
delta 34.812 km


Figure 145: Comparison of $\mathrm{PM}_{2.5}$ data for sites 420070014 and 420070014. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll\$8lata points are colored by month.


Figure 146: Comparison of $\mathrm{PM}_{2.5}$ data for sites 420110011 and 420110011. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with\&data points are colored by month.


Figure 147: Comparison of $\mathrm{PM}_{2.5}$ data for sites 420410101 and 420410101 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll$\$ \$$ ata points are colored by month.

## County 1: Delaware State 1: Pennsylvania

 Sites: 420450002 \& 421010055

Site_ID

- 420450002
- 421010055


Figure 148: Comparison of $\mathrm{PM}_{2.5}$ data for sites 420450002 and 420450002 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll\$\&ata points are colored by month.

## County 1: Lancaster State 1: Pennsylvania

 Sites: 420710007 \& 420750100
delta 33.457 km


Figure 149: Comparison of $\mathrm{PM}_{2.5}$ data for sites 420710007 and 420710007. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with8dlata points are colored by month.


Figure 150: Comparison of $\mathrm{PM}_{2.5}$ data for sites 420910013 and 420910013. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll $8 \$$ ata points are colored by month.

## County 1: Northampton State 1: Pennsylvania Sites: 420950025 \& 420950027


delta 5.702 km


Figure 151: Comparison of $\mathrm{PM}_{2.5}$ data for sites 420950025 and 420950025 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll\$8ata points are colored by month.

## County 1: Philadelphia State 1: Pennsylvania

 Sites: 421010047 \& 421010057


Figure 152: Comparison of $\mathrm{PM}_{2.5}$ data for sites 421010047 and 421010047 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with\&tata points are colored by month.

## County 1: Philadelphia State 1: Pennsylvania

 Sites: 421010055 \& 421010047
delta 3.052 km


Figure 153: Comparison of $\mathrm{PM}_{2.5}$ data for sites 421010055 and 421010055 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll $8 \$ a t a$ points are colored by month.

## County 1: Washington State 1: Pennsylvania

 Sites: 421250005 \& 420030064


Figure 154: Comparison of $\mathrm{PM}_{2.5}$ data for sites 421250005 and 421250005 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with8\$ata points are colored by month.


Figure 155: Comparison of $\mathrm{PM}_{2.5}$ data for sites 421250200 and 421250200. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with90ata points are colored by month.


Figure 156: Comparison of $\mathrm{PM}_{2.5}$ data for sites 421255001 and 421255001 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with9data points are colored by month.

## County 1: Westmoreland State 1: Pennsylvania

 Sites: 421290008 \& 420030064


Figure 157: Comparison of $\mathrm{PM}_{2.5}$ data for sites 421290008 and 421290008 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witliq\$ata points are colored by month.

County 1: York State 1: Pennsylvania Sites: 421330008 \& 420430401

delta 33.782 km


Figure 158: Comparison of $\mathrm{PM}_{2.5}$ data for sites 421330008 and 421330008 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with9 Bata points are colored by month.

County 1: Kent State 1: Rhode Island Sites: 440030002 \& 440070022


Site_ID

- 440030002
- 440070022
delta 33.186 km


Figure 159: Comparison of $\mathrm{PM}_{2.5}$ data for sites 440030002 and 440030002 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witlh9data points are colored by month.

## County 1: Providence State 1: Rhode Island

 Sites: 440070022 \& 440071010
delta 5.871 km


Figure 160: Comparison of $\mathrm{PM}_{2.5}$ data for sites 440070022 and 440070022 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll9tata points are colored by month.

## County 1: Charleston State 1: South Carolina Sites: 450190048 \& 450190049


delta 23.295 km


Figure 161: Comparison of $\mathrm{PM}_{2.5}$ data for sites 450190048 and 450190048. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witll96ata points are colored by month.

## County 1: Greenville State 1: South Carolina

 Sites: 450450015 \& 450830011


Figure 162: Comparison of $\mathrm{PM}_{2.5}$ data for sites 450450015 and 450450015 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with 9 \#ata points are colored by month.

## County 1: Lexington State 1: South Carolina

 Sites: 450630008 \& 450790019
delta 13.767 km


Figure 163: Comparison of $\mathrm{PM}_{2.5}$ data for sites 450630008 and 450630008 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with9\$ata points are colored by month.


Figure 164: Comparison of $\mathrm{PM}_{2.5}$ data for sites 482011035 and 482011035 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), with $9 \$$ ata points are colored by month.

## County 1: Salt Lake State 1: Utah

Sites: 490353006 \& 490353010

delta 7.274 km


Figure 165: Comparison of $\mathrm{PM}_{2.5}$ data for sites 490353006 and 490353006. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witn00ata points are colored by month.


Figure 166: Comparison of $\mathrm{PM}_{2.5}$ data for sites 490490002 and 490490002. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witß0data points are colored by month.

County 1: Weber State 1: Utah
Sites: 490570002 \& 490353010

delta 47.136 km


Figure 167: Comparison of $\mathrm{PM}_{2.5}$ data for sites 490570002 and 490570002. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witßo\&ata points are colored by month.

County 1: Pierce State 1: Washington
Sites: 530530029 \& 530332004

delta 27.817 km


Figure 168: Comparison of $\mathrm{PM}_{2.5}$ data for sites 530530029 and 530530029. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witß0Bata points are colored by month.

## County 1: Snohomish State 1: Washington

 Sites: 530610005 \& 530330080


Figure 169: Comparison of $\mathrm{PM}_{2.5}$ data for sites 530610005 and 530610005. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witß0data points are colored by month.

## County 1: Snohomish State 1: Washington

 Sites: 530610020 \& 530611007


Figure 170: Comparison of $\mathrm{PM}_{2.5}$ data for sites 530610020 and 530610020. Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witbotata points are colored by month.

## County 1: Snohomish State 1: Washington

 Sites: 530611007 \& 530610005


Figure 171: Comparison of $\mathrm{PM}_{2.5}$ data for sites 530611007 and 530611007 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witBobata points are colored by month.

## County 1: Brown State 1: Wisconsin

Sites: 550090005 \& 550870009

delta 38.931 km


Figure 172: Comparison of $\mathrm{PM}_{2.5}$ data for sites 550090005 and 550090005 . Top panel shows time series for both sites for years 2012-2014. Bottom panel shows scatter plot of paired data, along with slope for the linear regression and correlation coefficient (r2), witnotata points are colored by month.

## 5 Comparison of air quality variability for ozone sensitivity tests

Results from the ozone sensitivity analysis discussed in Section 2.2.3.
5.1 All available data, no quarterly subsets


Figure 173: Bootstrap results for the ozone 2013 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.
5.2 All available data, with quarterly subsets


Figure 174: Bootstrap results for the ozone 2013 DVs, showing the $50 \%, 65 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

## 6 Analysis of temporal lag on ozone data and results from a blocked bootstrap sensitivity analysis

This section presents results from an analysis to examine the temporal correlation of air quality levels, i.e., the tendency of high concentration days to occur after other days with high concentrations. Such behavior, if present, would be a function of both emission trends (e.g., weekday traffic versus weekend traffic) and meteorology (e.g., high pressure systems often hinder the transport of pollutants and also accompany higher temperatures, which tend to increase the formation of ozone). The primary motivation for this assessment is to determine whether the implementation of a block bootstrap procedure is needed for the bootstrapping analysis described in Section 2.2.3 in order to account for possible temporal correlation, and if so, what is the appropriate block size. If not properly accounted for, correlation can affect the assessment of uncertainty (i.e., the standard errors used to calculate confidence intervals). While in this analysis confidence intervals were constructed using empirical percentiles, it is important to consider whether autocorrelation may be affecting the distributional characteristics of the bootstrapped data. Thus a sensitivity analysis is considered.

A block bootstrap method can be used in the presence of autocorrelation to replicate the correlation structure in the data. Blocks are designed such that the dependence between adjacent or closely spaced measurements is contained within a block, and there is induced independence between measurements in adjacent blocks. Block size selection can be tricky, as the blocks should be large enough to induce independence but small enough to retain important characteristics of the data, including natural variation and overall trends (i.e., the variance-bias trade-off for avoiding over-smoothing). There is no one agreed upon method for selection of block size for bootstrapping procedures. Many considerations can come into play, including practical issues and subject-matter scientific expertise. The analysis presented here first attempts to determine the "length of lag" in the ambient ozone data (i.e., how long do correlations of concentrations between MDA8 values persist). Based on the lag analysis, a secondary "blocked" bootstrap analysis was completed which sampled blocks of days corresponding to the lag found in the initial analysis. Ultimately, a 7-day lag was selected from the lag analysis. The resultant bootstrap results were similar to the original non-parametric bootstrap, which sampled individual days rather than blocks of 7 -days.

### 6.1 Analysis procedure and results

The R software package [R Core Team, 2017] was used to conduct the lag analysis. The acf (autocorrelation function) and pacf (partial autocorrelation function) were used to determine the autocorrelation of the time series of MDA8 values at each measurement site for all data available from 2016. The results from the network-wide correlations were summarized in Figures 175 and 176.

The results from the acf analysis suggest that autocorrelations drop off after lag 3, as the mean and median correlation coefficients at 4,5 and 6 days lag are equivalent (top panel of Figure 175). While the correlations are still within the $95 \%$ confidence interval returned from acf out to the 6 -day lag, the fact that the distribution of the differences between the individual correlation and the confidence intervals (middle and bottom panel of Figure 175) are virtually identical starting at 3 days of lag suggest that correlations at this level would be found at any lag period. The pacf analysis accounts for the autocorrelation found in the previous lag periods (i.e., the correlation found for the 2-day lag removes the correlation found from the 1-day lag). The results from this analysis suggest that the autocorrelation is only significant to one day. Taking these results into account, a 3-day lag should appropriately account for any autocorrelation in the ozone data. This is implemented in the bootstrapping analysis via a 7 -day block size to account for +-3 days surrounding the sampled daily value. Thus, prior to bootstrapping, the data is grouped into fixed blocks of size $\mathrm{n} \overline{7}$ and the sampline with replacement is performed on the blocks. This is also consistent with block sizes used in Inoue and Shintani [2006] and Hall and Horowitz [1996]. A 7-day block size also addresses the consideration of weekly (7-day) pollution patterns across weekday to weekend that may exist.

A second bootstrap analysis was completed for the 2016 ozone data using a block sampling method, with the 7-day block sample size, in order to determine the effect of possible temporal autocorrelation on the bootstrap confidence intervals. The analysis was conducted with the R "boot" package with the tsboot (time seties bootstrap) package with block resampling with fixed block lengths. Simple blocking, rather than overlapping blocks of randomly varying widths, should suffice for initial consideration of possible effect of dependence on bootstrapped confidence intervals (Lahiri [1999] and Andrews [2002]). The results from
this bootstrap approach are shown in Figures 177 and 178 (which can be compared to the results from the non-paremetric bootstrap in Sections 3.1 and 4.2 in the main document). The results detailed in Figure 178 indicate slightly greater variability in the blocked bootstrap result, with the mean variability from the blocked bootstrap was $1.62 \%$, versus $1.42 \%$ from the non-parametric bootstrap, and the median was $1.55 \%$, versus $1.47 \%$ from the non-parametric bootstrap. while there are a few sites with notable larger variability, as with the non-parametric bootstrap, there is no large-scale trend in the variability. The only location of note is perhaps the Uinta Basin in Utah, where a cluster of sites are grayed out in the map, indicating variability greater than the color scale. These sites have the highest variability from the blocked bootstrap. The Uinta Basin is known to have a unique patter in high-ozone days, with the maximum concentrations occurring in the winter during unique meteorological events, such that the high days are always clustered together. As a result, this highly unique ozone pattern has distinctly different results in the blocked bootstrap as compared to the non-parametric bootstrap.


Figure 175: Mean (red lines) and median (black lines) correlations from the acf analysis for ozone data from 2016.

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Figure 176: Mean (red lines) and median (black lines) correlations from the pacf analysis for ozone data from 2016.


Figure 177: Blocked-bootstrap results for the ozone 2016 DVs, showing the $50 \%, 68 \%, 75 \%$, and $95 \%$ CIs, along with the mean and median bootstrap DVs. The top panel shows the DVs at the various CIs, the middle panel shows the relative difference between the CI and the actual DV, and the bottom panel shows the distribution of the relative differences between the CI and the actual DV.

## 2016 bootstrap 50th percentile uncert



Figure 178: Blocked-bootstrap results from the $50 \%$ CIs for the 2016 ozone DVs. The top panel shows the relative difference between the CI and the actual DV, the middle panel shows the absolute difference between the values for the DVs at each site and the CI, and the bottom panel shows the spatial distribution of the relative difference between the $50 \%$ CIs for the 2015 ozone DV at each site.

## 7 Results from cluster analyses and other spatial groupings

This section presents results from several cluster analyses and other analyses conducted to examine the presence of spatial groupings or trends. If strong correlation in the variability can be found in natural spatial groupings, there may be reason to consider the variability at a regional, rather than national, level. The primary purpose of this analysis is to attempt to identify natural spatial groupings and determine if there strong correlations in the variability within these spatial groupings and if the variability between spatial groupings are significantly different. Since there is no clear pathway to determine the spatial correlations, the analysis presented here consists of several iterations of cluster analysis as well as an analysis of variability based on well-established climate regions to explore this issue from various perspectives.

### 7.1 Cluster analyses

Cluster analysis is an analysis technique that attempts to group data by similar characteristics of the data in question. This is generally done by assigning quantitative values to each characteristic and measuring and minimizing the "distance" between the existing clusters. The "distance" parameter can be calculated in a variety of ways, but the most common (and the one used here) is simply the Euclidian distance between the input variables. Two types of clustering algorithms are applied, a K-means algorithm and a hierarchical algorithm. The K-mean algorithm uses a pre-determined number of clusters and initially randomly assigns all items to clusters. The distance between cluster centers and all individuals are calculated, then individuals are reassigned to their closest cluster. The algorithm repeats a set number of times or until a minimum convergence threshold is reached. Hierarchical algorithms do not use a predetermined a number of clusters, but instead start with each individual as part of their own cluster. The first step in a hierarchical analysis combines the two closest clusters (which are just the two closest members at the first step). Each subsequent step combines the next closest clusters, until only 2 clusters are left. The R software package $[\mathrm{R}$ Core Team, 2017] was used to conduct the cluster analysis, using the kmeans and hclust functions. The analysis was performed on the results from the 2014-2016 PM variability results, as described in the following sections.

### 7.1.1 Cluster analysis with latitude, longitude, and variability values

This cluster analysis used the latitude, longitude (both in degrees eastwest and northsouth), and the relative variability (as a percentage of the site's DV). Thus, the distance between individuals and clusters is defined as the difference between the latitude, longitude, and relative variability. Since the longitudes and latitude varies on a much larger scale between sites (longitude ranges from -64 to -160 degrees, latitude ranges from 17 to 64 degrees) than the relative variability ( $0-5$ percent for the annual and $0-75$ percent for the daily DVs), the spatial input component will have a greater impact on the resulting than the site-level variability (clusters for the annual and daily DVs were computed separately). That is, the spatial closeness will be the primary factor in forming these clusters, but the analysis will then try to group nearby sites with similar levels of variability. Hierarchical and K-mean clustering were applied independently.

The clusters formed from this analysis is shown in Figures 179 and 180 and statistics are summarized in Tables 1-4. The K-means analysis used 10 clusters, which was picked based on the number of EPA Regions. The figure also shows the hierarchical cluster results at 10 clusters for comparison. The clusters from the hierarchical analysis have relatively little recognizable geographic correlation. For example, cluster 1 (orange circles in both the annual and 24 -hr figures) consists of a group of sites over California and Arizona and a group over the south eastern US (Florida, Georgia, Alabama), with a major discontinuity in this grouping, with no data points in New Mexico, Texas, Louisiana, and Mississippi. Table 1 and 2 show the statistics from the hierarchical clusters for the annual and $24-\mathrm{hr}$ standards. The table includes a comparison of the mean variability from each cluster to the mean from the entire dataset using a Welch Modified Two-Sample t -Test (determined from the tsum.test function from the BSDA package in R ) to determine if the means are significantly different. For the annual standard, the $p$ values are all fairly high, with the smallest value just over 0.1 , which is well above the nominal $p$ value of 0.5 typically identified as an indicator that the means may be different. For the $24-\mathrm{hr}$ standard, there are 2 clusters with p values less than 0.05 . Cluster 7 has a p value of 0.02 , which may be different than the annual mean, but the sites in this cluster (light blue squares with an "x") are spread across the country, i.e., they are not spatially distinct. Cluster 8 has the smallest p value (0.006) and has the smallest mean variability. For the most part, this cluster is in the
same region (purple asterisk), in the eastern US, from North Carolina up to New York. However, this cluster is interspersed with several other clusters. Thus, while it has distinct variability values and is spatially correlated, it is not spatially distinct.

The results from the K-mean cluster analysis are starkly different from the hierarchical analysis. The clusters are all geographically distinct and the results of the t-test indicate that several of the clusters are distinctly different from the mean dataset. For the annual standard, half of the clusters have p-values less than $0.05(2,3,4,8$, and 10$)$ while 7 clusters have p-values less than 0.05 for the daily standard ( $1,2,3$, $4,5,6$, and 9 , though cluster 1 and 9 only have a few members and cluster 2 is close enough to 0.05 to discount as significantly different, leaving only 4 clusters of note). On the surface, this suggests there are regional differences in the variability. However, the differences between the results from the annual and daily standards suggest the result is less certain. For example, cluster 4 in the annual analysis stands out as having the largest mean variability and a very small p-value, suggesting the variability in this subset is significantly different from the mean dataset. However, these sites are part of a larger cluster in the daily results (cluster 8), which include California sites, and has lower mean variability than the mean from the dataset (though not significantly different, with a p-value of 0.31 ). Another example of inconsistency between the annual and daily results is cluster 3 in the annual results, which roughly correlates to cluster 6 in the daily results. In this case, the clusters represent approximately the same geographic region. However, for the annual result, cluster 3 has mean variability that appears to be significantly higher than the mean dataset's ( p -value of 0.016 ), but significantly lower mean variability for the daily standard than the mean dataset's ( p -value of 0.018 ). Thus, these particular geographic areas have higher than average variability in the long-term, but lower than average variability in the short-term. The inconsistent results from the K-means analysis make it difficult draw specific conclusions about the geographic nature of the variability as estimated by this analysis.

Table 1: Comparison of hierarchical clusters for lat-long-annual variability

| n.sites | grp | mean | median | sd | ann.pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 107 | 1 | 1.628 | 1.538 | 0.7296 | 0.1969 |
| 44 | 2 | 1.917 | 1.786 | 0.7377 | 0.1052 |
| 43 | 3 | 1.759 | 1.724 | 0.7835 | 0.7972 |
| 57 | 4 | 1.759 | 1.744 | 0.5889 | 0.7024 |
| 43 | 5 | 1.659 | 1.630 | 0.5025 | 0.4108 |
| 44 | 6 | 1.745 | 1.765 | 0.4914 | 0.8207 |
| 73 | 7 | 1.736 | 1.754 | 0.5604 | 0.8929 |
| 26 | 8 | 1.674 | 1.714 | 0.6251 | 0.6762 |
| 49 | 9 | 1.816 | 1.744 | 0.7380 | 0.4171 |
| 38 | 10 | 1.660 | 1.453 | 0.8483 | 0.6384 |
| 524 | All | 1.727 | 1.705 | 0.6700 | 1.0000 |

Table 2: Comparison of hierarchical clusters for lat-long-24-hr variability

| n.sites | grp | mean | median | sd | TF.pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 107 | 1 | 5.985 | 3.846 | 8.882 | 0.718242 |
| 44 | 2 | 6.396 | 5.013 | 5.046 | 0.365465 |
| 43 | 3 | 6.339 | 5.556 | 6.332 | 0.501141 |
| 57 | 4 | 5.150 | 4.054 | 3.758 | 0.370173 |
| 43 | 5 | 6.192 | 4.762 | 6.745 | 0.618803 |
| 44 | 6 | 5.098 | 4.692 | 3.403 | 0.336031 |
| 73 | 7 | 4.720 | 4.167 | 2.598 | 0.021686 |
| 26 | 8 | 4.338 | 4.006 | 1.917 | 0.005972 |
| 49 | 9 | 5.989 | 4.545 | 8.297 | 0.787386 |
| 38 | 10 | 6.217 | 4.583 | 6.185 | 0.594067 |
| 524 | all | 5.659 | 4.447 | 6.163 | 1.000000 |

Table 3: Comparison of K-means clusters for lat-long-annual variability

| n.sites | grp | mean | median | sd | ann.pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 61 | 1 | 1.634 | 1.613 | 0.5826 | $2.508 \mathrm{e}-01$ |
| 26 | 2 | 1.425 | 1.291 | 0.5835 | $1.618 \mathrm{e}-02$ |
| 96 | 3 | 1.863 | 1.796 | 0.4657 | $1.599 \mathrm{e}-02$ |
| 26 | 4 | 2.487 | 2.395 | 0.7843 | $4.550 \mathrm{e}-05$ |
| 58 | 5 | 1.661 | 1.658 | 0.5383 | $3.941 \mathrm{e}-01$ |
| 38 | 6 | 1.619 | 1.695 | 0.6162 | $3.044 \mathrm{e}-01$ |
| 57 | 7 | 1.573 | 1.471 | 0.5912 | $7.068 \mathrm{e}-02$ |
| 66 | 8 | 1.423 | 1.373 | 0.4362 | $2.550 \mathrm{e}-06$ |
| 57 | 9 | 1.663 | 1.471 | 0.8888 | $6.006 \mathrm{e}-01$ |
| 39 | 10 | 2.266 | 2.174 | 0.7903 | $1.556 \mathrm{e}-04$ |
| 524 | all | 1.727 | 1.705 | 0.6700 | $1.000 \mathrm{e}+00$ |

Table 4: Comparison of K-means clusters for lat-long-24-hr variability

| n.sites | grp | mean | median | sd | TF.pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 3 | 1 | 61.111 | 58.333 | 12.729 | $1.701 \mathrm{e}-02$ |
| 59 | 2 | 4.794 | 4.762 | 2.367 | $3.604 \mathrm{e}-02$ |
| 44 | 3 | 9.083 | 8.477 | 3.979 | $2.320 \mathrm{e}-06$ |
| 104 | 4 | 3.807 | 3.333 | 2.131 | $8.750 \mathrm{e}-08$ |
| 33 | 5 | 4.041 | 2.941 | 3.060 | $9.146 \mathrm{e}-03$ |
| 109 | 6 | 4.751 | 4.545 | 2.849 | $1.831 \mathrm{e}-02$ |
| 38 | 7 | 4.994 | 4.762 | 2.825 | $2.154 \mathrm{e}-01$ |
| 68 | 8 | 5.165 | 4.202 | 3.342 | $3.111 \mathrm{e}-01$ |
| 7 | 9 | 30.768 | 30.952 | 9.002 | $3.049 \mathrm{e}-04$ |
| 59 | 10 | 5.020 | 3.846 | 3.136 | $1.938 \mathrm{e}-01$ |
| 524 | all | 5.659 | 4.447 | 6.163 | $1.000 \mathrm{e}+00$ |

Annual NAAQS, Hierarchical clusters


Annual NAAQS, kmeans clusters


Figure 179: Hierarchical and K-means clusters for the annual variability for 2016.

24-hr NAAQS, Hierarchical clusters


24-hr NAAQS, kmeans clusters


Figure 180: Hierarchical and K-means clusters for the 24-hr variability for 2016.

### 7.1.2 Cluster analysis with time series of variability values (2014-2016)

This cluster analysis used the relative variability (as a percentage of the site's DV) from each site over 3 DV periods (2014-2016). Thus, the distance between individuals and clusters is defined as the difference between each year's variability values (i.e., the variability from 2014 data, the variability from 2015 data, the variability from 2016 data) for a particular standard. Unlike the previous analysis, all input variables are on the same scale, such that no one parameter is driving the cluster formation. Therefore, this analysis attempts to group sites with similar levels of variability over time in order to see if those variability trends have spatial correlation. Since this approach incorporates the variability over time, it reflects the final composite variability value determined in the main analysis, which is the average over 3 DV periods. Hierarchical and K-mean clustering were applied independently.

The clusters formed from this analysis is shown in Figures 181 and 182 and statistics are summarized in Tables 5-8. The K-means analysis used 10 clusters, which was picked based on the number of EPA Regions. The figure also shows the hierarchical cluster results at 10 clusters for comparison. As with the latlongvariability analysis presented in the previous section, the clusters from the hierarchical analysis have relatively little recognizable geographic correlation. However, most of the clusters have mean variability levels that are distinctly different from the mean dataset (note that the mean values presented here represent the mean from all years), though this approach also resulted in more clusters with very few members, such that the annual results only had 5 clusters with 20 or more members and the 24 -hr results only had 3 clusters with 20 or more members. The spatial distribution of the results from the K-means analysis was similar to the hierarchical results, in that relatively little recognizable geographic correlation. However, the K-mean algorithm resulted in more meaningful clusters in terms of number of members and the statistical significance. Thus, while the cluster analysis conducted with the 3 -year variability trends resulted in groups that were distinct with respect to their variability levels, it showed essentially no spatial correlation, suggesting that geographic differences in variability do not need to be taken into account.

Table 5: Comparison of hierarchical clusters for 2014-2016 variability, annual

| n*sites | grp | mean | median | sd | ann pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 86 | 1 | 1.027 | 1.053 | 0.2387 | $1.418 \mathrm{e}-49$ |
| 84 | 2 | 1.475 | 1.449 | 0.2964 | $9.408 \mathrm{e}-08$ |
| 30 | 3 | 2.422 | 2.381 | 0.2443 | $2.756 \mathrm{e}-19$ |
| 147 | 4 | 1.877 | 1.852 | 0.2730 | $1.498 \mathrm{e}-05$ |
| 20 | 5 | 1.488 | 1.559 | 0.4272 | $3.258 \mathrm{e}-02$ |
| 7 | 6 | 2.185 | 2.439 | 0.8897 | $2.129 \mathrm{e}-01$ |
| 12 | 7 | 3.017 | 3.008 | 0.3734 | $3.841 \mathrm{e}-08$ |
| 9 | 8 | 3.099 | 3.125 | 0.4706 | $1.585 \mathrm{e}-05$ |
| 1 | 9 | 4.843 | 5.128 | 0.8896 | NA |
| 2 | 10 | 3.987 | 4.139 | 0.5126 | $9.888 \mathrm{e}-02$ |
| 398 | 11 | 1.716 | 1.666 | 0.5855 | $1.000 \mathrm{e}+00$ |

Table 6: Comparison of hierarchical clusters for 2014-2016 variability, 24-hr

| n sites | grp | mean | median | sd | TF*pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 272 | 1 | 3.630 | 3.333 | 1.662 | $1.499 \mathrm{e}-08$ |
| 49 | 2 | 8.034 | 7.895 | 2.365 | $1.311 \mathrm{e}-11$ |
| 58 | 3 | 4.848 | 4.545 | 2.134 | $7.556 \mathrm{e}-01$ |
| 9 | 4 | 11.821 | 11.765 | 2.320 | $1.106 \mathrm{e}-05$ |
| 4 | 5 | 9.097 | 5.409 | 7.870 | $3.701 \mathrm{e}-01$ |
| 1 | 6 | 18.480 | 20.312 | 4.399 | NA |
| 1 | 7 | 55.556 | 75.000 | 41.107 | NA |
| 1 | 8 | 25.966 | 29.630 | 7.354 | NA |
| 2 | 9 | 13.220 | 14.460 | 6.831 | $3.363 \mathrm{e}-01$ |
| 1 | 10 | 41.250 | 46.667 | 20.340 | NA |


| n*sites | grp | mean | median | sd | TF*pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 398 | 11 | 4.957 | 4.129 | 4.143 | $1.000 \mathrm{e}+00$ |

Table 7: Comparison of K-means clusters for 2014-2016 variability, annual

| n`sites | grp | mean | median | sd | ann pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 23 | 1 | 1.027 | 1.053 | 0.2387 | $1.068 \mathrm{e}-14$ |
| 3 | 2 | 1.475 | 1.449 | 0.2964 | $2.939 \mathrm{e}-01$ |
| 61 | 3 | 2.422 | 2.381 | 0.2443 | $1.781 \mathrm{e}-38$ |
| 66 | 4 | 1.877 | 1.852 | 0.2730 | $3.753 \mathrm{e}-04$ |
| 48 | 5 | 1.488 | 1.559 | 0.4272 | $1.382 \mathrm{e}-03$ |
| 5 | 6 | 2.185 | 2.439 | 0.8897 | $3.038 \mathrm{e}-01$ |
| 68 | 7 | 3.017 | 3.008 | 0.3734 | $4.822 \mathrm{e}-50$ |
| 28 | 8 | 3.099 | 3.125 | 0.4706 | $3.779 \mathrm{e}-16$ |
| 27 | 9 | 4.843 | 5.128 | 0.8896 | $9.066 \mathrm{e}-17$ |
| 69 | 10 | 3.987 | 4.139 | 0.5126 | $2.528 \mathrm{e}-56$ |
| 398 | 11 | 1.716 | 1.666 | 0.5855 | $1.000 \mathrm{e}+00$ |

Table 8: Comparison of K-means clusters for 2014-2016 variability, 24-hr

| n•sites | grp | mean | median | sd | TF'pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 2 | 1 | 3.630 | 3.333 | 1.662 | $4.577 \mathrm{e}-01$ |
| 59 | 2 | 8.034 | 7.895 | 2.365 | $2.016 \mathrm{e}-13$ |
| 44 | 3 | 4.848 | 4.545 | 2.134 | $7.770 \mathrm{e}-01$ |
| 104 | 4 | 11.821 | 11.765 | 2.320 | $4.609 \mathrm{e}-65$ |
| 37 | 5 | 9.097 | 5.409 | 7.870 | $3.098 \mathrm{e}-03$ |
| 46 | 6 | 18.480 | 20.312 | 4.399 | $1.172 \mathrm{e}-26$ |
| 2 | 7 | 55.556 | 75.000 | 41.107 | $3.319 \mathrm{e}-01$ |
| 22 | 8 | 25.966 | 29.630 | 7.354 | $6.561 \mathrm{e}-12$ |
| 73 | 9 | 13.220 | 14.460 | 6.831 | $7.360 \mathrm{e}-16$ |
| 9 | 10 | 41.250 | 46.667 | 20.340 | $6.812 \mathrm{e}-04$ |
| 398 | 11 | 4.957 | 4.129 | 4.143 | $1.000 \mathrm{e}+00$ |

Annual NAAQS, Hierarchical clusters


Annual NAAQS, kmeans clusters


Figure 181: Hierarchical and K-means clusters for the annual variability for 2014-2016.

24-hr NAAQS, Hierarchical clusters


24-hr NAAQS, kmeans clusters


Figure 182: Hierarchical and K-means clusters for the 24-hr variability for 2014-2016.

### 7.1.3 Cluster analysis with time series of variability values (2012-2016)

This cluster analysis used the relative variability (as a percentage of the site's DV) from each site over 5 DV periods (2012-2016). Thus, the distance between individuals and clusters is defined as the difference between each year's variability value (i.e., the variability from 2012 data, ..., the variability from 2016 data) for a particular standard. Unlike the previous analysis, all input variables are on the same scale, such that no one parameter is driving the cluster formation. Therefore, this analysis attempts to group sites with similar levels of variability over time in order to see if those variability trends have spatial correlation. Since this approach incorporates the variability over time, it partly reflects the final composite variability value determined in the main analysis, which is the average over 3 DV periods. The extended period is evaluated in addition to the 3 DV periods presented above in order to improve correlations that may exist with a longer data record. Hierarchical and K-mean clustering were applied independently.

The clusters formed from this analysis is shown in Figures 183 and 184 and statistics are summarized in Tables 9-12. The K-means analysis used 10 clusters, which was picked based on the number of EPA Regions. The figure also shows the hierarchical cluster results at 10 clusters for comparison. The results from this analysis are fairly similar to the results using the 3 DV periods. The clusters are not spatially distinct; many clusters have few members, though most have distinct variability levels. Thus, while the cluster analysis conducted with the 5 -year variability trends resulted in groups that were distinct with respect to their variability levels, it showed essentially no spatial correlation, suggesting that geographic differences in variability do not need to be taken into account.

Table 9: Comparison of hierarchical clusters for 2012-2016 variability, annual

| n*sites | grp | mean | median | sd | ann pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 76 | 1 | 1.138 | 1.099 | 0.2967 | $1.272 \mathrm{e}-27$ |
| 30 | 2 | 2.292 | 2.273 | 0.3028 | $6.841 \mathrm{e}-12$ |
| 55 | 3 | 1.533 | 1.531 | 0.3474 | $9.338 \mathrm{e}-04$ |
| 105 | 4 | 1.809 | 1.802 | 0.3136 | $6.702 \mathrm{e}-02$ |
| 1 | 5 | 3.295 | 2.632 | 1.2706 | NA |
| 16 | 6 | 2.929 | 2.871 | 0.3333 | $1.926 \mathrm{e}-11$ |
| 2 | 7 | 3.691 | 3.562 | 1.0601 | $2.315 \mathrm{e}-01$ |
| 1 | 8 | 3.117 | 3.670 | 0.8943 | NA |
| 1 | 9 | 4.096 | 4.348 | 0.5319 | NA |
| 3 | 10 | 2.185 | 2.232 | 0.7266 | $3.884 \mathrm{e}-01$ |
| 290 | 11 | 1.727 | 1.678 | 0.5550 | $1.000 \mathrm{e}+00$ |

Table 10: Comparison of hierarchical clusters for 2012-2016 variability, 24-hr

| n`sites | grp | mean | median | sd | TF'pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 193 | 1 | 3.460 | 3.226 | 1.469 | $6.142 \mathrm{e}-09$ |
| 25 | 2 | 7.603 | 7.143 | 2.917 | $1.610 \mathrm{e}-04$ |
| 32 | 3 | 5.251 | 4.762 | 2.776 | $5.508 \mathrm{e}-01$ |
| 33 | 4 | 7.187 | 7.143 | 2.787 | $1.074 \mathrm{e}-04$ |
| 1 | 5 | 36.947 | 10.000 | 37.861 | NA |
| 1 | 6 | 13.357 | 7.692 | 10.734 | NA |
| 2 | 7 | 14.391 | 12.812 | 5.456 | $2.455 \mathrm{e}-01$ |
| 1 | 8 | 36.444 | 10.000 | 39.143 | NA |
| 1 | 9 | 23.033 | 28.571 | 9.620 | NA |
| 1 | 10 | 27.333 | 18.750 | 23.875 | NA |
| 290 | 11 | 4.927 | 4.132 | 3.802 | $1.000 \mathrm{e}+00$ |

Table 11: Comparison of K-means clusters for 2012-2016 variability, annual

| n*sites | grp | mean | median | sd | ann pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 46 | 1 | 1.138 | 1.099 | 0.2967 | $1.113 \mathrm{e}-18$ |
| 39 | 2 | 2.292 | 2.273 | 0.3028 | $5.306 \mathrm{e}-15$ |
| 56 | 3 | 1.533 | 1.531 | 0.3474 | $8.645 \mathrm{e}-04$ |
| 51 | 4 | 1.809 | 1.802 | 0.3136 | $1.358 \mathrm{e}-01$ |
| 34 | 5 | 3.295 | 2.632 | 1.2706 | $2.922 \mathrm{e}-08$ |
| 3 | 6 | 2.929 | 2.871 | 0.3333 | $2.210 \mathrm{e}-02$ |
| 3 | 7 | 3.691 | 3.562 | 1.0601 | $8.448 \mathrm{e}-02$ |
| 21 | 8 | 3.117 | 3.670 | 0.8943 | $5.988 \mathrm{e}-07$ |
| 21 | 9 | 4.096 | 4.348 | 0.5319 | $5.424 \mathrm{e}-16$ |
| 16 | 10 | 2.185 | 2.232 | 0.7266 | $2.442 \mathrm{e}-02$ |
| 290 | 11 | 1.727 | 1.678 | 0.5550 | $1.000 \mathrm{e}+00$ |

Table 12: Comparison of K-means clusters for 2012-2016 variability, 24-hr

| n. sites | grp | mean | median | sd | TF ${ }^{\circ}$ pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 1 | 1 | 3.460 | 3.226 | 1.469 | NA |
| 72 | 2 | 7.603 | 7.143 | 2.917 | $1.189 \mathrm{e}-09$ |
| 67 | 3 | 5.251 | 4.762 | 2.776 | $4.262 \mathrm{e}-01$ |
| 20 | 4 | 7.187 | 7.143 | 2.787 | $2.264 \mathrm{e}-03$ |
| 26 | 5 | 36.947 | 10.000 | 37.861 | $2.218 \mathrm{e}-04$ |
| 75 | 6 | 13.357 | 7.692 | 10.734 | $2.885 \mathrm{e}-09$ |
| 2 | 7 | 14.391 | 12.812 | 5.456 | $2.455 \mathrm{e}-01$ |
| 3 | 8 | 36.444 | 10.000 | 39.143 | $2.978 \mathrm{e}-01$ |
| 2 | 9 | 23.033 | 28.571 | 9.620 | $2.285 \mathrm{e}-01$ |
| 22 | 10 | 27.333 | 18.750 | 23.875 | $2.491 \mathrm{e}-04$ |
| 290 | 11 | 4.927 | 4.132 | 3.802 | $1.000 \mathrm{e}+00$ |

Annual NAAQS, Hierarchical clusters


Annual NAAQS, kmeans clusters


Figure 183: Hierarchical and K-means clusters for the annual variability for 2012-2016.

24-hr NAAQS, Hierarchical clusters


24-hr NAAQS, kmeans clusters


Figure 184: Hierarchical and K-means clusters for the 24-hr variability for 2012-2016.

### 7.2 Spatial analysis using NOAA Climate Regions

The National Oceanic and Atmospheric Administration (NOAA) has identified 9 "climate regions" [Thomas and Koss, 1984], which have been identified to have distinct climatologically characteristics (more information available at the NOAA website). This spatial grouping thus represents an independent spatial grouping with which to evaluate regional variability characteristics. The mean annual and 24 -hr variability values from sites within these regions are compared in Figure 185 and detailed in Tables 13 and 14. The Pacific Northwest (region 4) and the Central Northwest (region 9) stand out as having higher variability, which was seen in the first K-means cluster analysis (using latitude, longitude, and the variability). The p-values for the annual results are less than 0.05 for these two regions (though the p-value for region 9 is just barely less than 0.05 and the p-value for region 4 is still relatively large). The p-values for these two regions from the 24 -hr results are well above the nominal value of 0.05 and so are not significantly different from the mean dataset. Thus, the results again make it difficult draw specific conclusions about the geographic nature of the variability as estimated by this analysis, though the overall interpretation of these results is that most regions are not significantly different from the mean dataset.

Table 13: Comparison of variability within NOAA climate regions, annual

| Region Number | n sites | ann mean | ann median | ann sd | ann pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 1 | 96 | 1.724119413 | 1.724137931 | 0.538832598 | 0.986301656 |
| 2 | 69 | 1.864963958 | 1.875 | 0.501458469 | 0.547340281 |
| 3 | 94 | 1.457900874 | 1.388888889 | 0.545905166 | 0.245378188 |
| 4 | 22 | 2.473011166 | 2.405978785 | 0.845285667 | 0.013781951 |
| 5 | 39 | 1.719076105 | 1.704545455 | 0.622791499 | 0.970268689 |
| 6 | 70 | 1.563384611 | 1.583124478 | 0.459051349 | 0.469019357 |
| 7 | 25 | 1.623411728 | 1.595744681 | 0.621819606 | 0.676247393 |
| 8 | 66 | 1.610690042 | 1.405159932 | 0.84597489 | 0.627212461 |
| 9 | 42 | 2.255001105 | 2.198067633 | 0.808280411 | 0.047892639 |
| All | 523 | 1.727970703 | 1.727970703 | 0.670071968 | 1 |

Table 14: Comparison of variability within NOAA climate regions, 24-hr

| Region Number | n sites | TF mean | TF median | TF sd | TF pval |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 1 | 96 | 5.861069073 | 4.545454545 | 6.966363904 | 0.924845491 |
| 2 | 69 | 4.690627066 | 4.545454545 | 1.965280928 | 0.632945983 |
| 3 | 94 | 3.628720758 | 3.125 | 2.092141946 | 0.326832786 |
| 4 | 22 | 10.13095985 | 7.417582418 | 11.55838373 | 0.165608839 |
| 5 | 39 | 5.280129178 | 5 | 3.051945505 | 0.853550834 |
| 6 | 70 | 5.893319944 | 4.653679654 | 5.146873277 | 0.911597545 |
| 7 | 25 | 5.383605813 | 4 | 3.836720273 | 0.896970478 |
| 8 | 66 | 5.93939837 | 3.923076923 | 10.5914199 | 0.90680014 |
| 9 | 42 | 8.69767221 | 7.692307692 | 3.979459168 | 0.166016078 |
| All | 523 | 5.660892679 | 4.347826087 | 6.168440212 | 1 |



Figure 185: Comparison of variability within NOAA climate regions for 2016.

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