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September 18, 2003

Michael Koerber
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Des Plaines, IL 60018

STI Ref. No. 903480

Re: $PM_{2.5}$ Forecasting – Synoptic Typing

Dear Mike,

Thank you for giving Sonoma Technology, Inc. (STI) the opportunity to provide data analysis and $PM_{2.5}$ forecasting services to six cities in the Midwest. As part of this effort, this technical memorandum summarizes the work developing a conceptual model of the major meteorological features that affect $PM_{2.5}$ concentrations in the six Midwest cities during the summer. The following tasks were performed to complete this task:

- Acquire daily $PM_{2.5}$ data for Milwaukee, Chicago, Detroit, Cleveland, Columbus, and St. Louis for May through September, 1999 – 2002.
- Perform synoptic typing of the surface meteorology, upper-air meteorology, and inversion layer strength and height to understand the relationship between large-scale weather patterns and $PM_{2.5}$.
- Utilize this typing to develop a conceptual model on summertime $PM_{2.5}$ concentrations in the Midwest, including rules of thumb and forecasting tools.

Our conclusions are summarized in this letter. These conclusions are followed by more detailed results in the attachments: (1) discussions of results, including forecasting guidelines based on synoptic typing; (2) $PM_{2.5}$ concentrations by synoptic types; (3) $PM_{2.5}$ concentrations by inversion typing; (4) change in $PM_{2.5}$ concentrations by AQI (Air Quality Index) category and frequency of synoptic type by AQI category; (5) $PM_{2.5}$ concentrations by inversion type under the presence of upper-level features; (6) change in $PM_{2.5}$ concentration by change in upper-air typing; and (7) change in $PM_{2.5}$ concentration by change in inversion typing.

Conclusions

A number of analyses using synoptic typing results were conducted and were, in general, consistent with wintertime $PM_{2.5}$ analyses. Analyses were based on the maximum 24-hr $PM_{2.5}$ concentration among the FRM monitors for each city. These analyses produced several key conclusions:

- $PM_{2.5}$ concentrations are often higher at all cities when an upper-level ridge is present, and lower when an upper-level trough occurs. The presence of these synoptic features generally dictate whether the six cities' $PM_{2.5}$ concentrations are similar. For example, if a ridge is present over Columbus and Cleveland (set 1) but a trough is dominating Milwaukee and Chicago (set 2), these sets of cities will generally have different $PM_{2.5}$ concentrations.

- $PM_{2.5}$ concentrations are often higher at all cities when calm winds, a stationary front, a surface high, or southerly flow is present, while concentrations are lower when a front passes through, a surface low is present, or flow is northerly or westerly.

- Inversion height and inversion strength to 925 mb at 12Z do not appear to be as important in the summer as in winter, when inversions can trap $PM_{2.5}$ for multiple days. In the summer, inversions often dissipate in the morning and, therefore, do not appear to significantly affect $PM_{2.5}$ concentrations. One exception is St. Louis, where a strong or moderate inversion was present for nearly all days with $PM_{2.5}$ concentrations above 40 $\mu g/m^3$.

- The two-day trend in 500-mb regime appears to be very useful for forecasting, as persistence of the same regime can lead to increased $PM_{2.5}$. Tables detailing the frequency of occurrence and the typical change in $PM_{2.5}$ associated with each two-day trend combination are provided in Attachment 1.

- The two-day trend in inversion strength may be useful for forecasting, though generally this is secondary to synoptic conditions. Tables detailing the frequency of occurrence and the typical change in $PM_{2.5}$ associated with each two-day trend combination are provided in Attachment 1.

- A high correlation (i.e., $r^2 > 0.60$) in $PM_{2.5}$ concentrations was found between a number of cities: Cleveland with Detroit, Columbus and Chicago, Detroit with Chicago and Columbus, and Milwaukee and Chicago.

The following attachments provide details supporting our conclusions. If you have any questions about this memorandum, please contact Timothy Dye or me.

Sincerely,

Steven G. Brown
Air Quality Analyst

Paul T. Roberts for TSD

Timothy S. Dye
Vice President

ATTACHMENT 1: OVERVIEW, RESULTS AND DISCUSSION

OVERVIEW

Synoptic typing was completed for Milwaukee, Chicago, Detroit, Cleveland, Columbus and St. Louis for May through September, 1999-2002. Nine surface influence metrics (types) and four 500-mb influence metrics were determined. Three metrics each of inversion strength and height were determined using 12Z (0700 CDT) soundings. The metrics are summarized in **Table A1-1** and further described below. Examples of metric types are shown below in **Figures A1-1 through A1-8**.

Table A1-1. Metrics used in synoptic typing for surface and 500 mb meteorology and inversion strength and height (one from each category is used for each city, each day).

Surface meteorology	500-mb	Inversion strength	Inversion height
High	Ridge	0-4°C below 925 mb (weak)	Surface to 951 mb
Low	Trough	4-6°C below 925 mb (moderate)	950 mb – 901 mb
Stationary front	Zonal	>6°C below 925 mb (strong)	Higher than 901 mb
Frontal passage	Flat		
Calm winds			
Northerly flow			
Westerly flow			
Southerly flow			
Easterly flow			

Surface Meteorology Metrics

- High – Part of a surface high is located over the city and is the dominant feature for that day.
- Low – Part of a surface low is located over the city and is the dominant feature for that day.
- Stationary front – A stationary front is situated over the city and is the dominant feature for that day.
- Frontal passage – A cold front passed through the city during the 24-hr period of the day.
- Calm winds – Winds are calm, usually in conjunction with a surface high.
- Northerly flow – No dominant feature is evident, and winds are from the north.
- Westerly flow – No dominant feature is evident, and winds are from the west.
- Southerly flow – No dominant feature is evident, and winds are from the south.
- Easterly flow – No dominant feature is evident, and winds are from the east.

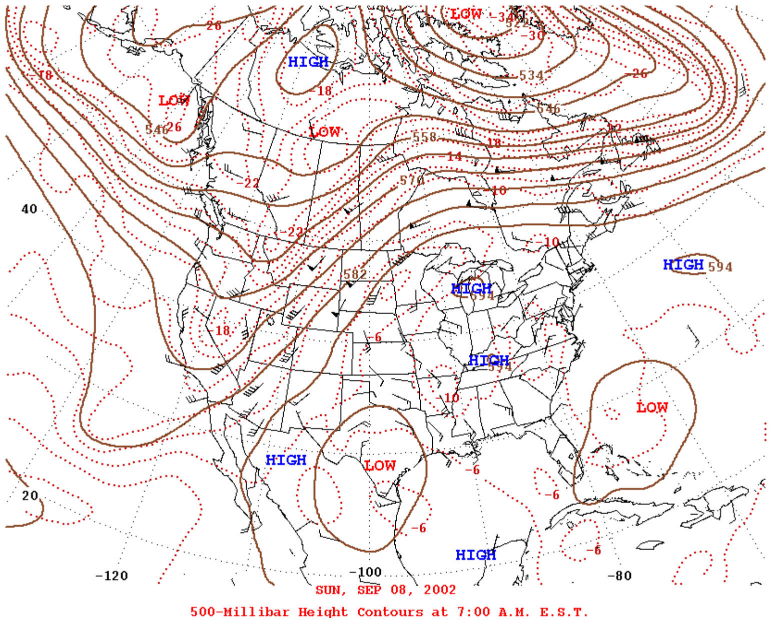

Figure A1-1. 500-mb map for September 8, 2002, at 12Z. Example of a ridge (cutoff high) over Chicago, Milwaukee, Detroit, Cleveland, Columbus, and St Louis.

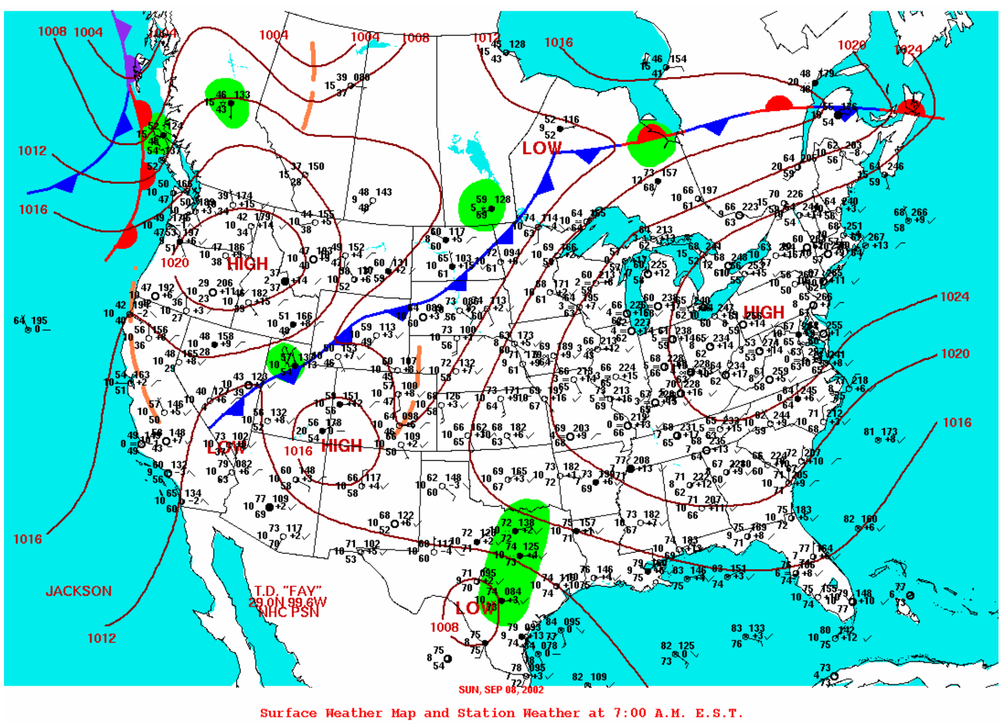

Figure A1-2. Surface map for September 8, 2002, at 12Z. Example of minimal winds and high pressure over Milwaukee, Chicago, Columbus, and St. Louis, and high pressure over Detroit and Cleveland. All cities had an AQI in the high Moderate to USG range.

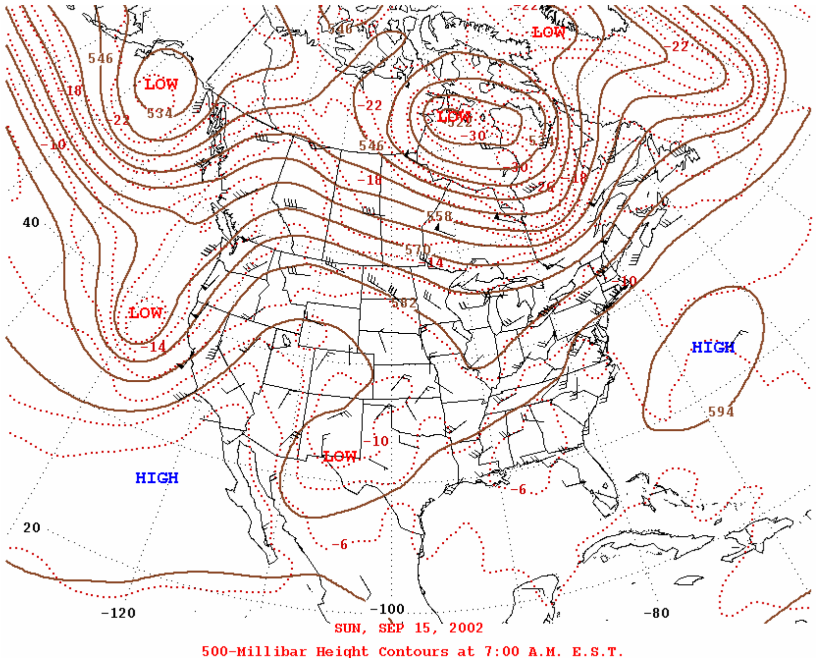

Figure A1-3. 500-mb map for September 15, 2002, at 12Z. Example of a trough affecting all six cities.

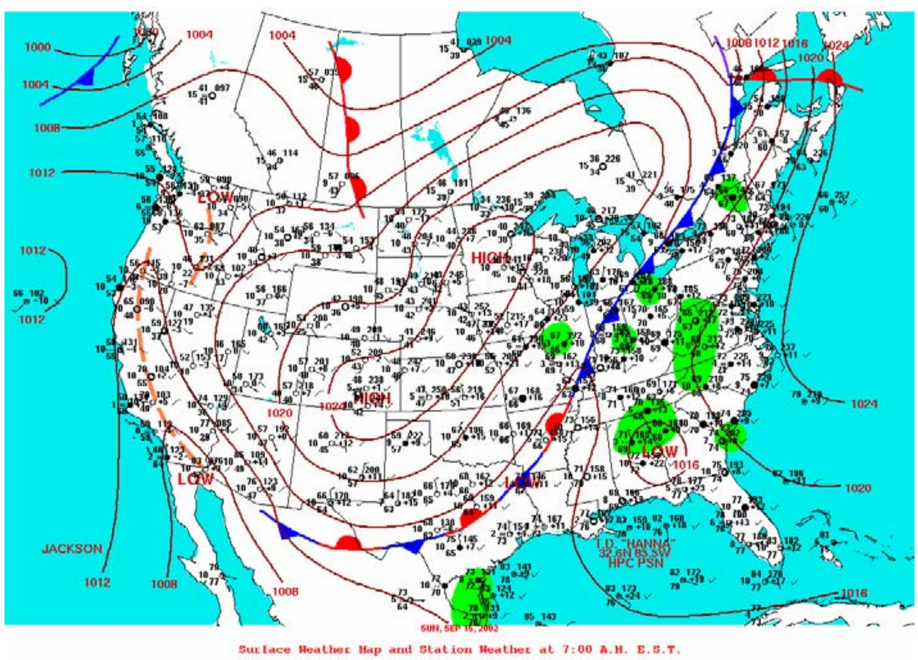

Figure A1-4. Surface map for September 15, 2002, at 12Z. Example of a frontal passage affecting Milwaukee, Chicago, Detroit, Cleveland, and Columbus, and calm winds at St. Louis. The first five cities saw a large decrease in $PM_{2.5}$ concentrations with advection of a clean air mass, while concentrations in St. Louis remained high Moderate.

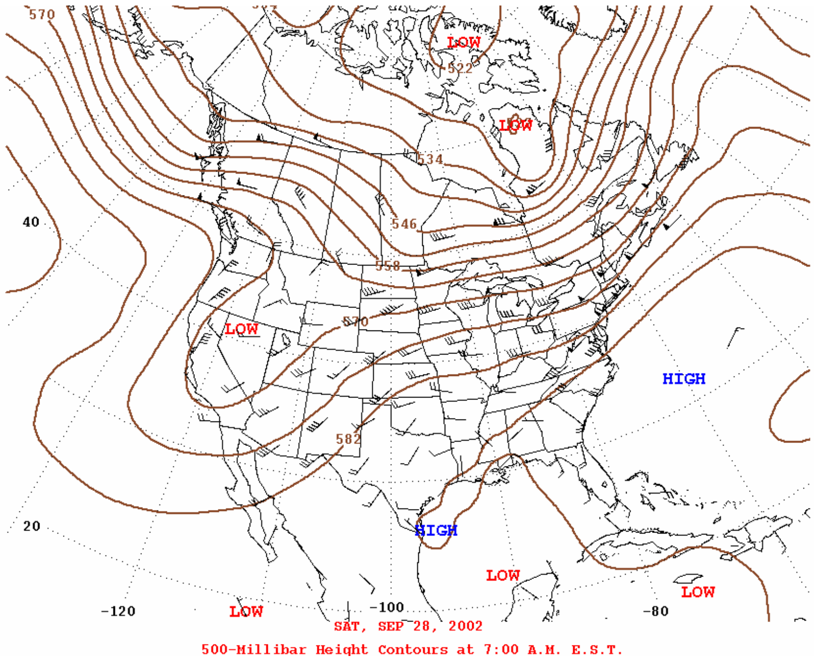

Figure A1-5. 500-mb map for September 28, 2002, at 12Z. Example of zonal flow over Detroit, Cleveland, Columbus, and St. Louis, and a ridge beginning over Milwaukee and Chicago (which intensified over the next 24 hours).

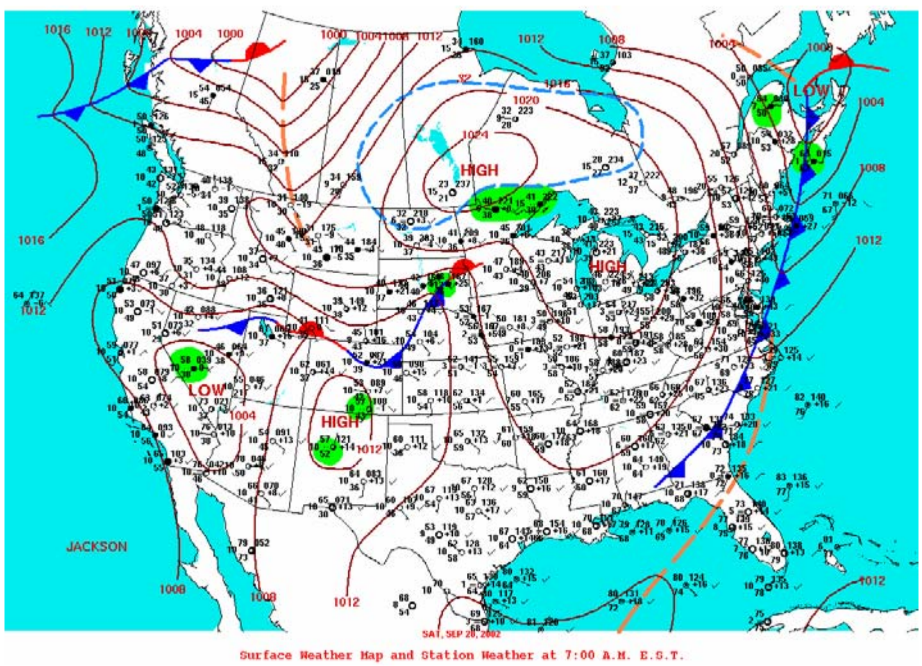

Figure A1-6. Surface map for September 28, 2002, at 12Z. Example of a surface high over Milwaukee, Chicago, Detroit, Cleveland, and Columbus, and minimal winds at St. Louis. Concentrations increased from the previous day at every city but Detroit, and all cities had AQIs of Moderate.

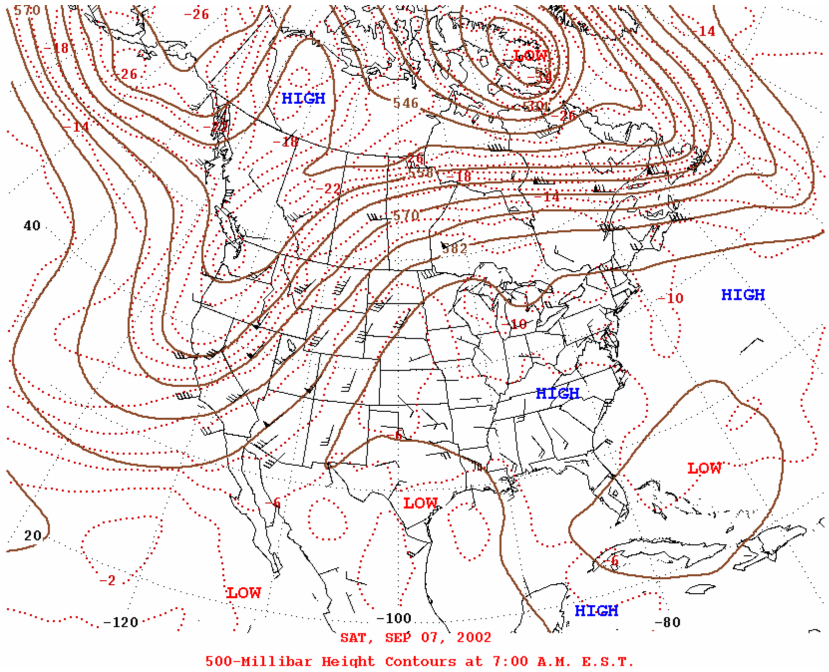

Figure A1-7. 500-mb map on September 7, 2002, at 12Z. Example of a ridge intensifying over Milwaukee, Chicago, Cleveland, Columbus, and Detroit, and a flat regime over St. Louis.

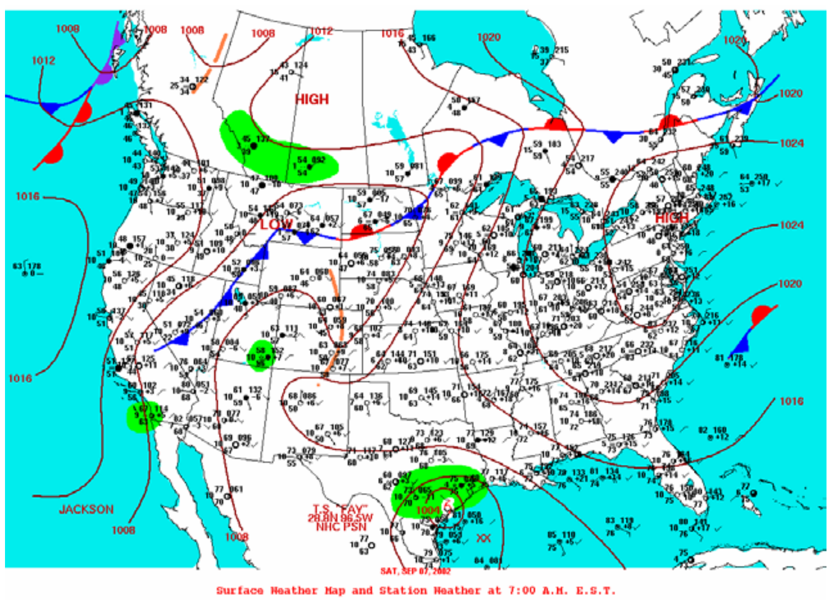

Figure A1-8. Surface map on September 7, 2002, at 12Z. Example of southerly flow at Milwaukee and Cleveland; minimal winds at Columbus, Chicago, and St. Louis; and northerly flow at Detroit. $PM_{2.5}$ concentrations increased at all cities on this day, though with a wide range of increases and maximum levels.

500-mb Meteorology Metrics

- Ridge – An upper-level ridge, or cut-off high, is over the city.
- Trough – An upper-level trough, or cut-off low, is over the city.
- Zonal – There is no obvious trough or ridge, and winds are zonal.
- Flat – There is no obvious trough or ridge; winds are low and generally not westerly.

Inversion Strength Metrics

- Weak – The inversion at 12Z up to 925 mb is non-existent or less than 4°C.
- Moderate – The inversion at 12Z up to 925 mb is between 4°C and 6°C.
- Strong – The inversion at 12Z up to 925 mb is greater than 6°C.

Inversion Height Metrics

- Low – Inversion stops below 951 mb.
- Moderate – Inversion stops between 950 mb and 901 mb.
- High – Inversion stops above 900 mb.

STATISTICS

Daily maximum 24-hr $PM_{2.5}$ concentration data for all six cities were available for May through September, 1999 to 2002. Data for Milwaukee was available only every third day in 2002, and for Chicago, every third day in 1999. The highest concentration over all sites within each city was used as the maximum concentration for the city on that day. The number of sites, data completeness (assuming data was available daily) and summary statistics are summarized in **Table A1-2**.

These statistics give an overview of $PM_{2.5}$ concentrations and changes in $PM_{2.5}$ concentrations at each city, so forecasters have a base knowledge of typical concentrations for each city. Cleveland and Milwaukee experienced over 40 days with $PM_{2.5}$ concentrations greater than 40 $\mu g/m^3$, while other cities experienced less than 30; this indicates that local sources may play an important role in Cleveland and Milwaukee. Milwaukee also had the highest number of days when $PM_{2.5}$ concentrations increased by more than 20 $\mu g/m^3$ from one day to the next, more than twice as many days as any other city; because only one-in-three day data were available in 2002, this statistic was derived using only 1999 through 2001 data. This indicates that Milwaukee results may be different than those from nearby Chicago. Cleveland, Columbus, and Detroit all showed similar results, though some differences were seen in synoptic typing. St. Louis is farther away from the other cities and is expected to have different results.

Table A1-2. Statistics by city for summer (May-September) $PM_{2.5}$ data from 1999-2002.

1999-2002 May-Sept $PM_{2.5}$ Stats	Chicago	Cleveland	Columbus	Detroit	Milwaukee	St. Louis
Number of sites	26	12	5	12	10	15
Completeness[1] (%)	84	84	98	98	84	99
90th percentile (µg/m^3)	35	37	33	32	38	32
95th percentile (µg/m^3)	41	42	38	38	47	39
99th percentile (µg/m^3)	48	53	46	49	57	51
N total	515	602	597	599	514	603
N < 15 µg/m^3	189	182	227	277	218	212
N > 40 µg/m^3	27	44	23	25	42	24
N > 65 µg/m^3	0	0	1	0	1	2
N in 99th percentile	5	6	6	6	5	6
N in 95th percentile	26	30	30	30	26	30
N Δ PM > 15 µg/m^3 from previous day	19	38	24	25	29	13
N Δ PM > 20 µg/m^3 from previous day	5	9	8	6	18	9

[1] Assuming data was available daily.

$PM_{2.5}$ CONCENTRATIONS BY SYNOPTIC TYPE

Distributions of $PM_{2.5}$ concentrations by surface and 500-mb type were computed in order to examine the typical concentrations found under each regime. This climatology enables forecasters to determine the typical range of concentrations found under each regime for a particular city. Examples for Cleveland are shown in **Figures A1-9 through A1-11**. Results from all six cities are provided in Attachment 2. Findings from this analysis include:

- Generally, higher concentrations (i.e., above 30 µg/m^3) occur with southerly flow, minimal (calm) winds, or the presence of a surface high or stationary front.
- Low concentrations (i.e., generally below 20 µg/m^3) most often occur when a front passes through, when a surface low is present, or when there is northerly or westerly flow.
- Easterly flow can produce a wide range of concentrations.
- An upper-level ridge or flat flow generally produces higher $PM_{2.5}$ concentrations (i.e., above 30 µg/m^3), while a trough or zonal flow produces lower concentrations (i.e., generally below 20 µg/m^3).

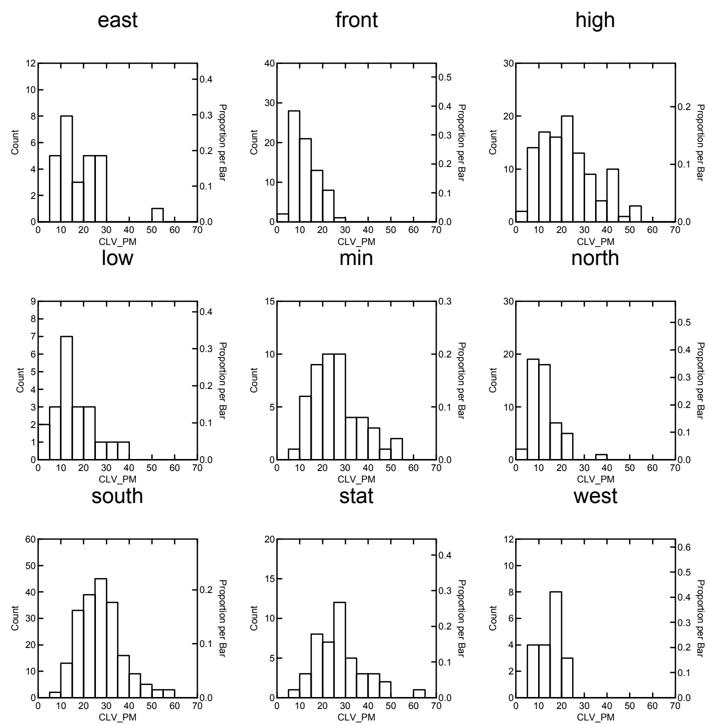

Figure A1-9. $PM_{2.5}$ concentrations by surface type at Cleveland, May-September, 1999-2002.

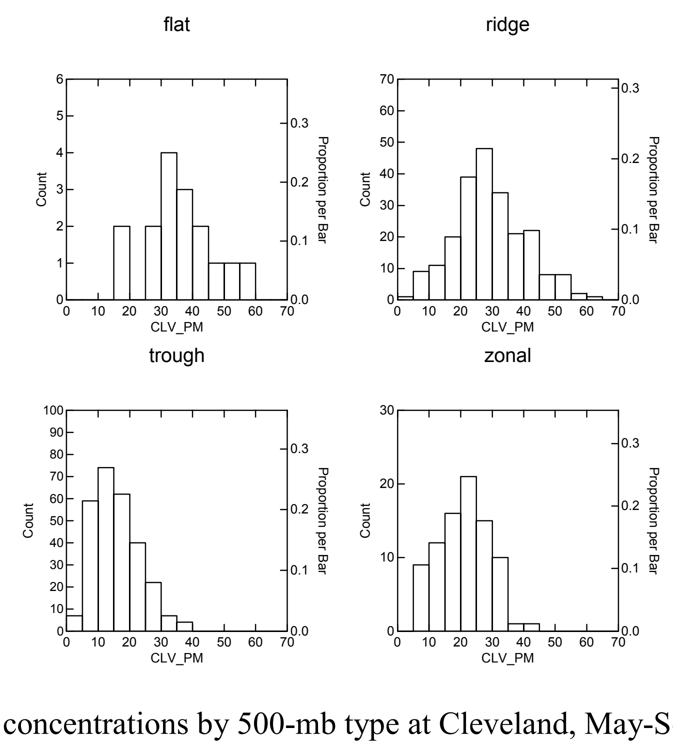

Figure A1-10. $PM_{2.5}$ concentrations by 500-mb type at Cleveland, May-September, 1999-2002.

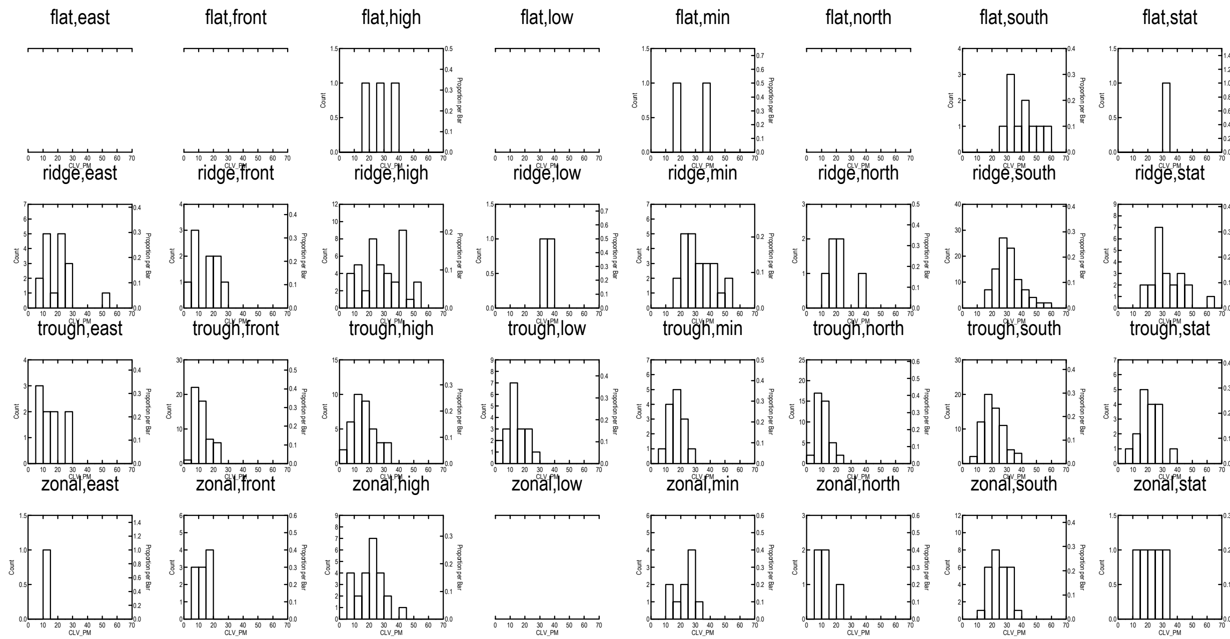

Figure A1-11. $PM_{2.5}$ concentrations by surface and 500-mb type at Cleveland, May-September, 1999-2002. Blank plot indicates no occurrence.

$PM_{2.5}$ CONCENTRATIONS BY INVERSION STRENGTH AND HEIGHT

Distributions of $PM_{2.5}$ concentrations by inversion strength and height were used to examine the typical concentrations in each regime. This climatology enables forecasters to determine the typical range of concentrations found under each regime for a particular city. In the winter, the strength and depth of the morning inversion layer are important factors that affect the $PM_{2.5}$ level (e.g., see http://www.airnowdata.org/pm25forecasting/index.html). Examples for Detroit are shown in **Figures A1-12 through A1-14**. Results from all six cities are given in Attachment 3.

In general, inversion strength and height in the summer do not significantly affect $PM_{2.5}$ concentrations in the five northern cities. This is in contrast to the winter when an inversion can persist throughout an entire day and for consecutive days, thus trapping PM and allowing concentrations to increase. In the summer, sufficient radiation generally breaks the morning inversion layer; thus, the height and strength of the inversion do not appear to be as important as the synoptic features affecting the area. While the strength of the inversion layer does not greatly affect $PM_{2.5}$ concentrations, the presence of a morning inversion layer, regardless of the strength or height, does appear to increase the likelihood of higher $PM_{2.5}$ concentrations.

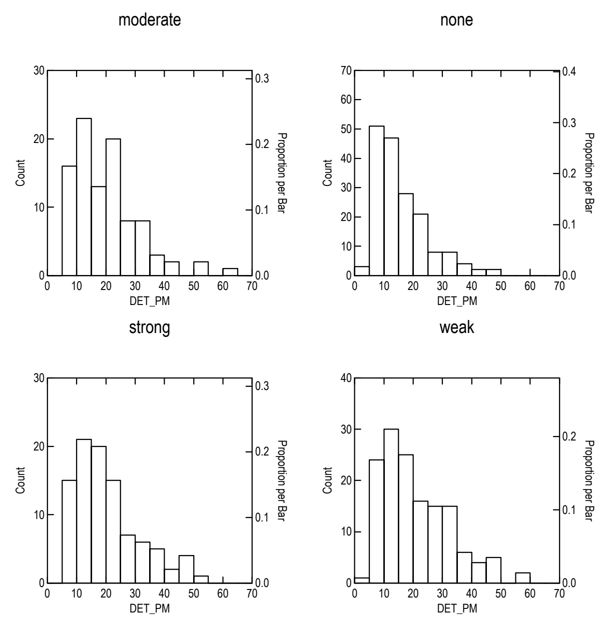

Figure A1-12. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Detroit during May-September, 1999-2002, by inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb).

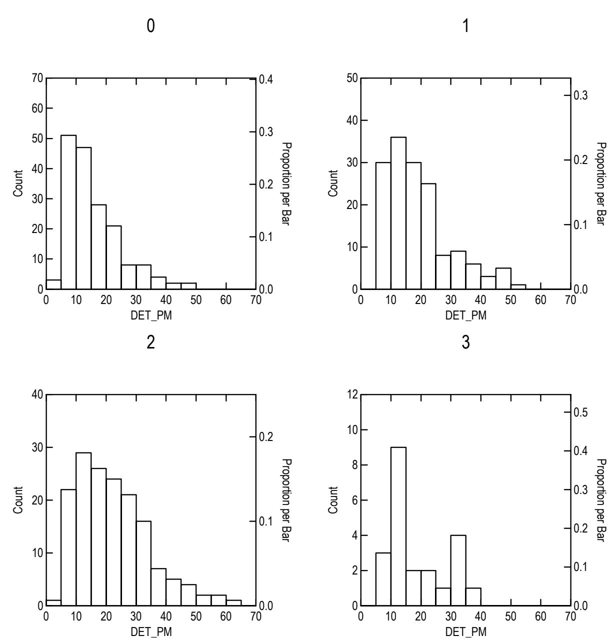

Figure A1-13. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Detroit during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb).

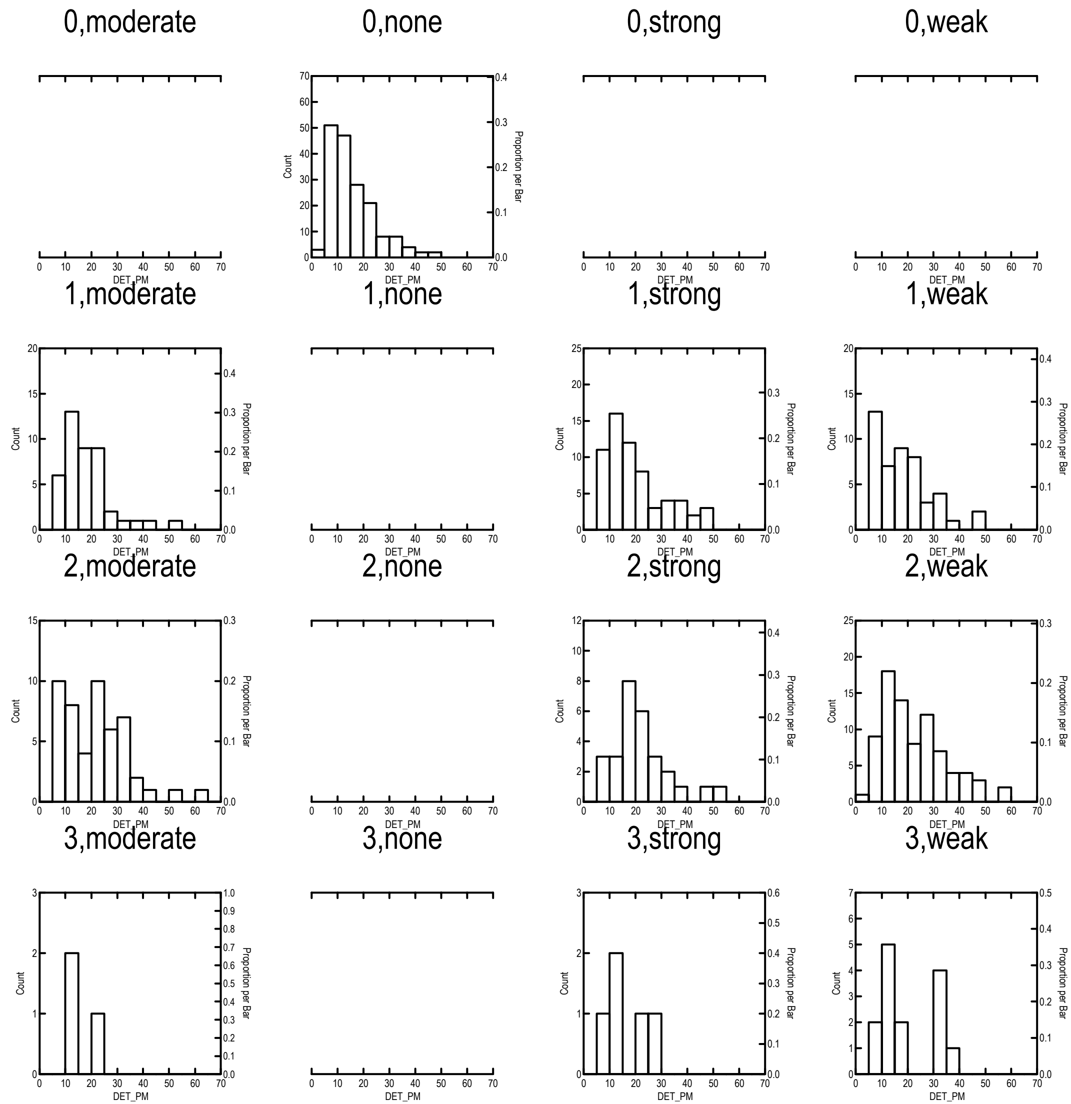

Figure A1-14. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Detroit during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb) and inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb). Blank plot indicates no occurrence.

St. Louis differed from the other five cities (see **Figures A1-15 through A1-17**). In St. Louis, $PM_{2.5}$ concentrations above 30 $\mu g/m^3$ occurred nearly exclusively under a strong or moderate inversion and inversion heights less than 900 mb. Similarly, a strong or moderate inversion with a height less than 900 mb was present during all but one day when $PM_{2.5}$ concentrations were Unhealthy for Sensitive Groups (USG). Further analysis to examine the relationship between the inversion layer height and strength and the 500-mb synoptic type may give additional insight into the dependence of summertime $PM_{2.5}$ concentrations on inversions in St. Louis.

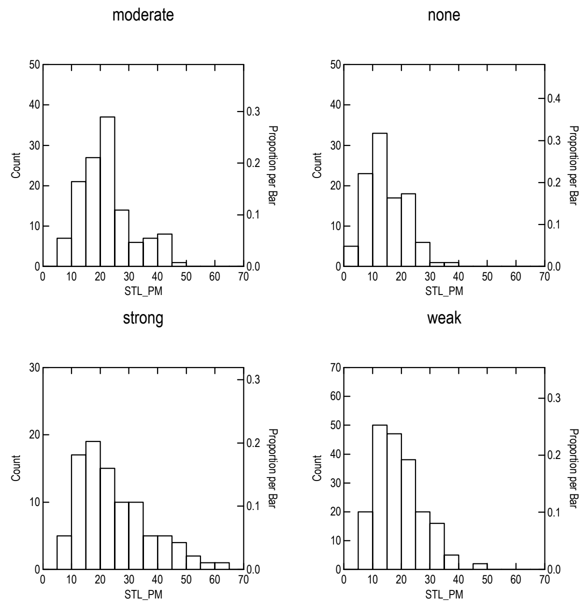

Figure A1-15. $PM_{2.5}$ concentrations ($\mu g/m^3$) at St. Louis during May-September ,1999-2002, by inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb).

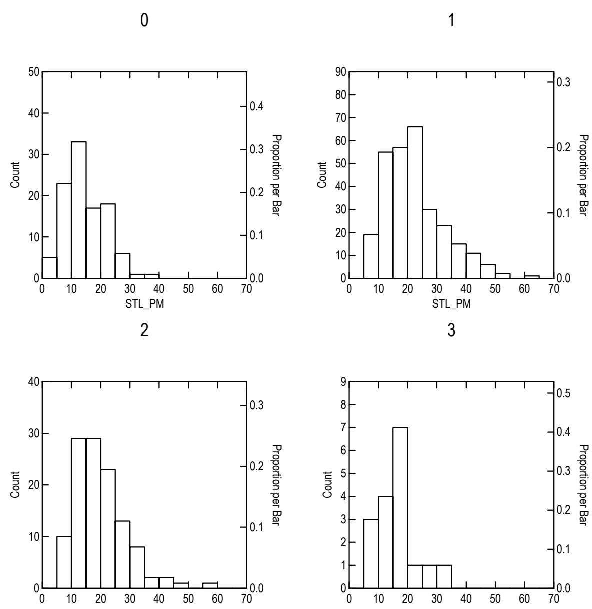

Figure A1-16. $PM_{2.5}$ concentrations ($\mu g/m^3$) at St. Louis during May-September, 1999-2002, by inversion height. 0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb.

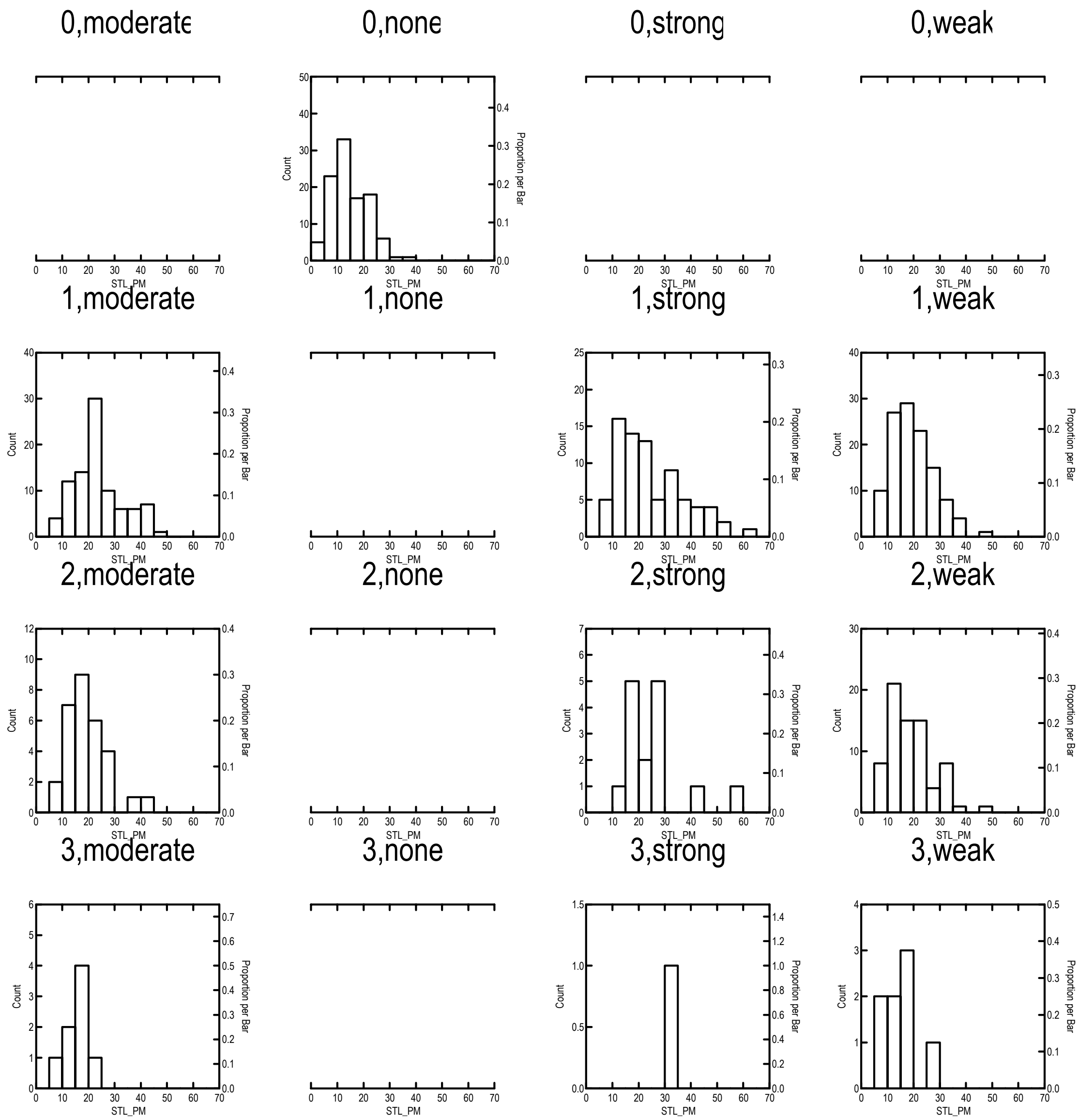

Figure A1-17. $PM_{2.5}$ concentrations ($\mu g/m^3$) at St. Louis during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb) and inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb). Blank plot indicates no occurrence. Blank plots indicate no occurrence.

ANALYSIS BY AIR QUALITY INDEX (AQI) CATEGORY

This analysis utilizes Air Quality Index (AQI) categories; the Moderate category was divided into low Moderate (15-25 $\mu g/m^3$) and high Moderate (25-40 $\mu g/m^3$). An examination of the daily change in $PM_{2.5}$ by the previous day's AQI category provides insight into the typical changes given a certain AQI category, i.e., if today is high Moderate, what is the typical $PM_{2.5}$ change for the next day? For example, Figure **A1-18** shows a two-day trend in Cleveland in $PM_{2.5}$ concentration by the previous day's AQI category. **Table A1-3** summarizes the probability of a given change in $PM_{2.5}$ from the previous day based on the previous day's AQI. If the previous day's AQI category was Good, there was usually an increase in $PM_{2.5}$ concentrations on the following day, while $PM_{2.5}$ can either increase or decrease from the previous day from the low Moderate category. There was usually a decrease in $PM_{2.5}$ when the previous day's AQI was high Moderate or USG.

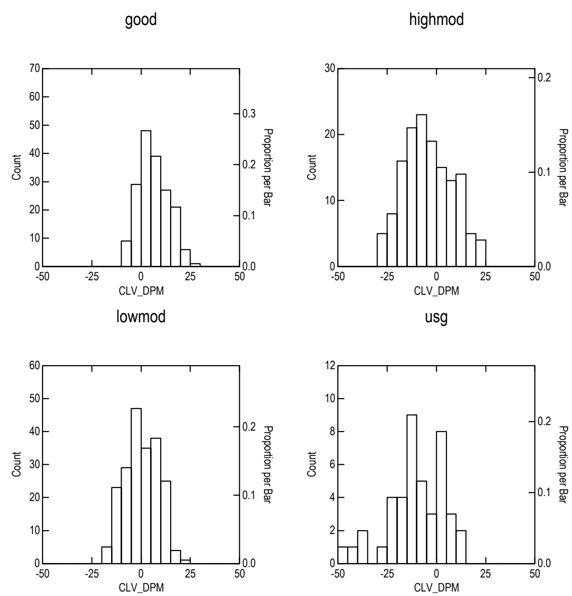

Figure A1-18. Changes in $PM_{2.5}$ concentrations from the previous day at Cleveland by previous day's AQI category, May-September 1999-2002 (lowmod = low moderate, 15-25 µg/m^3; highmod = high moderate, 25-40 µg/m^3).

Table A1-3. Probability (% chance) of the change in $PM_{2.5}$ (increase or decrease) from the previous day by the previous day's AQI category.

City	Good	Low Moderate	High Moderate	USG
Chicago	75% ↑ 0-25	90% ↓/↑ 0-10	65% ↓ 0-30	70% ↓ 0-30
Columbus	80% ↑ 0-25	60% ↑ 0-25	65% ↓ 0-35	90% ↓ 0-35
Milwaukee	70% ↑ 0-25	90% ↓/↑ 0-15	60% ↓ 0-30	80% ↓ 0-45
Cleveland	80% ↑ 0-25	75% ↓/↑ 0-10	60% ↓ 0-30	65% ↓ 0-50
Detroit	75% ↑ 0-20	70% ↓/↑ 0-10	65% ↓ 0-25	75% ↓ 0-40
St. Louis	75% ↑ 0-15	85% ↓/↑ 0-10	65% ↓ 0-25	65% ↓ 0-25

The number of times each synoptic type occurred with each AQI category was investigated to provide the forecaster further insight into the typical conditions that are present for a particular AQI category. **Figures A1-19 through A1-22** show the number of instances each surface and 500-mb type occurred under each AQI category for Cleveland. When the AQI is USG, there is generally an upper-level ridge and either a surface high or southerly flow, while an AQI of Good usually occurs when an upper-level trough and surface front moves through or there is northerly flow. Attachment 4 shows these graphs for all six cities.

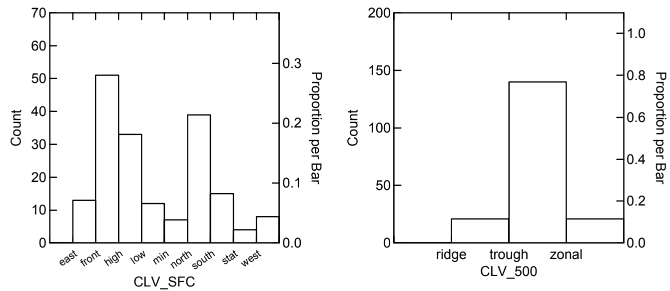

Figure A1-19. Number of instances of surface type and 500-mb type at Cleveland with AQI of Good.

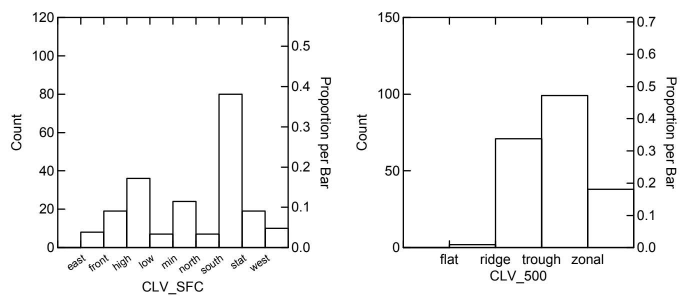

Figure A1-20. Number of instances of surface type and 500-mb type at Cleveland with AQI of low Moderate.

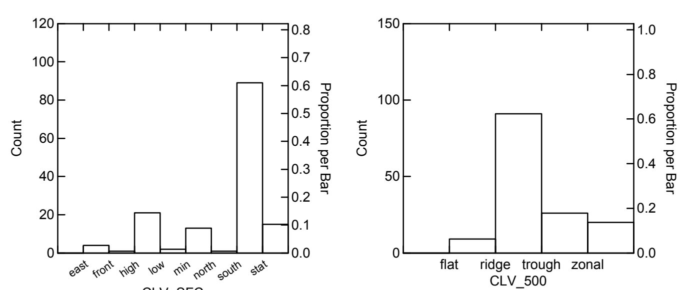

Figure A1-21. Number of instances of surface type and 500-mb type at Cleveland with AQI of high Moderate.

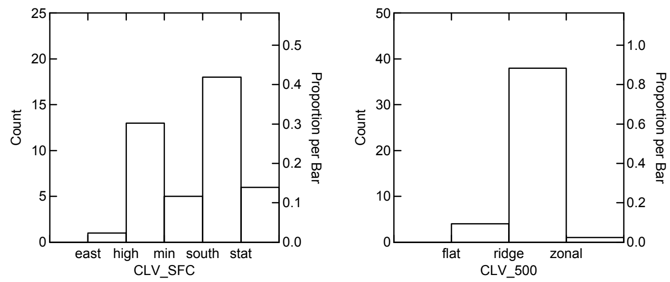

Figure A1-22. Number of instances of surface type and 500-mb type at Cleveland with AQI of USG.

ANALYSIS OF INVERSIONS AND 500-MB TYPE

$PM_{2.5}$ concentrations by inversion strength and height when an upper-level trough and upper-level ridge were present were examined. This enables for further investigation into how much inversion strength and height affect the maximum $PM_{2.5}$ concentration for each city, and how dominant the synoptic meteorology is in the summer. **Figures A1-23 and A1-24** show examples of $PM_{2.5}$ concentrations at Milwaukee by inversion strength and height when an upper-level ridge and trough are present, respectively. Results for all cities are shown in Attachment 5. In general, synoptic meteorology appears to be much more important than inversion strength and height at most cities, since the trends in $PM_{2.5}$ concentrations between inversion groups are not very different. This is likely due to the fact that the summertime inversion layers routinely break during the course of the day, while in the winter, they may remain intact for multiple days. Therefore, while inversion strength and height play a role in $PM_{2.5}$ concentrations, their importance may be dwarfed by the synoptic meteorology.

ANALYSIS BY TWO-DAY TRENDS IN 500-MB TYPES (PERSISTENCE)

To determine how trends in 500-mb regimes are related to changes in $PM_{2.5}$ concentrations, the change in $PM_{2.5}$ concentration by the two-day trend in 500-mb type was examined. **Figure A1-25** shows results for Columbus: when a trough changes to a ridge, there is often an increase of 5-20 $\mu g/m^3$ of $PM_{2.5}$; when a ridge changes to zonal flow, there is usually a decrease in $PM_{2.5}$ concentrations. Graphical results for other cities are provided in Attachment 6. **Tables A1-4 through A1-9** detail the percent occurrence of, as well as the probability and change in $PM_{2.5}$ that is likely to occur with, each two-day 500-mb combination.

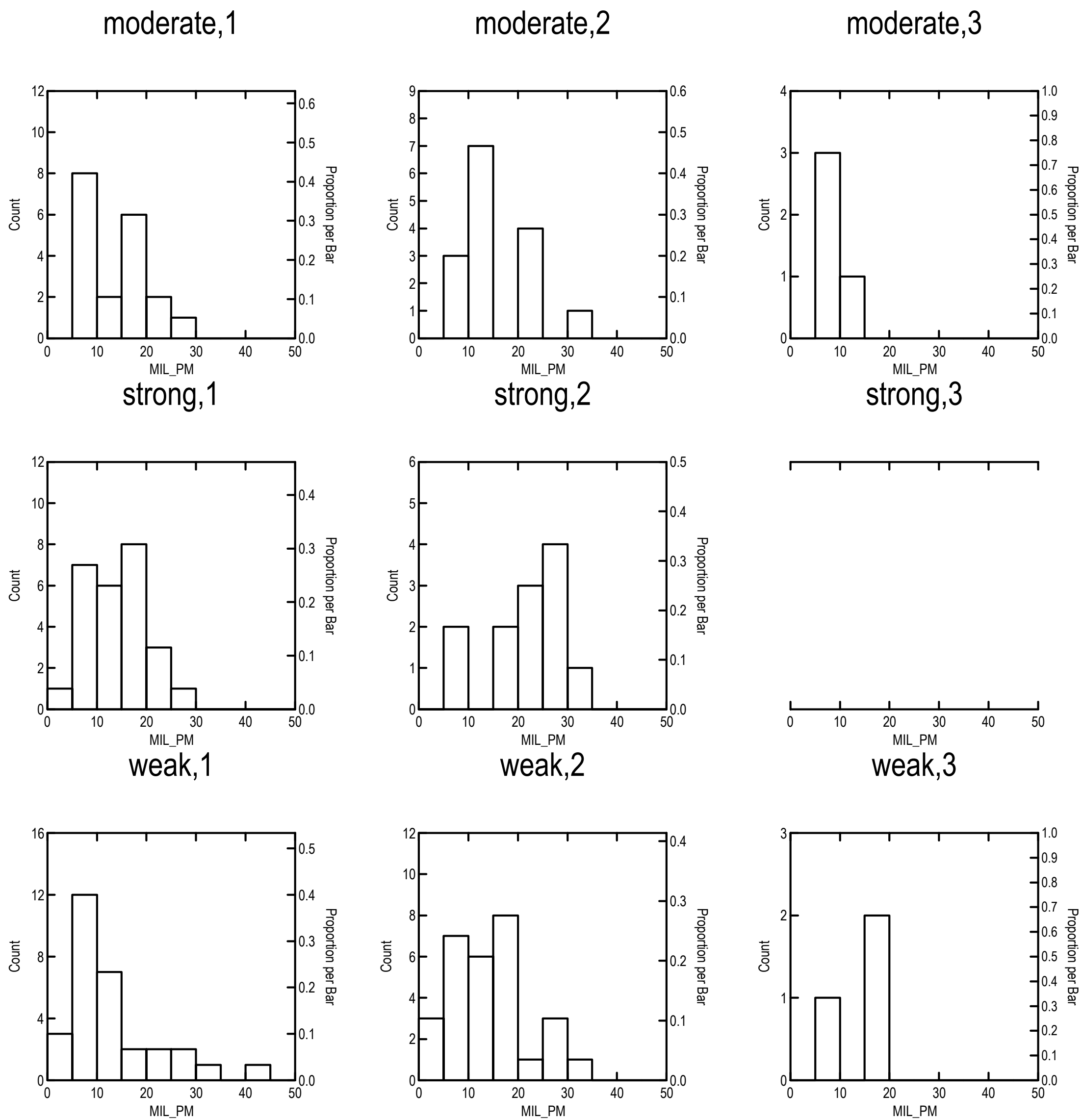

Figure A1-23. $PM_{2.5}$ concentrations at Milwaukee during May–September, 1999-2002, when an upper-level trough is present by inversion strength (none = no inversion present, weak = 0-4°C inversion below 925 mb, moderate = 4-6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb) and inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb). Blank plot indicates no occurrence.

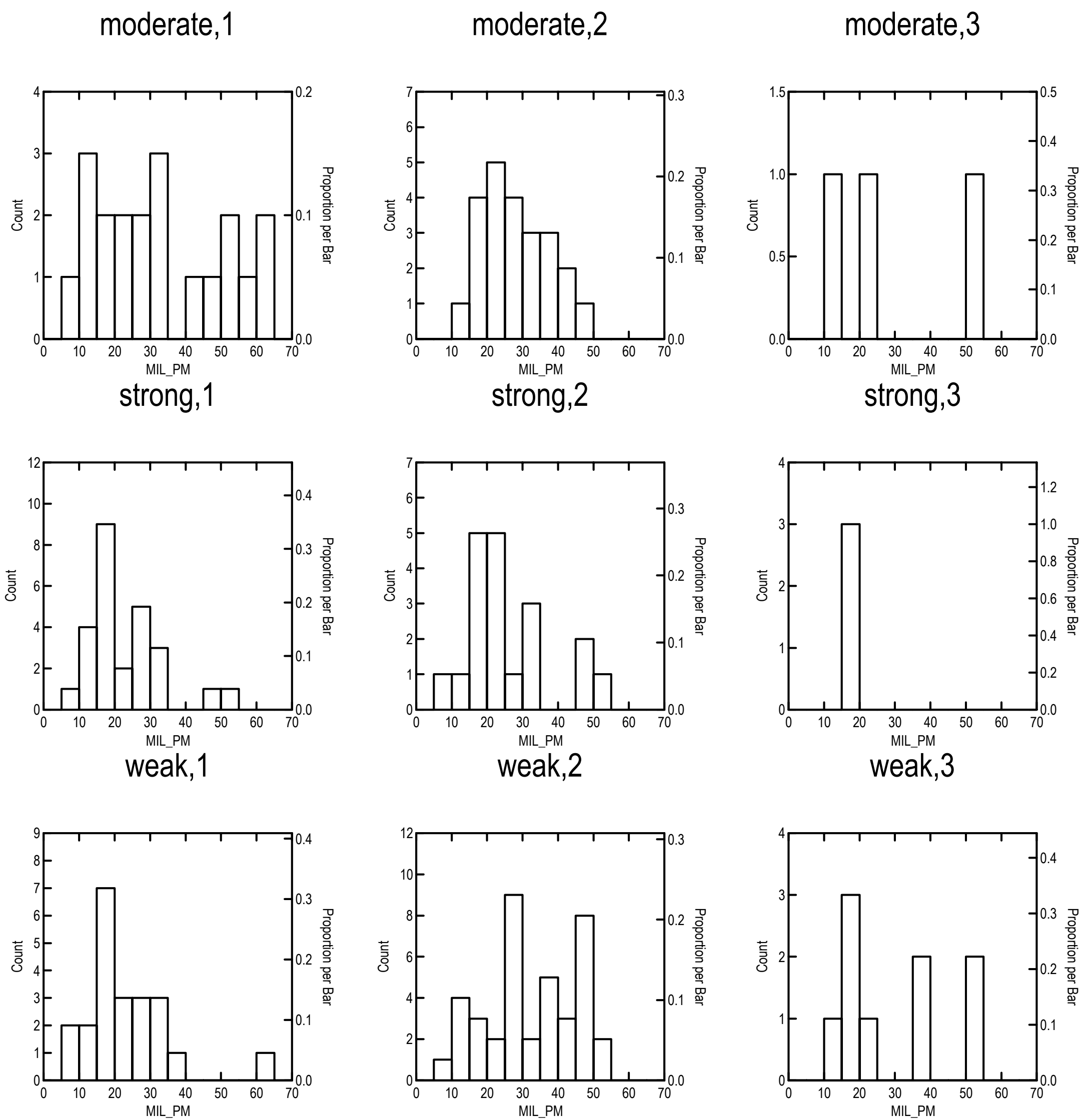

Figure A1-24. $PM_{2.5}$ concentrations at Milwaukee during May–September, 1999-2002, when an upper-level ridge is present by inversion strength (none = no inversion present, weak = 0-4°C inversion below 925 mb, moderate = 4-6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb) and inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb).

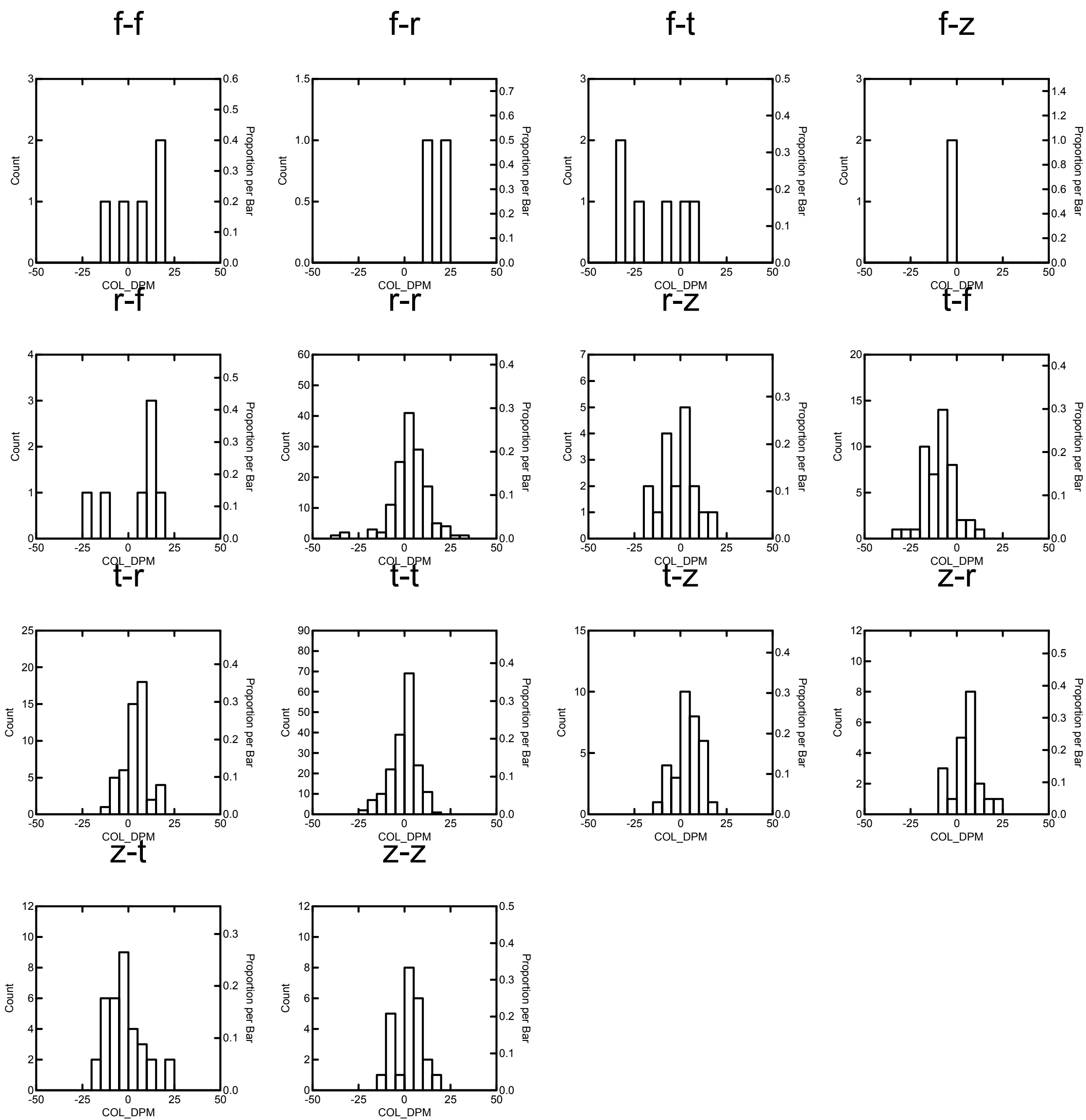

Figure A1-25. Changes in concentrations of $PM_{2.5}$ at Cleveland by two-day 500-mb combinations, such as a flat to flat regime in successive days in the upper left of the figure. (f = flat, z = zonal, t = trough and r = ridge).

Table A1-4. Frequency (% of time during May–September 1999-2002) of occurrence for each two-day trend in 500-mb type at Chicago, the probability of a change (% chance) in $PM_{2.5}$ concentration, the direction (increase ↑ or decrease ↓) and amount (in μg/m^3) of $PM_{2.5}$ change.

			2nd day			
			Flat	Ridge	Trough	Zonal
1st day	Flat	Frequency	< 2%	< 2%	< 2%	< 2%
	Ridge	Frequency	< 2%	26%	< 2%	4%
		Probability		70% ↓ 0-20 μg/m^3		70% ↓ 0-25 μg/m^3
	Trough	Frequency	8%	10%	28%	5%
		Probability	80% ↓ 0-30 μg/m^3	70% ↑ 0-35 μg/m^3	50/50 ↓/↑ 0-20 μg/m^3	75% ↑ 0-25 μg/m^3
	Zonal	Frequency	< 2%	3%	7%	4%
		Probability		70% ↑ 0-20 μg/m^3	50/50 ↓/↑ 0-20 μg/m^3	80% ↑ 0-25 μg/m^3

Table A1-5. Frequency (% of time during May–September 1999-2002) of occurrence for each two-day trend in 500-mb type at Milwaukee, the probability of a change (% chance) in $PM_{2.5}$ concentration, the direction (increase ↑ or decrease ↓) and amount (in μg/m^3) of $PM_{2.5}$ change.

			2nd day			
			Flat	Ridge	Trough	Zonal
1st day	Flat	Frequency	< 2%	< 2%	< 2%	< 2%
	Ridge	Frequency	< 2%	26%	< 2%	3%
		Probability		65% ↑ 0-20 μg/m^3		60% ↓ 0-0 μg/m^3
	Trough	Frequency	9%	9%	29%	6%
		Probability	85% ↓ 0-30 μg/m^3	70% ↑ 0-20 μg/m^3	50/50 ↓/↑ 0-20 μg/m^3	85% ↑ 0-25 μg/m^3
	Zonal	Frequency	< 2%	3%	7%	5%
		Probability		70% ↑ 0-20 μg/m^3	75% ↓ 0-25 μg/m^3	60% ↑ 0-20 μg/m^3

Table A1-6. Frequency (% of time during May–September, 1999-2002) of occurrence for each two-day trend in 500-mb type at Columbus; the probability of a change (% chance) in $PM_{2.5}$ concentration; and the direction (increase ↑ or decrease ↓) and amount (in μg/m^3) of $PM_{2.5}$ change.

			2nd day			
			Flat	Ridge	Trough	Zonal
1st day	Flat	Frequency	< 2%	< 2%	< 2%	< 2%
	Ridge	Frequency	< 2%	24%	< 2%	3%
		Probability		70% ↑ 0-30 μg/m^3		70% ↑/↓ 0-10 μg/m^3
	Trough	Frequency	8%	9%	29%	6%
		Probability	85% ↓ 0-30 μg/m^3	80% ↑ 0-20 μg/m^3	50/50 ↓/↑ 0-15 μg/m^3	80% ↑ 0-20 μg/m^3
	Zonal	Frequency	< 2%	3%	6%	4%
		Probability		80% ↑ 0-25 μg/m^3	65% ↓ 0-20 μg/m^3	70% ↑ 0-20 μg/m^3

Table A1-7. Frequency (% of time during May–September, 1999-2002) of occurrence for each two-day trend in 500-mb type at Cleveland; the probability of a change (% chance) in $PM_{2.5}$ concentration; and the direction (increase ↑ or decrease ↓) and amount (in μg/m^3) of $PM_{2.5}$ change.

			2nd day			
			Flat	Ridge	Trough	Zonal
1st day	Flat	Frequency	< 2%	< 2%	< 2%	< 2%
	Ridge	Frequency	< 2%	25%	< 2%	4%
		Probability		65% ↑ 0-30 μg/m^3		75% ↓ 0-20 μg/m^3
	Trough	Frequency	8%	9%	31%	6%
		Probability	90% ↓ 0-30 μg/m^3	80% ↑ 0-25 μg/m^3	50/50 ↓/↑ 0-20 μg/m^3	80% ↑ 0-25 μg/m^3
	Zonal	Frequency	< 2%	4%	6%	5%
		Probability		75% ↑ 0-25 μg/m^3	65% ↓ 0-20 μg/m^3	65% ↑ 0-20 μg/m^3

Table A1-8. Frequency (% of time during May–September, 1999-2002) of occurrence for each two-day trend in 500-mb type at Detroit; the probability of a change (% chance) in $PM_{2.5}$ concentration; and the direction (increase ↑ or decrease ↓) and amount (in $\mu g/m^3$) of $PM_{2.5}$ change.

			2nd day			
			Flat	Ridge	Trough	Zonal
1st day	Flat	Frequency	< 2%	< 2%	< 2%	< 2%
	Ridge	Frequency	< 2%	21%	< 2%	4%
		Probability		70% ↑ 0-30 $\mu g/m^3$		65% ↓/↑ 0-25 $\mu g/m^3$
	Trough	Frequency	10%	9%	34%	7%
		Probability	85% ↓ 0-40 $\mu g/m^3$	85% ↑ 0-25 $\mu g/m^3$	50/50 ↓/↑ 0-20 $\mu g/m^3$	75% ↑ 0-20 $\mu g/m^3$
	Zonal	Frequency	< 2%	4%	7%	5%
		Probability		75% ↑ 0-25 $\mu g/m^3$	65% ↓ 0-20 $\mu g/m^3$	65% ↑ 0-20 $\mu g/m^3$

Table A1-9. Frequency (% of time during May–September, 1999-2002) of occurrence for each two-day trend in 500-mb type at St. Louis; the probability of a change (% chance) in $PM_{2.5}$ concentration; and the direction (increase ↑ or decrease ↓) and amount (in $\mu g/m^3$) of $PM_{2.5}$ change.

			2nd day			
			Flat	Ridge	Trough	Zonal
1st day	Flat	Frequency	6%	3%	5%	< 2%
		Probability	50/50 ↓/↑ 50 $\mu g/m^3$	70% ↑ 0-25 $\mu g/m^3$	75% ↓ 0-25 $\mu g/m^3$	
	Ridge	Frequency	4%	30%	< 2%	< 2%
		Probability	60% ↑ 0-15 $\mu g/m^3$	60% ↑ 0-30 $\mu g/m^3$		
	Trough	Frequency	6%	7%	29%	3%
		Probability	70% ↓ 0-25 $\mu g/m^3$	85% ↑ 0-25 $\mu g/m^3$	50/50 ↓/↑ 0-20 $\mu g/m^3$)	65% ↑ 0-20 $\mu g/m^3$
	Zonal	Frequency	< 2%	< 2%	3%	< 2%
		Probability			75% ↓0-20 $\mu g/m^3$)	

ANALYSIS BY INVERSION TYPE

To determine how trends in inversion strength are related to changes in $PM_{2.5}$ concentrations, the change in $PM_{2.5}$ concentration by the two-day trend in inversion strength was examined. This knowledge of the likely change in $PM_{2.5}$ with the two-day trend in inversion strength can be used by forecasters. **Figure A1-26** shows results for Chicago: when an inversion changes from moderate to a strong, there is generally an increase of 0-20 $\mu g/m^3$ of $PM_{2.5}$; transitioning from a moderate inversion to no inversion usually results in a decrease in $PM_{2.5}$ concentrations. Results for other cities are given in Attachment 7. **Tables A1-10 through A1-15** detail the percent occurrence for each two-day inversion strength trend, as well as the probability and change in $PM_{2.5}$ that is likely to occur for all cities.

REGIONAL COUPLING ANALYSIS

Often $PM_{2.5}$ concentrations within a region will be similar; assessing which cities often have similar concentrations can offer forecasters additional information about regional $PM_{2.5}$ concentrations. Scatter plot matrices and their corresponding correlation matrices were generated for $PM_{2.5}$ concentrations between each of the six cities. Results are shown in **Table A1-16 and Figure A1-27**. These results show that Chicago often has concentrations similar to Cleveland, Detroit, and Milwaukee (r^2 values greater than 0.60), but not necessarily Columbus or St. Louis. Additionally, the correlation (r^2 value) between Chicago and Milwaukee is only 0.61; this is expected to be higher because they are near each other geographically, and both on Lake Michigan. This suggests that local emissions may play a large role in these cites. Other observations are that Columbus is often similar to Cleveland, while St. Louis generally follows a different pattern than the other cities. Examination of these trends is important to determine which cities are often under the same meteorological regime and will, therefore, have similar $PM_{2.5}$ concentrations.

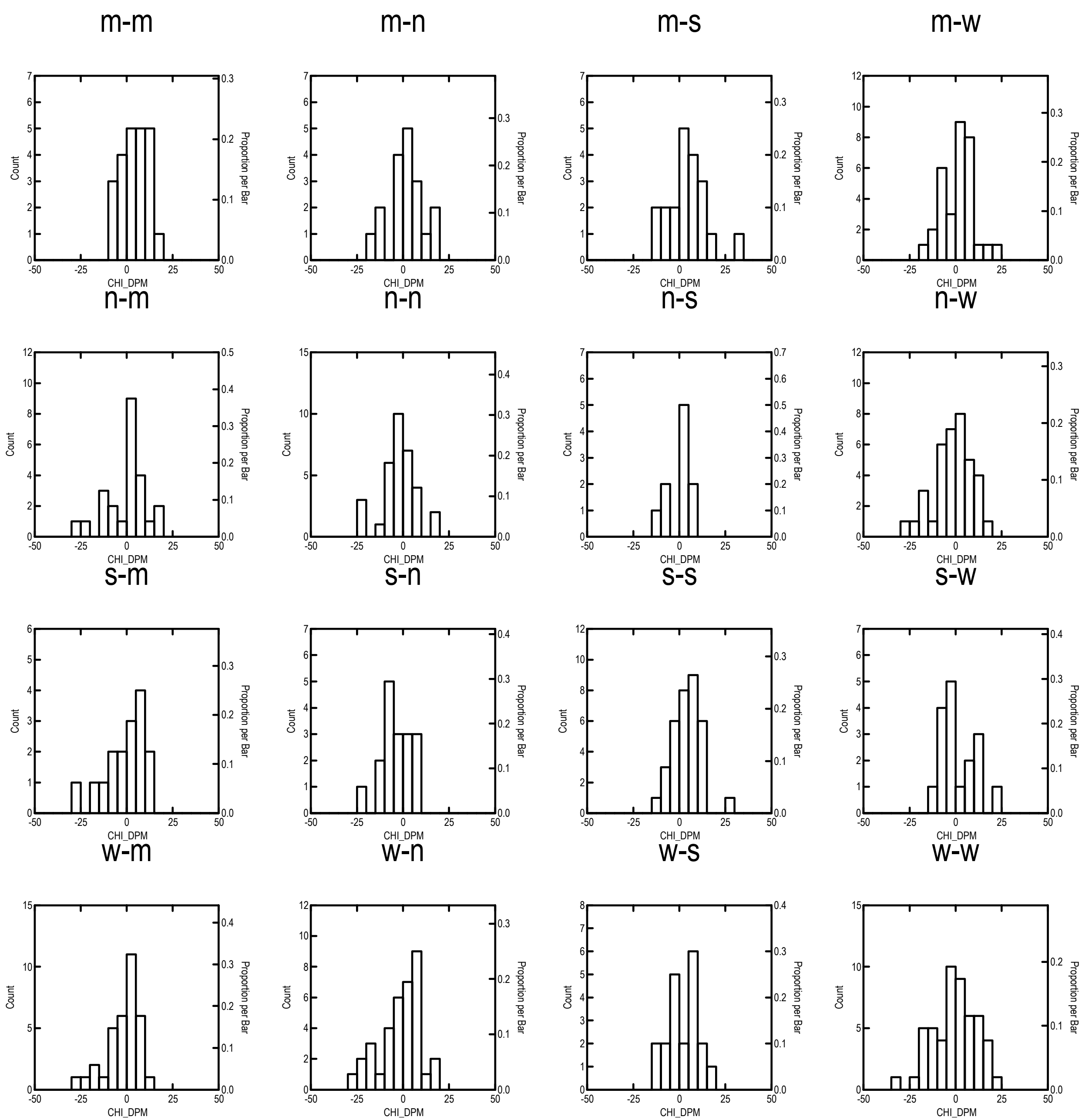

Figure A1-26. Changes in concentrations of $PM_{2.5}$ at Chicago by two-day inversion strength combinations, such as moderate inversion to moderate inversion in successive days in the upper left of the figure. (n = none, w = weak, m = moderate, s = strong).

Table A1-10. Frequency (% of time during May–September, 1999-2002) of occurrence for each two-day trend in inversion strength at Chicago; the probability of a change (% chance) in $PM_{2.5}$ concentration; and the direction (increase ↑ or decrease ↓) and amount (in μg/m³) of $PM_{2.5}$ change.

			2nd day			
			None	Weak	Moderate	Strong
1st day	None	Frequency	8%	9%	6%	2%
		Probability	65% ↓ 0-25 μg/m³	50/50 ↓/↑ 0-20 μg/m³	75% ↑ 0-20 μg/m³	70% ↑ 0-10 μg/m³
	Weak	Frequency	9%	12%	8%	5%
		Probability	50/50 ↓/↑ 0-20 μg/m³	50/50 ↓/↑ 0-25 μg/m³	50/50 ↓/↑ 0-25 μg/m³	55% ↑ 0-20 μg/m³
	Moderate	Frequency	4%	8%	5%	5%
		Probability	60% ↓ 0-20 μg/m³	50/50 ↓/↑ 0-25 μg/m³	70% ↑ 0-20 μg/m³	70% ↑ 0-20 μg/m³
	Strong	Frequency	4%	4%	8%	8%
		Probability	65% ↓ 0-25 μg/m³	60% ↓ 0-15 μg/m³	50/50 ↓/↑ 0-20 μg/m³	65% ↑ 0-30 μg/m³

Table A1-11. Frequency (% of time during May–September, 1999-2002) of occurrence for each two-day trend in inversion strength at Milwaukee; the probability of a change (% chance) in $PM_{2.5}$ concentration; and the direction (increase ↑ or decrease ↓) and amount (in μg/m³) of $PM_{2.5}$ change.

			2nd day			
			None	Weak	Moderate	Strong
1st day	None	Frequency	10%	8%	5%	3%
		Probability	70% ↓ 0-20 μg/m³	50/50 ↓/↑ 0-20 μg/m³	60% ↑ 0-15 μg/m³	70% ↑ 0-15 μg/m³
	Weak	Frequency	9%	11%	7%	5%
		Probability	75% ↓ 0-45 μg/m³	50/50 ↓/↑ 0-25 μg/m³	70% ↑ 0-25 μg/m³	70% ↑ 0-15 μg/m³
	Moderate	Frequency	4%	8%	4%	5%
		Probability	60% ↓ 0 – 25 μg/m³	50/50 ↓/↑ 0-25 μg/m³	50/50 ↓/↑ 0-25 μg/m³	70% ↑ 0-15 μg/m³
	Strong	Frequency	4%	6%	4%	7%
		Probability	55% ↓ 0-30 μg/m³	60% ↓ 0-30 μg/m³	60% ↑ 0-30 μg/m³	80% ↑ 0-25 μg/m³

Table A1-12. Frequency (% of time during May–September, 1999-2002) of occurrence for each two-day trend in inversion strength at Columbus; the probability of a change (% chance) in $PM_{2.5}$ concentration; and the direction (increase ↑ or decrease ↓) and amount (in μg/m³) of $PM_{2.5}$ change.

			2nd day			
			None	Weak	Moderate	Strong
1st day	None	Frequency	11%	10%	4%	2%
		Probability	50% ↓/↑ 0-20 μg/m³	60% ↑ 0-20 μg/m³	55% ↑ 0-15 μg/m³	60% ↑ 0-15 μg/m³
	Weak	Frequency	10%	14%	7%	5%
		Probability	60% ↓ 0-25 μg/m³	50% ↓/↑ 0-20 μg/m³	70% ↓ 0-20 μg/m³	60% ↑ 0-25 μg/m³
	Moderate	Frequency	4%	7%	6%	4%
		Probability	75% ↓ 0 – 25 μg/m³	50% ↓/↑ 0-20 μg/m³	70% ↓ 0-25 μg/m³	90% ↑ 0-25 μg/m³
	Strong	Frequency	4%	4%	4%	7%
		Probability	60% ↓ 0-5 μg/m³	75% ↓/↑ 0-10 μg/m³	80% ↑ 0-20 μg/m³	80% ↑ 0-25 μg/m³

Table A1-13. Frequency (% of time during May–September, 1999-2002) of occurrence for each two-day trend in inversion strength at Cleveland; the probability of a change (% chance) in $PM_{2.5}$ concentration; and the direction (increase ↑ or decrease ↓) and amount (in μg/m³) of $PM_{2.5}$ change.

			2nd day			
			None	Weak	Moderate	Strong
1st day	None	Frequency	14%	9%	7%	4%
		Probability	60% ↑ 0-30 μg/m³	60% ↑ 0-25 μg/m³	50% ↓/↑ 0-20 μg/m³	55% ↑ 0-15 μg/m³
	Weak	Frequency	10%	9%	5%	4%
		Probability	70% ↓ 0-30 μg/m³	70% ↓ 0-25 μg/m³	65% ↓ 0-20 μg/m³	80% ↑ 0-25 μg/m³
	Moderate	Frequency	6%	6%	3%	4%
		Probability	75% ↓ 0-20 μg/m³	75% ↓/↑ 0-10 μg/m³	70% ↑ 0-20 μg/m³	90% ↑ 0-20 μg/m³
	Strong	Frequency	4%	5%	5%	7%
		Probability	55% ↑ 0-15 μg/m³	60% ↑ 0-25 μg/m³	65% ↑ 0-25 μg/m³	85% ↑0-20 μg/m³

Table A1-14. Frequency (% of time during May–September, 1999-2002) of occurrence for each two-day trend in inversion strength at Detroit; the probability of a change (% chance) in $PM_{2.5}$ concentration; and the direction (increase ↑ or decrease ↓) and amount (in μg/m³) of $PM_{2.5}$ change.

			2nd day			
			None	Weak	Moderate	Strong
1st day	None	Frequency	14%	10%	7%	4%
		Probability	50% ↓/↑ 0-20 μg/m³	50% ↓/↑ 0-20 μg/m³	50% ↓/↑ 0-20 μg/m³	80% ↑ 0-20 μg/m³
	Weak	Frequency	10%	9%	5%	4%
		Probability	70% ↓ 0-25 μg/m³	50% ↓/↑ 0-20 μg/m³	75% ↑ 0-20 μg/m³	80% ↑ 0-15 μg/m³
	Moderate	Frequency	6%	6%	3%	4%
		Probability	60% ↓/↑ 0 – 25 μg/m³	50% ↓/↑ 0-20 μg/m³	80% ↑0-20 μg/m³	85% ↑ 0-15 μg/m³
	Strong	Frequency	4%	5%	5%	7%
		Probability	55% ↑ 0-25 μg/m³	85% ↑ 0-25 μg/m³	75% ↑0-25 μg/m³	80% ↑ 0-25 μg/m³

Table A1-15. Frequency (% of time during May–September, 1999-2002) of occurrence for each two-day trend in inversion strength at St. Louis; the probability of a change (% chance) in $PM_{2.5}$ concentration; and the direction (increase ↑ or decrease ↓) and amount (in μg/m³) of $PM_{2.5}$ change.

			2nd day			
			None	Weak	Moderate	Strong
1st day	None	Frequency	6%	8%	4%	2%
		Probability	50% ↓/↑ 0-25 μg/m³	75% ↑ 0-20 μg/m³	70% ↑ 0-15 μg/m³	80% ↑ 0-10 μg/m³
	Weak	Frequency	8%	17%	9%	4%
		Probability	60% ↑ 0-20 μg/m³	50% ↓/↑ 0-20 μg/m³	70% ↑ 0-15 μg/m³	65% ↑ 0-25 μg/m³
	Moderate	Frequency	4%	9%	7%	5%
		Probability	75% ↓ 0 – 20 μg/m³	80% ↓/↑ 0-10 μg/m³	65% ↓/↑ 0-5 μg/m³	70% ↑ 0-20 μg/m³
	Strong	Frequency	2%	5%	5%	7%
		Probability	80% ↓ 0-20 μg/m³	70% ↓ 0-15 μg/m³	75% ↓/↑ 0-10 μg/m³	80% ↑0-30 μg/m³

Table A1-16. Correlation (r^2) matrix of $PM_{2.5}$ concentrations during May-September, 1999-2002, at Milwaukee (MIL), Chicago (CHI), Cleveland (CLV), Columbus (COL), Detroit (DET), and St. Louis (STL).

	MIL	CHI	CLV	COL	DET
MIL	1.000				
CHI	0.61	1.000			
CLV	0.52	0.72	1.000		
COL	0.41	0.57	0.73	1.000	
DET	0.57	0.76	0.83	0.68	1.000
STL	0.39	0.55	0.39	0.40	0.41

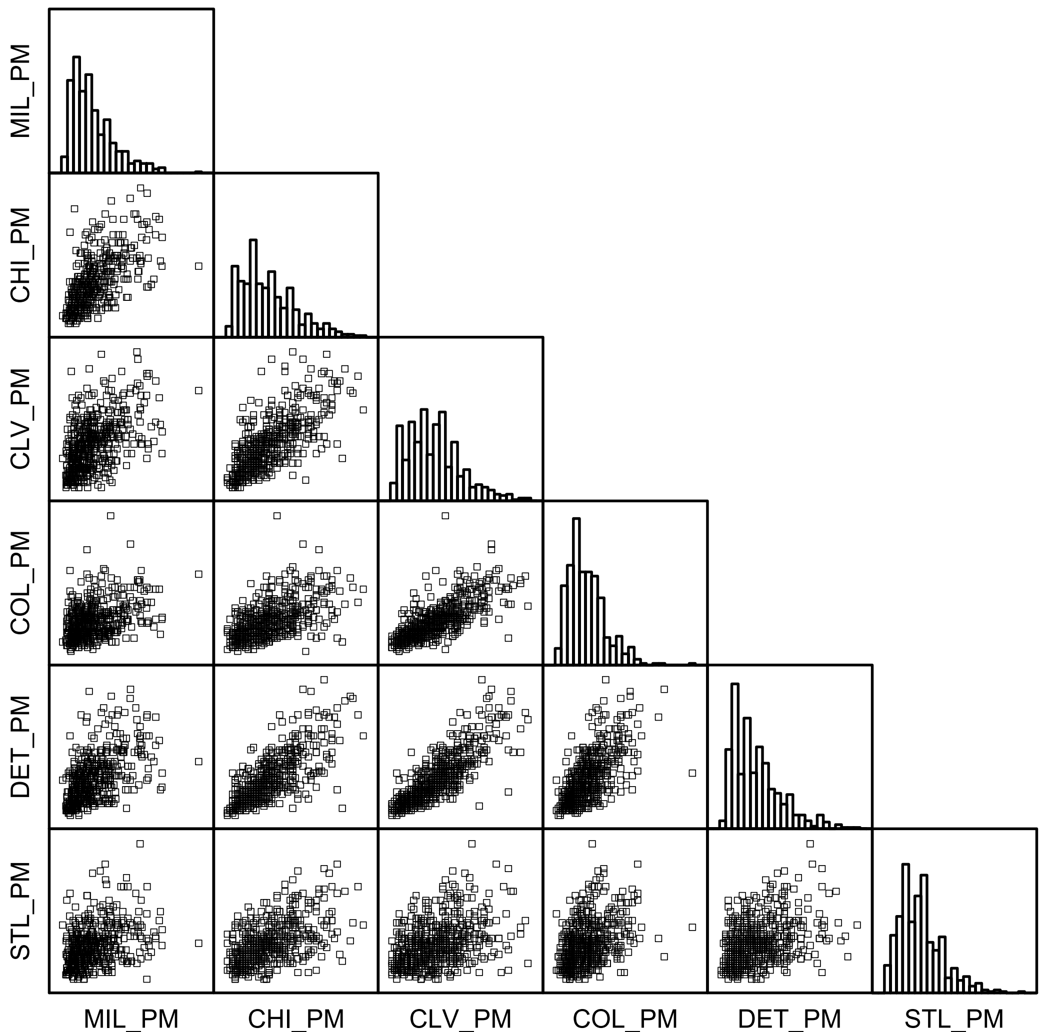

Figure A1-27. Scatter plot matrix of $PM_{2.5}$ concentrations during May-September, 1999-2002, at Milwaukee (MIL), Chicago (CHI), Cleveland (CLV), Columbus (COL), Detroit (DET), and St. Louis (STL).

Attachment 2

$PM_{2.5}$ Concentrations by Synoptic Type

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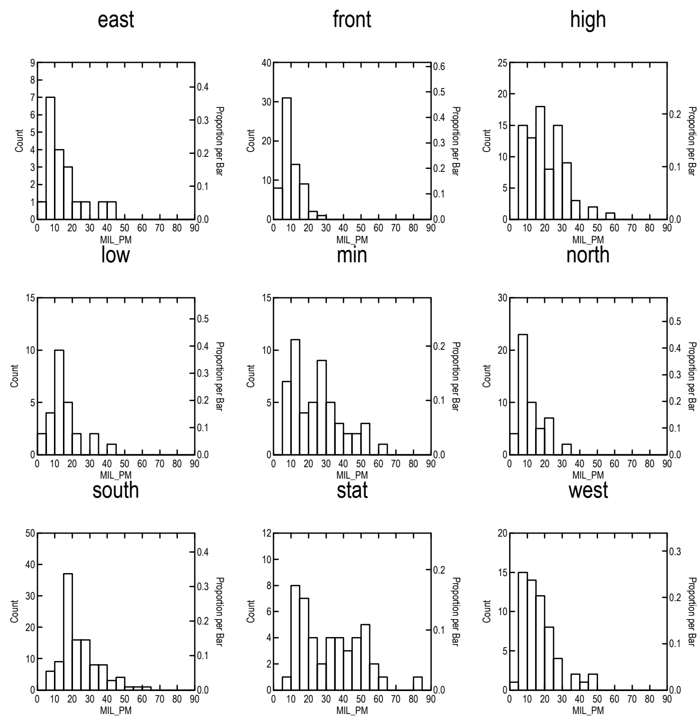

Figure A2-1. $PM_{2.5}$ concentrations by surface type at Milwaukee, May-September, 1999-2002.

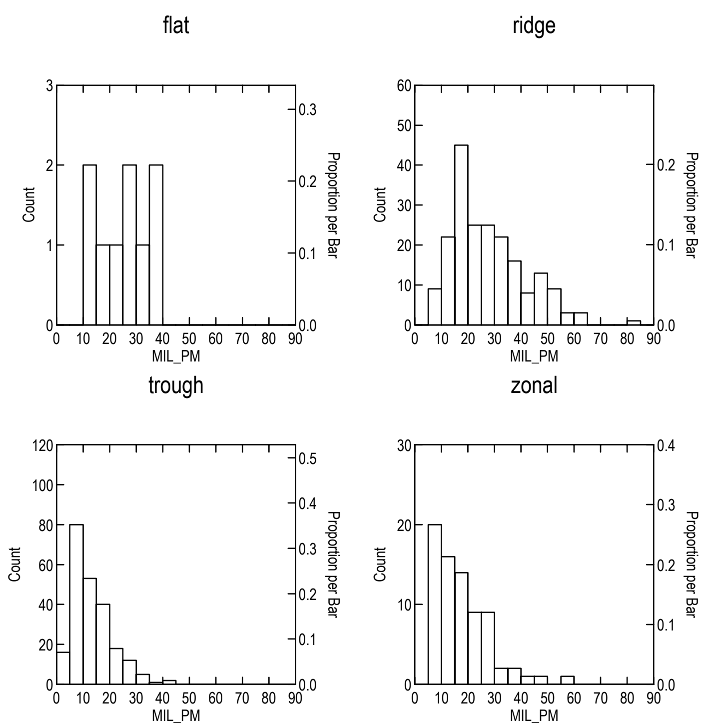

Figure A2-2. $PM_{2.5}$ concentrations by 500-mb type at Milwaukee, May-September, 1999-2002.

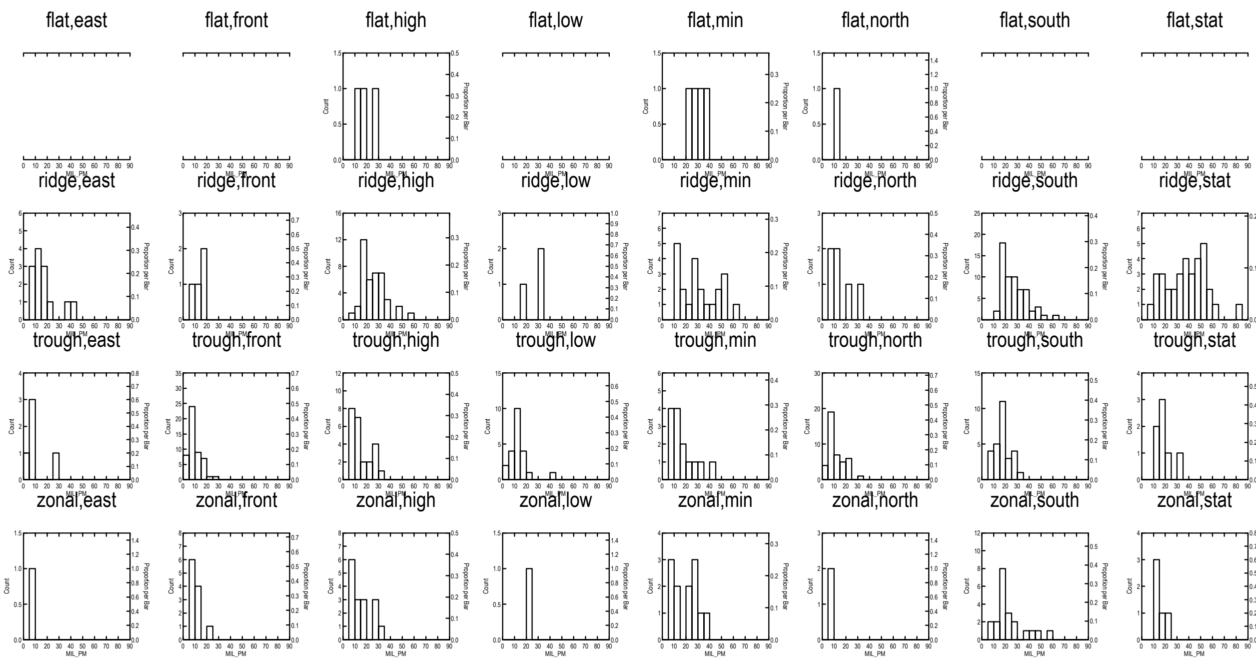

Figure A2-3. $PM_{2.5}$ concentrations by surface and 500-mb type at Milwaukee, May-September, 1999-2002. Blank plot indicates no occurrence.

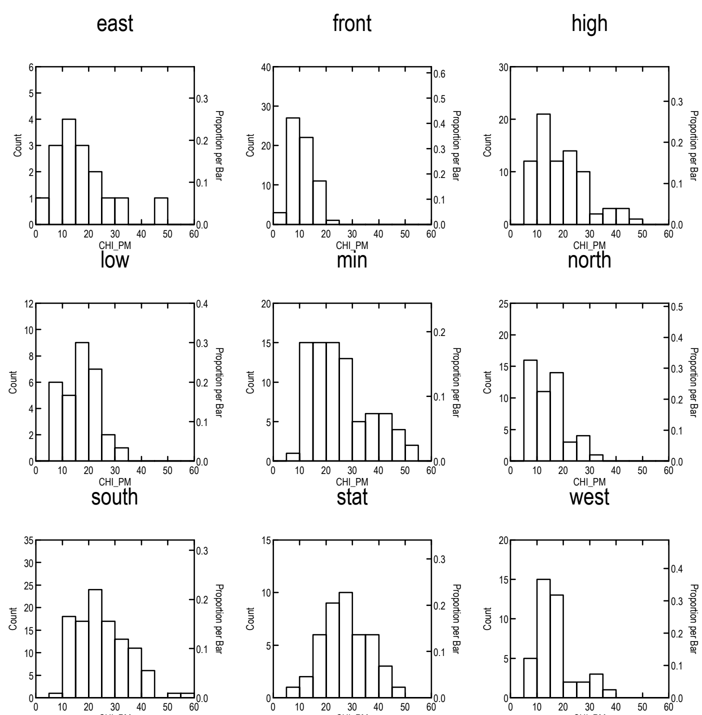

Figure A2-4. $PM_{2.5}$ concentrations by surface type at Chicago, May-September, 1999-2002.

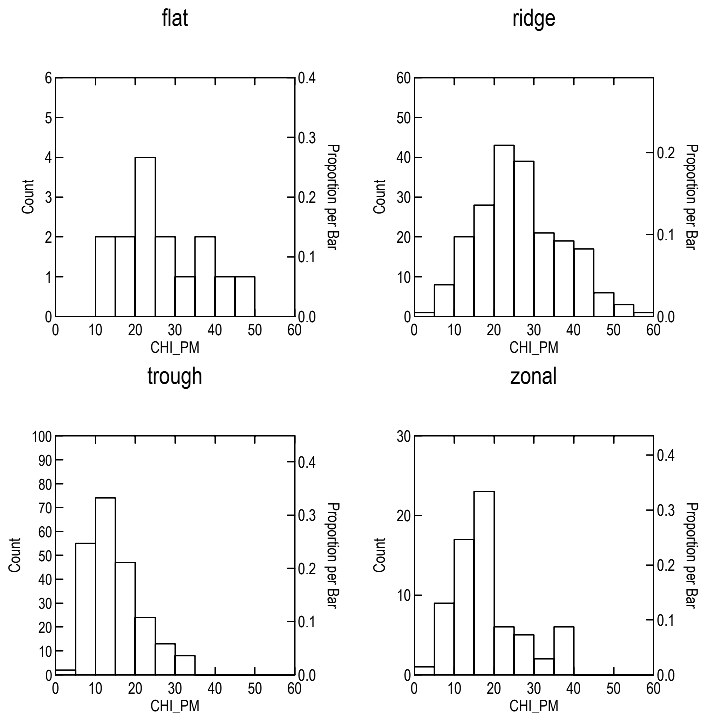

Figure A2-5. $PM_{2.5}$ concentrations by 500-mb type at Chicago, May-September, 1999-2002.

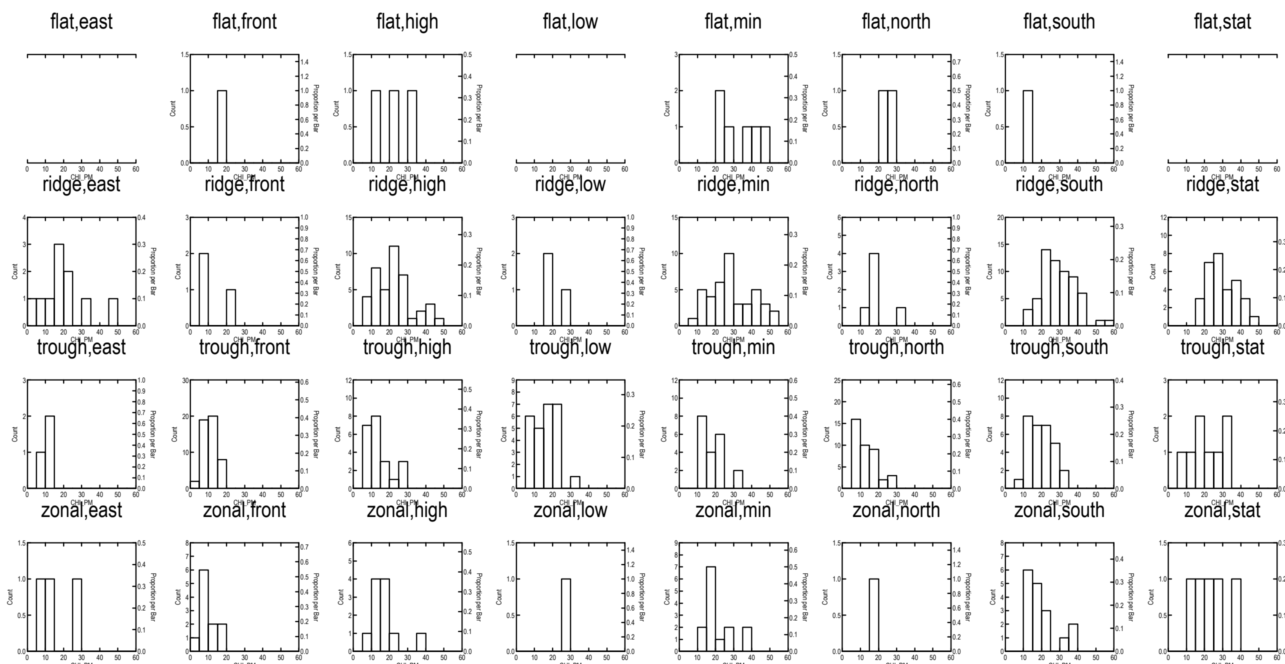

Figure A2-6. $PM_{2.5}$ concentrations by surface and 500-mb type at Chicago, May-September, 1999-2002. Blank plot indicates no occurrence.

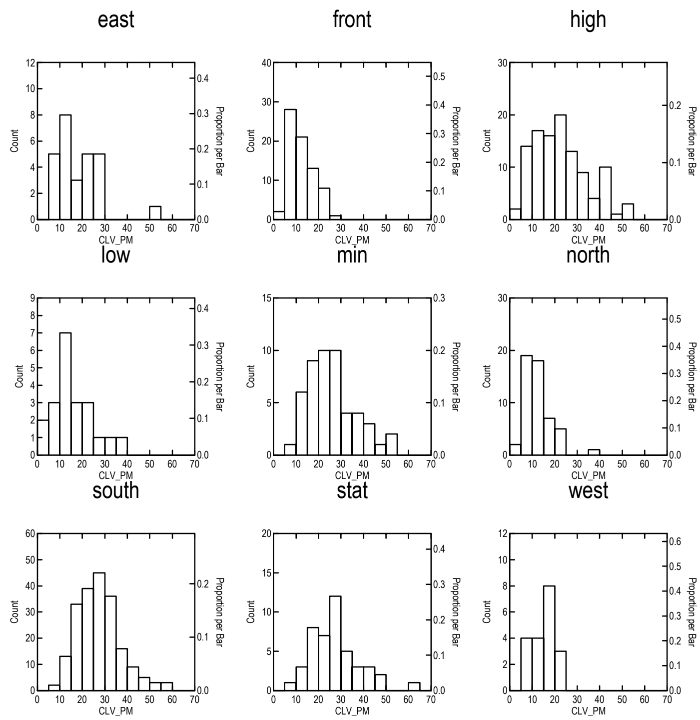

Figure A2-7. $PM_{2.5}$ concentrations by surface type at Cleveland, May-September, 1999-2002.

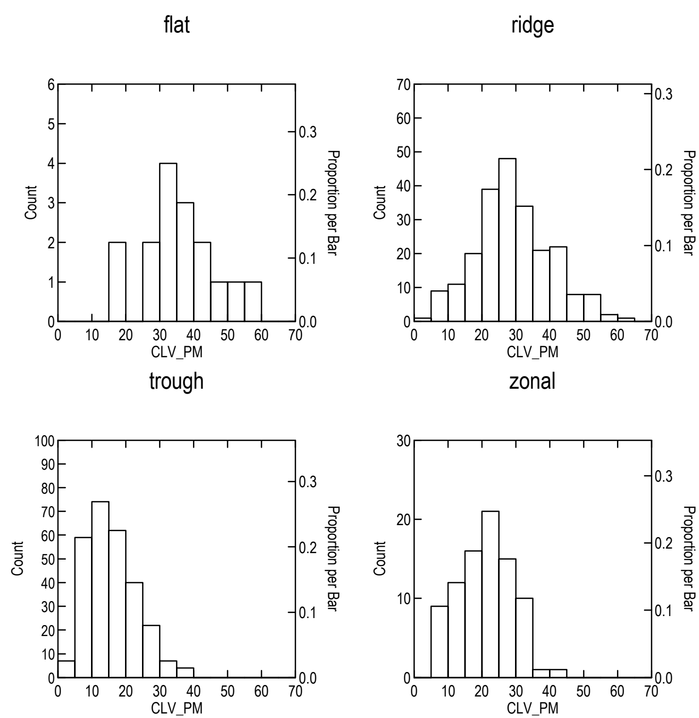

Figure A2-8. $PM_{2.5}$ concentrations by 500-mb type at Cleveland, May-September, 1999-2002.

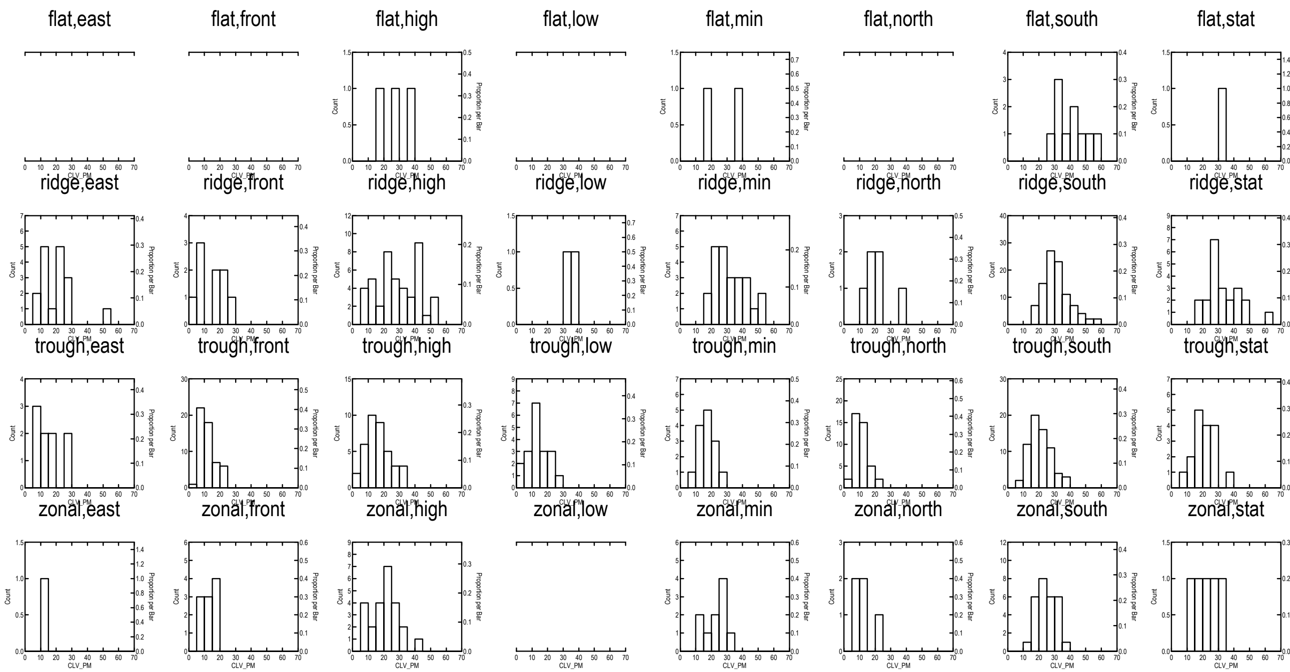

Figure A2-9. $PM_{2.5}$ concentrations by surface and 500-mb type at Cleveland, May-September, 1999-2002. Blank plot indicates no occurrence.

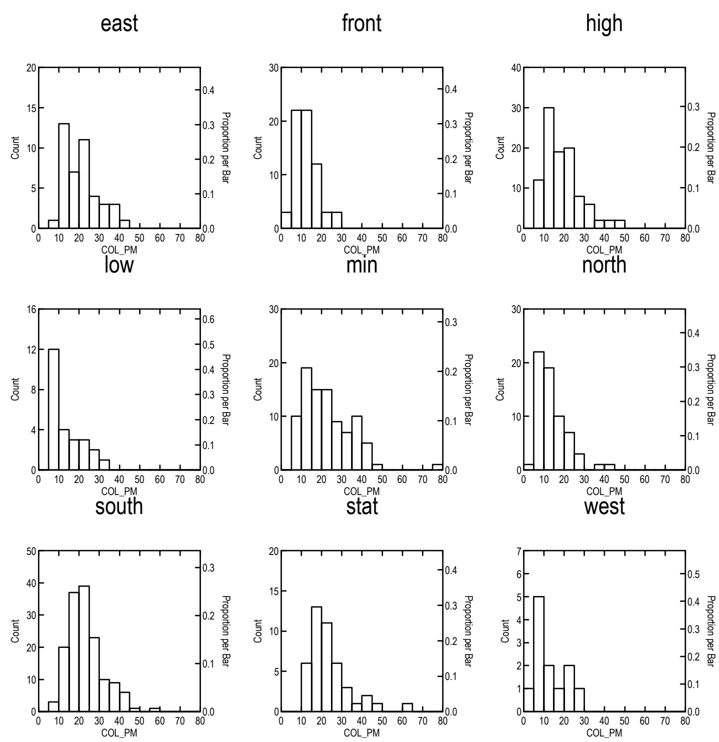

Figure A2-10. $PM_{2.5}$ concentrations by surface type at Columbus, May-September, 1999-2002.

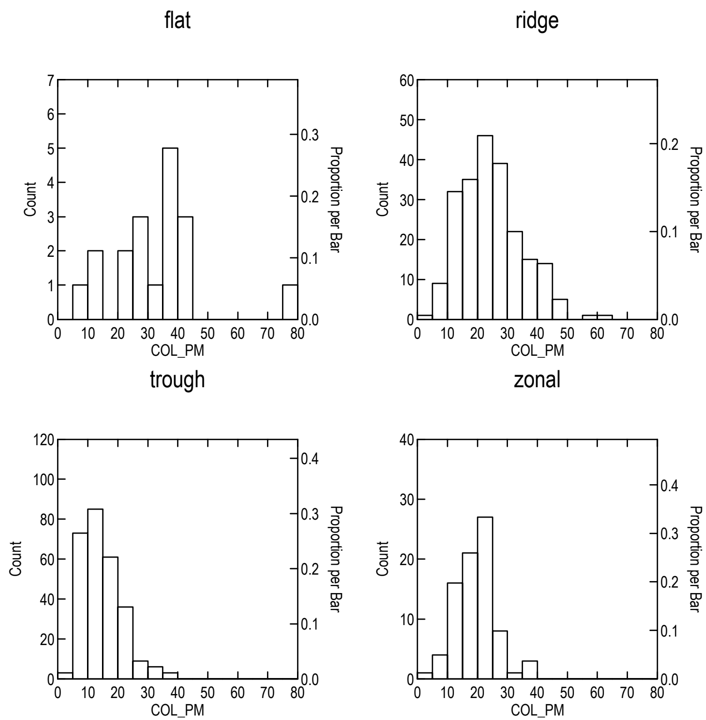

Figure A2-11. $PM_{2.5}$ concentrations by 500-mb type at Columbus, May-September, 1999-2002.

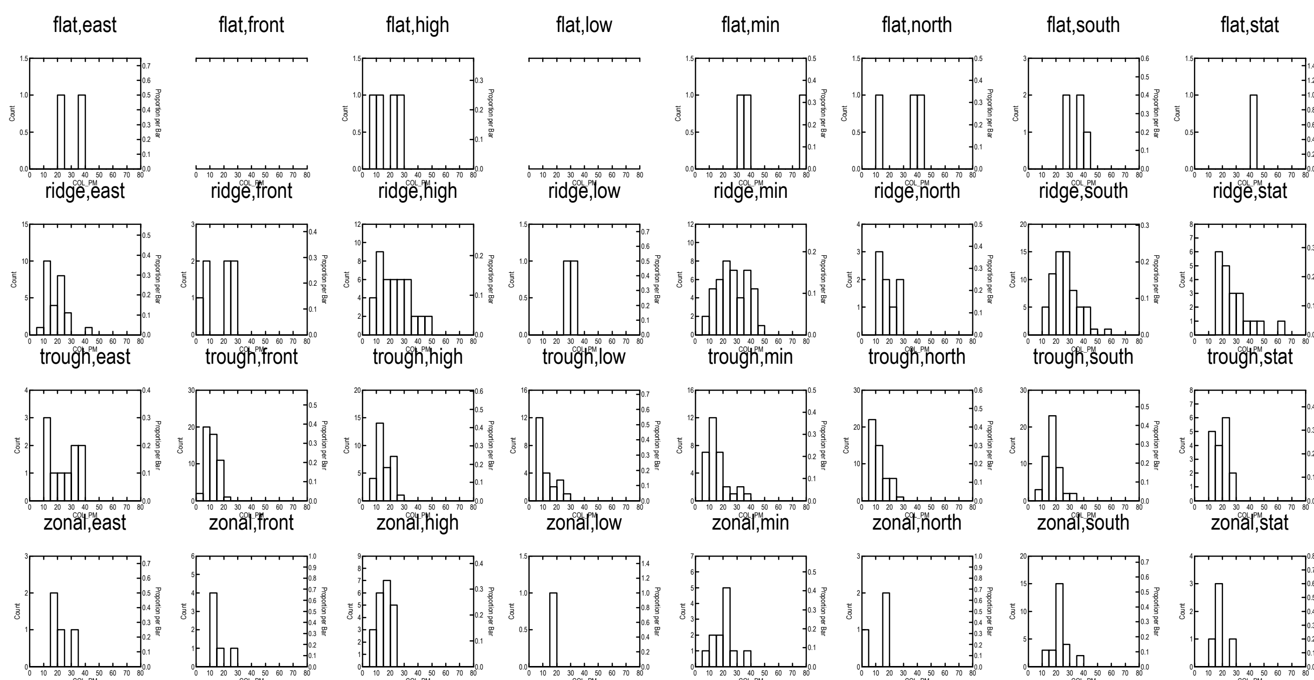

Figure A2-12. $PM_{2.5}$ concentrations by surface and 500-mb type at Columbus, May-September, 1999-2002. Blank plot indicates no occurrence.

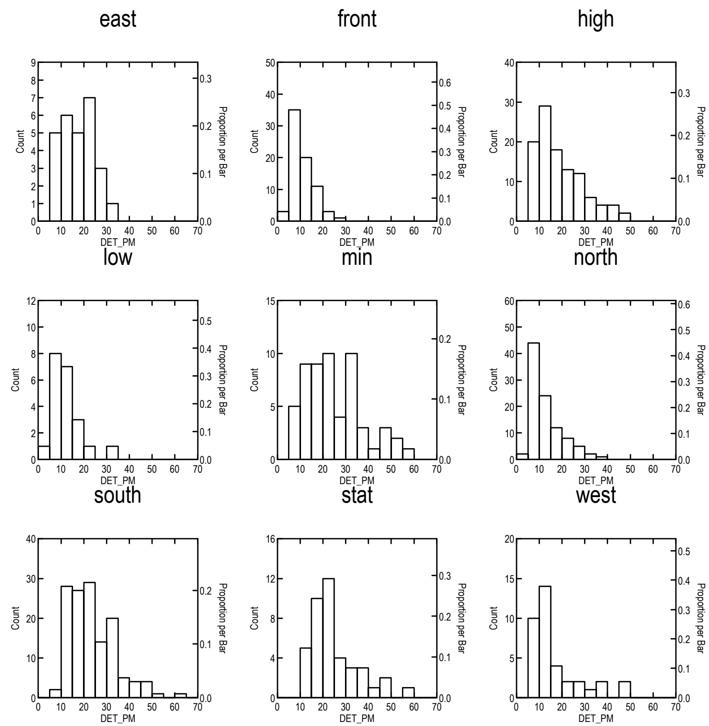

Figure A2-13. $PM_{2.5}$ concentrations by surface type at Detroit, May-September, 1999-2002.

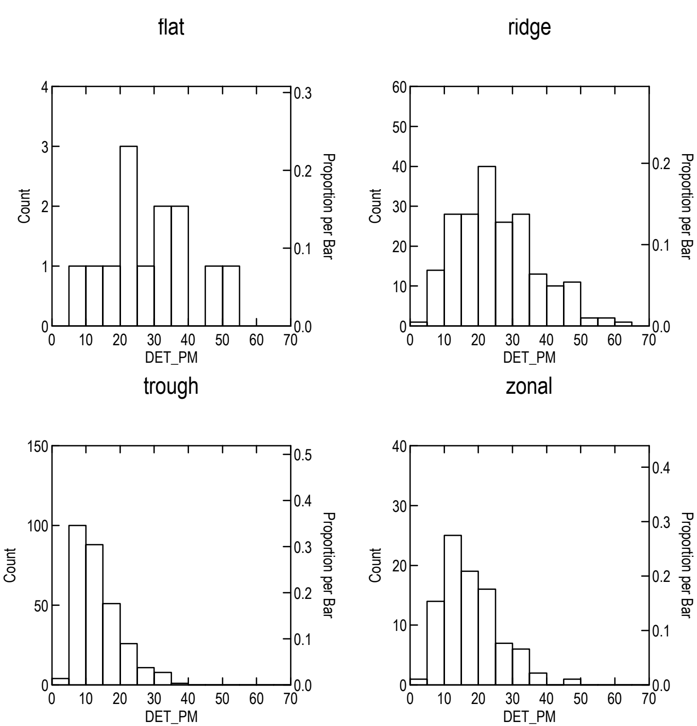

Figure A2-14. $PM_{2.5}$ concentrations by 500-mb type at Detroit, May-September, 1999-2002.

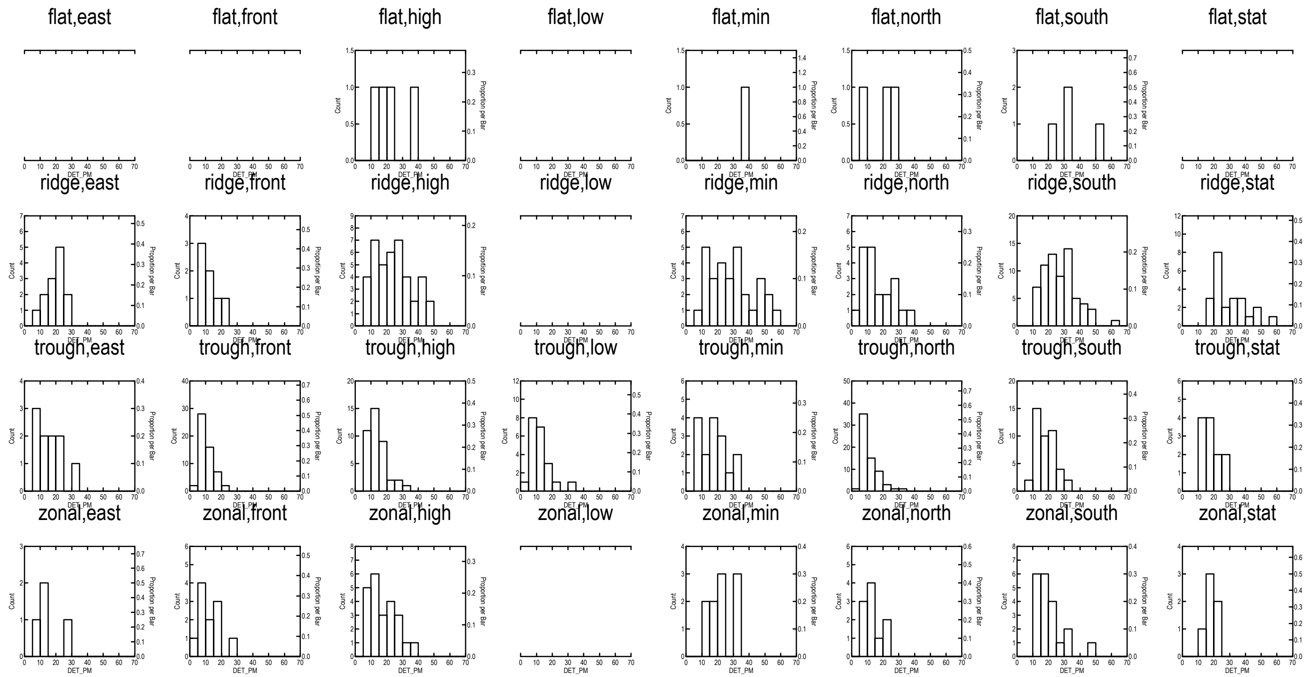

Figure A2-15. $PM_{2.5}$ concentrations by surface and 500-mb type at Detroit, May-September, 1999-2002. Blank plot indicates no occurrence.

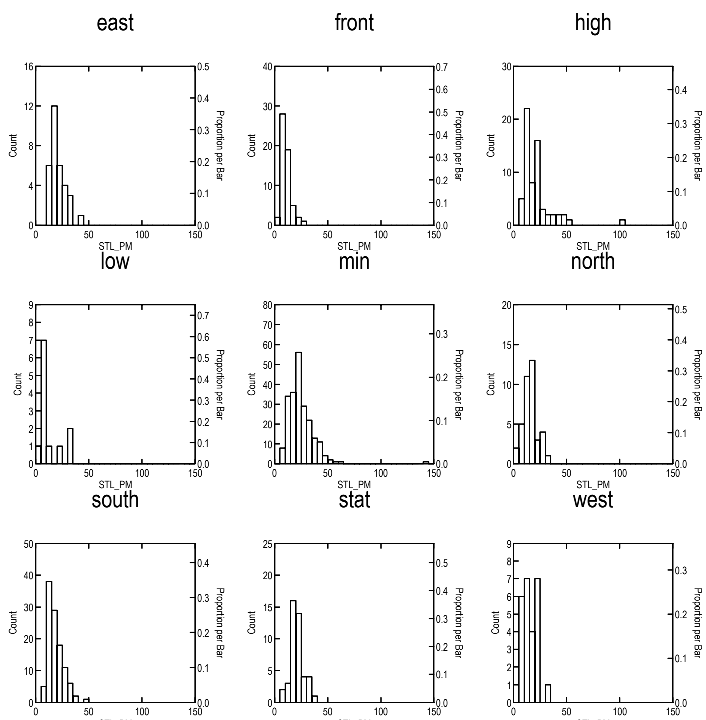

Figure A2-16. $PM_{2.5}$ concentrations by surface type at St. Louis, May-September, 1999-2002.

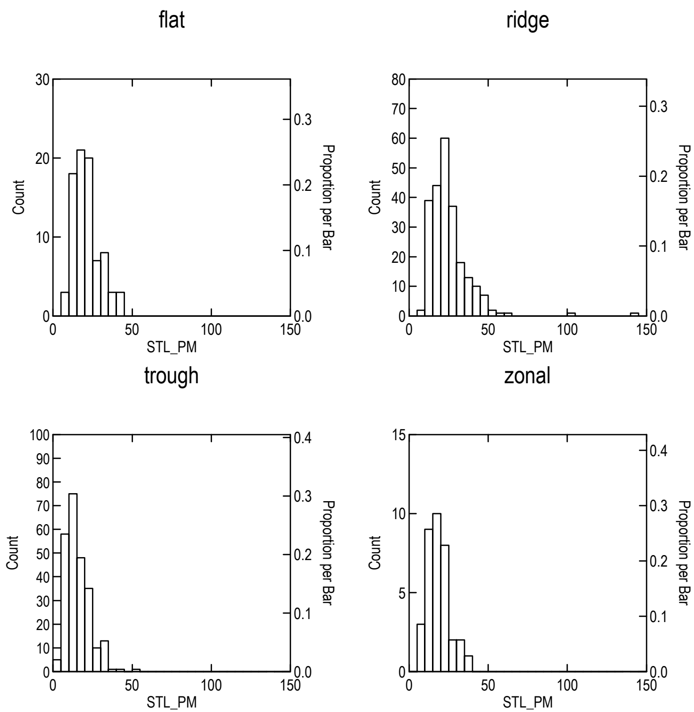

Figure A2-17. $PM_{2.5}$ concentrations by 500-mb type at St. Louis, May-September, 1999-2002.

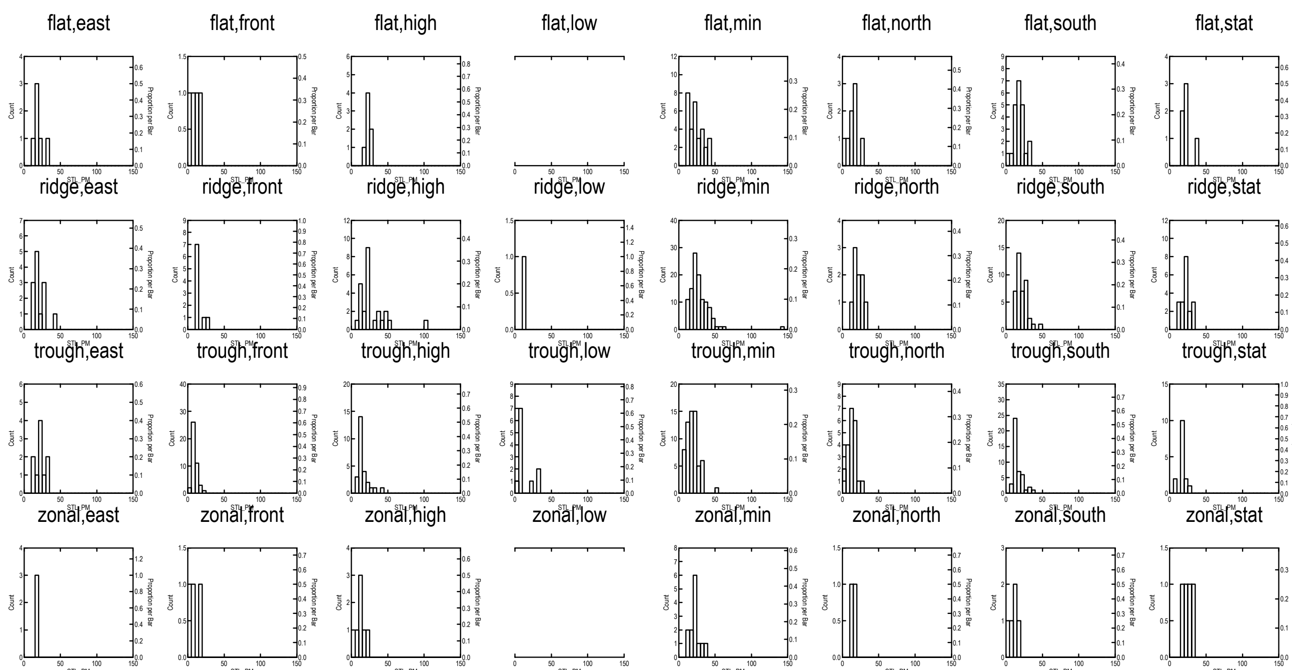

Figure A2-18. $PM_{2.5}$ concentrations by surface and 500-mb type at St. Louis, May-September, 1999-2002. Blank plot indicates no occurrence.

Attachment 3

$PM_{2.5}$ Concentrations by Inversion Type

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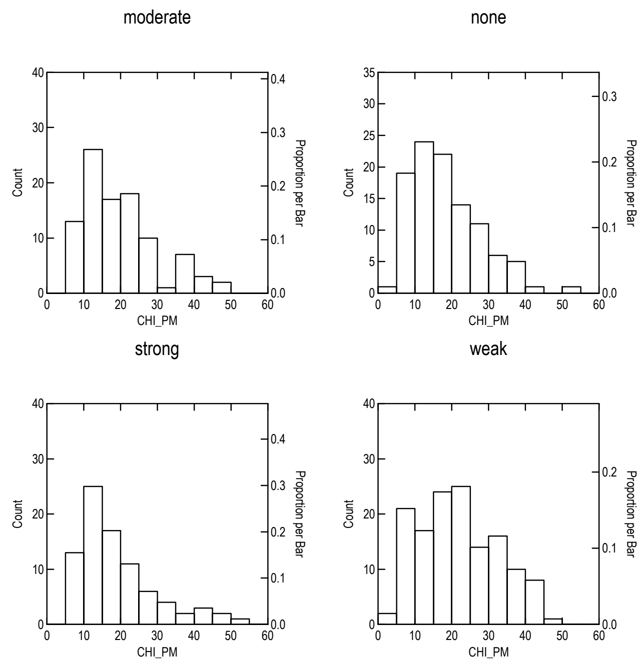

Figure A3-1. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Chicago during May-September, 1999-2002, by inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb).

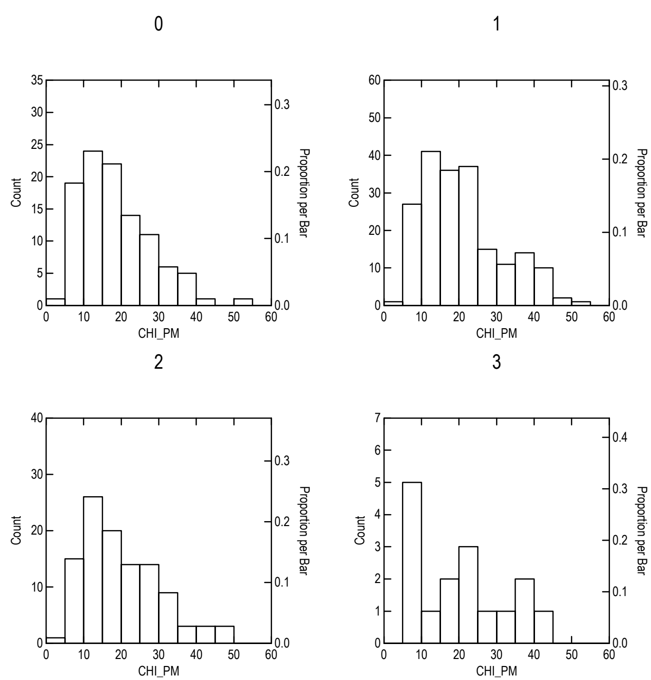

Figure A3-2. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Chicago during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb).

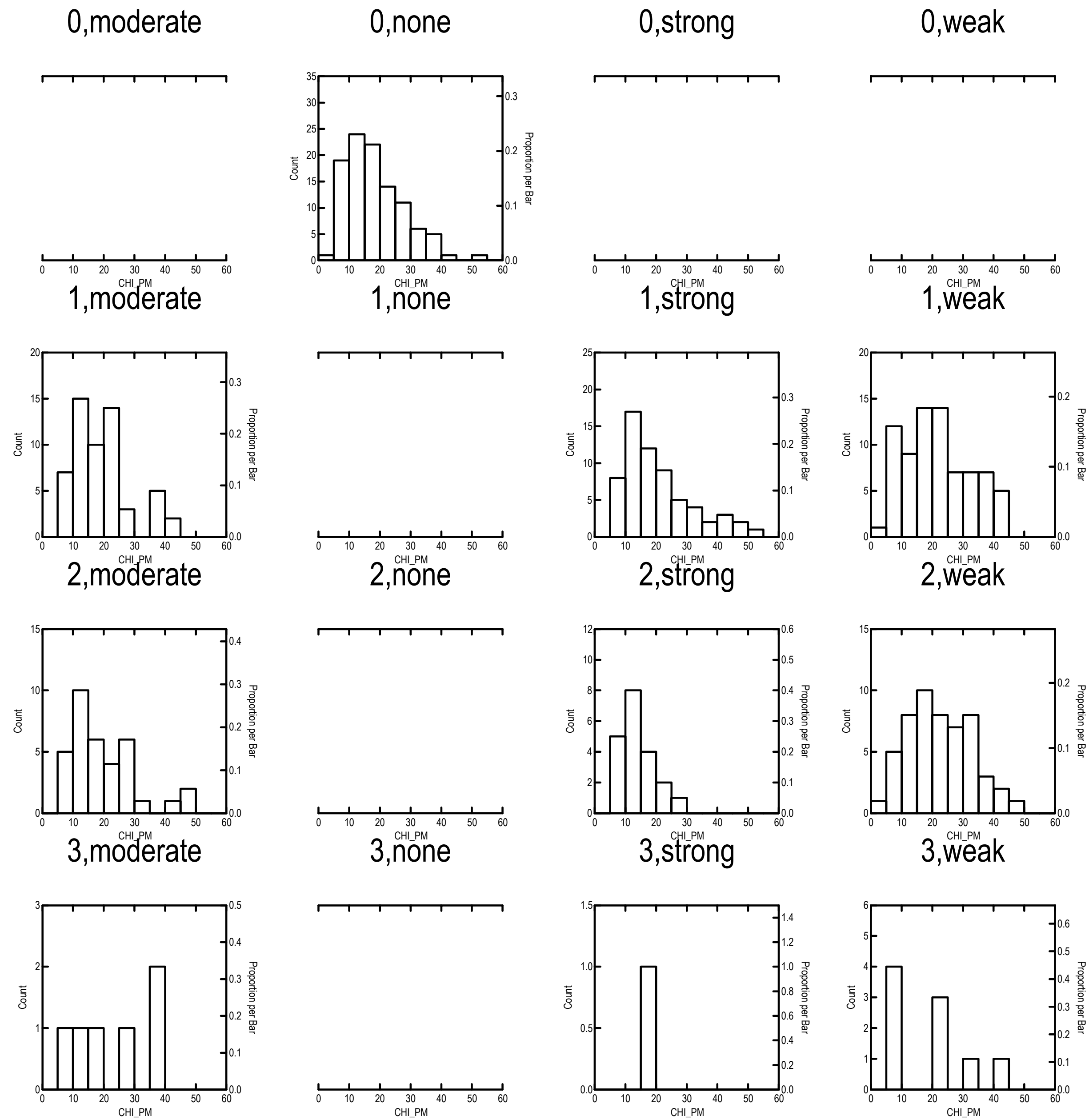

Figure A3-3. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Chicago during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb) and inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb). Blank plot indicates no occurrence.

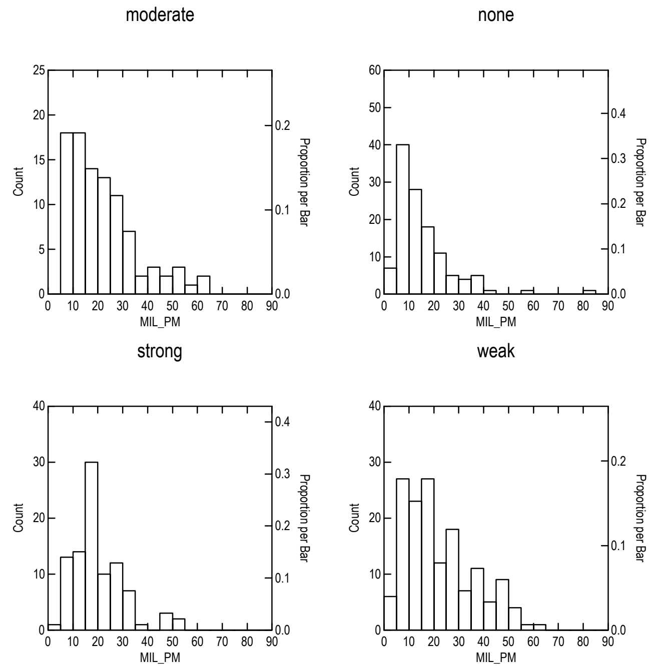

Figure A3-4. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Milwaukee during May-September, 1999-2002, by inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb).

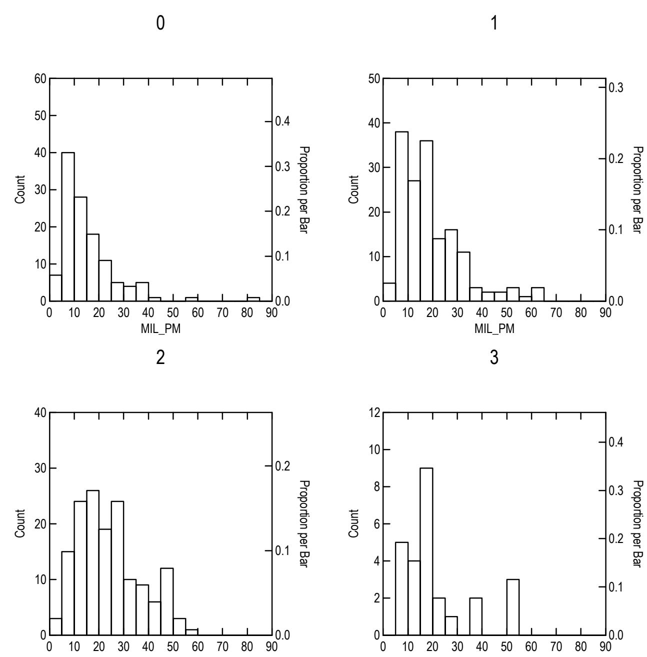

Figure A3-5. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Milwaukee during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb).

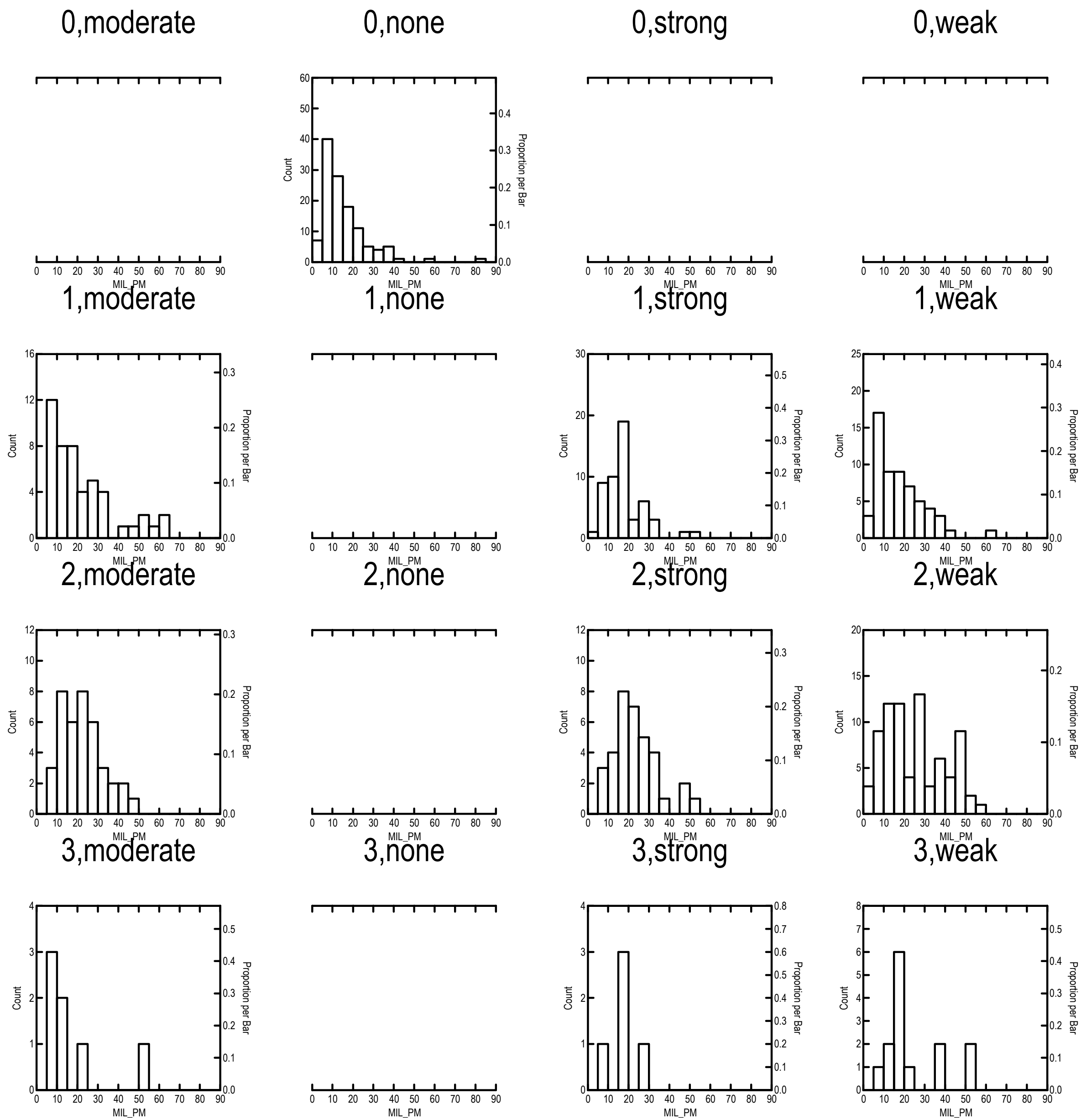

Figure A3-6. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Milwaukee during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb) and inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb). Blank plot indicates no occurrence.

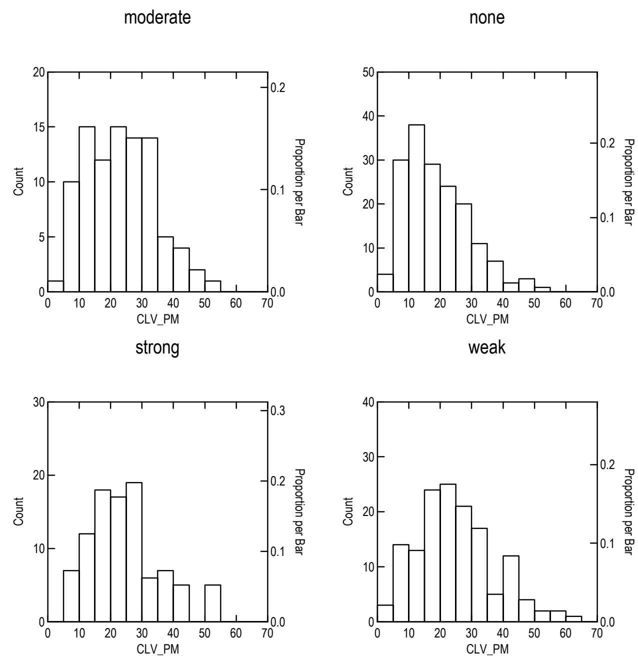

Figure A3-7. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Cleveland during May-September, 1999-2002, by inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb).

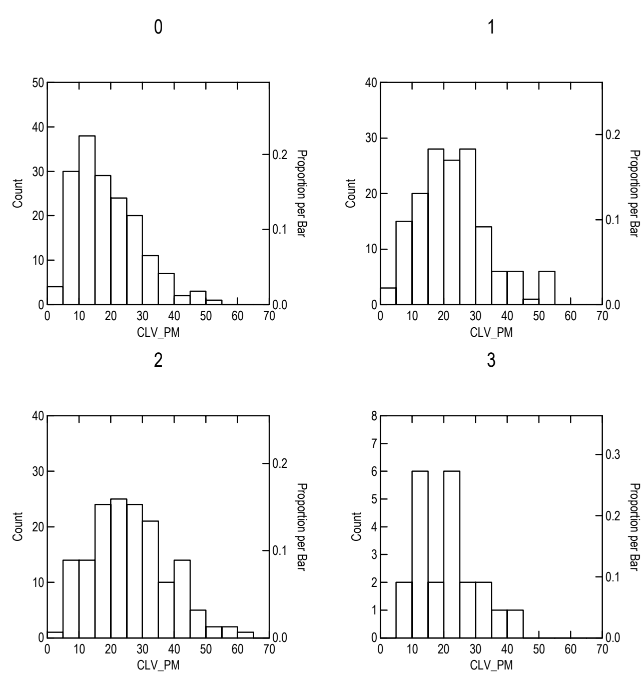

Figure A3-8. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Cleveland during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb).

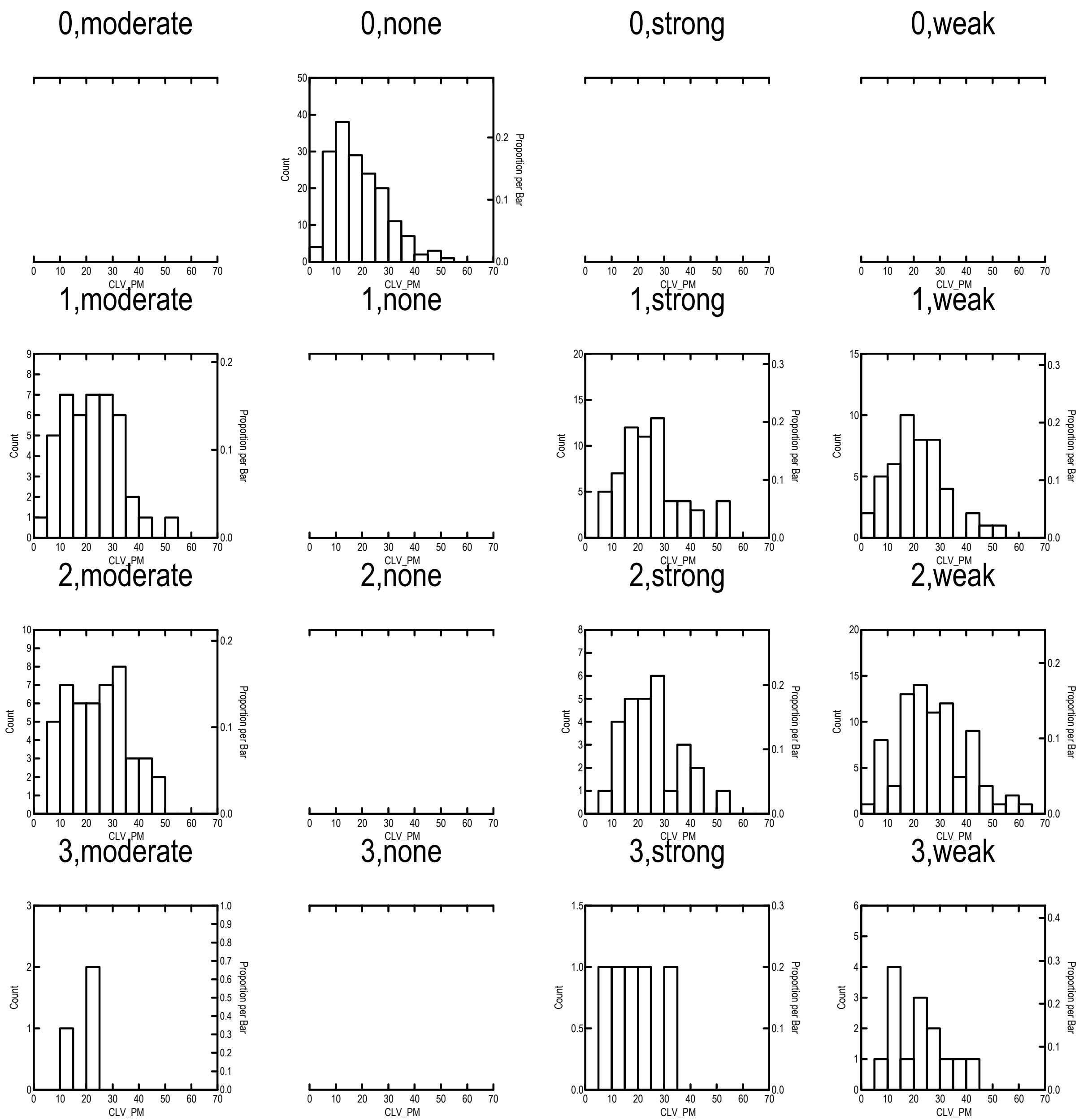

Figure A3-9. $PM_{2.5}$ concentrations (µg/m^3) at Cleveland during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb) and inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb). Blank plot indicates no occurrence.

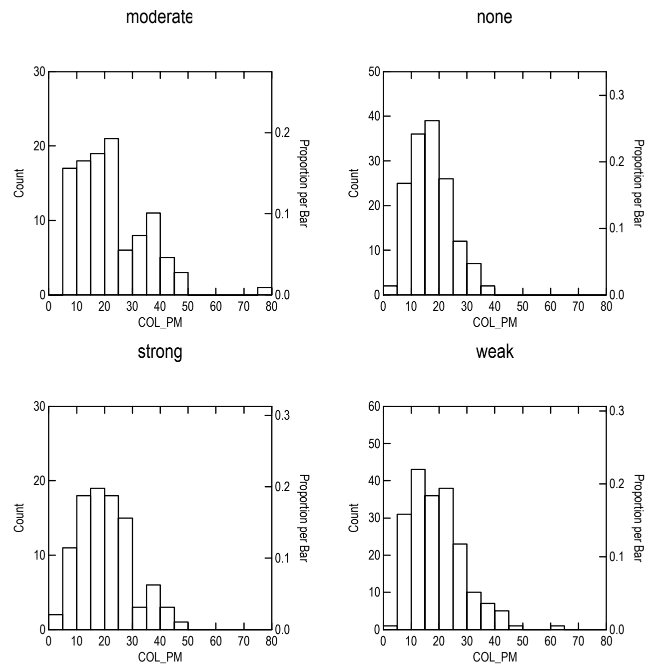

Figure A3-10. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Columbus during May-September, 1999-2002, by inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb).

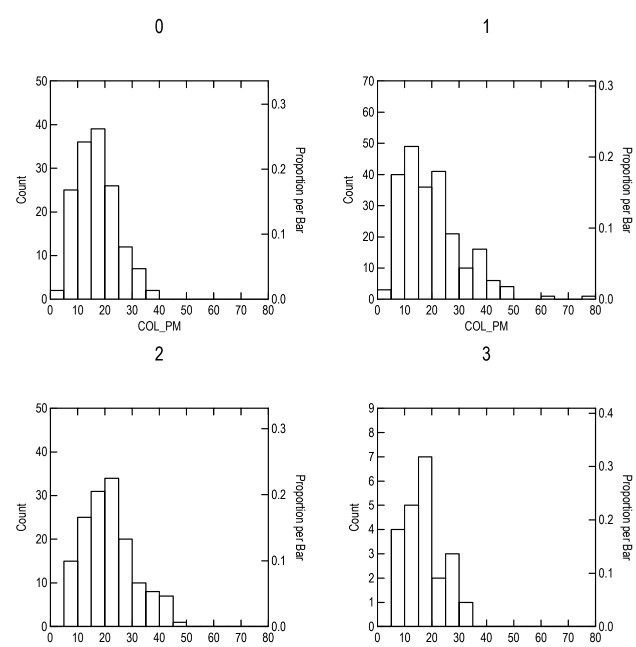

Figure A3-11. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Columbus during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb).

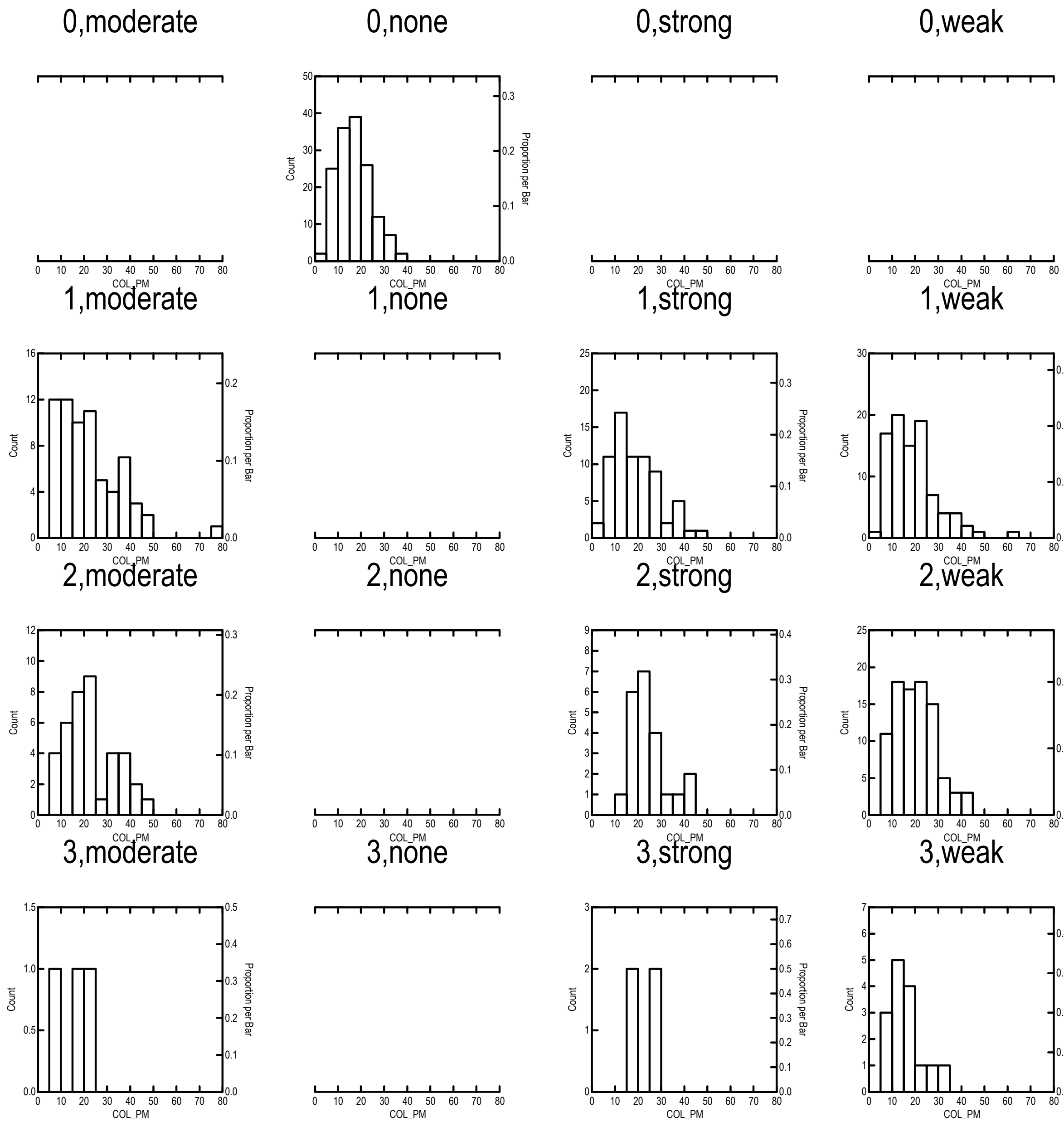

Figure A3-12. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Columbus during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb) and inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb). Blank plot indicates no occurrence.

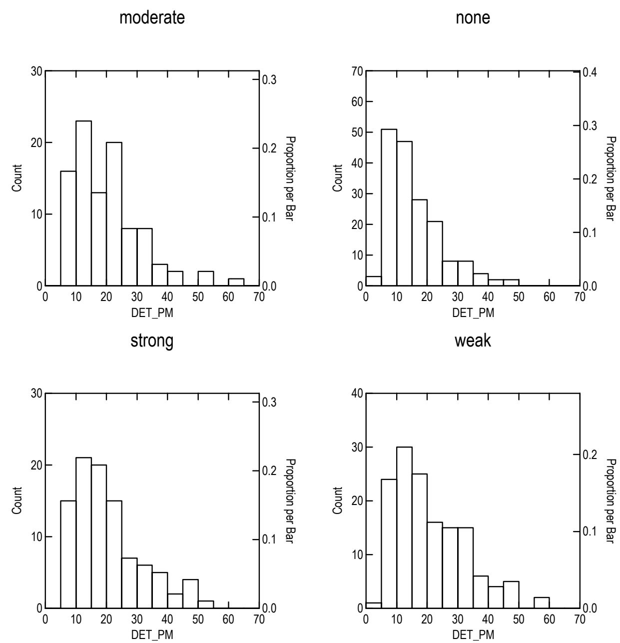

Figure A3-13. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Detroit during May-September, 1999-2002, by inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb).

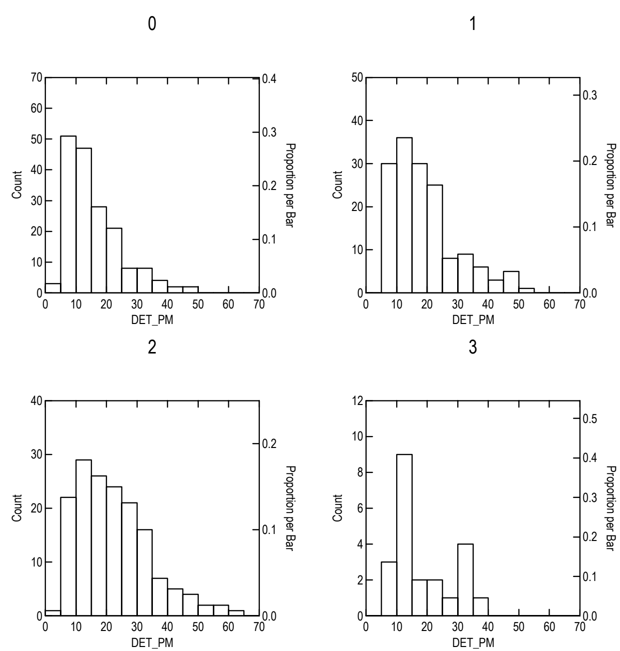

Figure A3-14. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Detroit during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb).

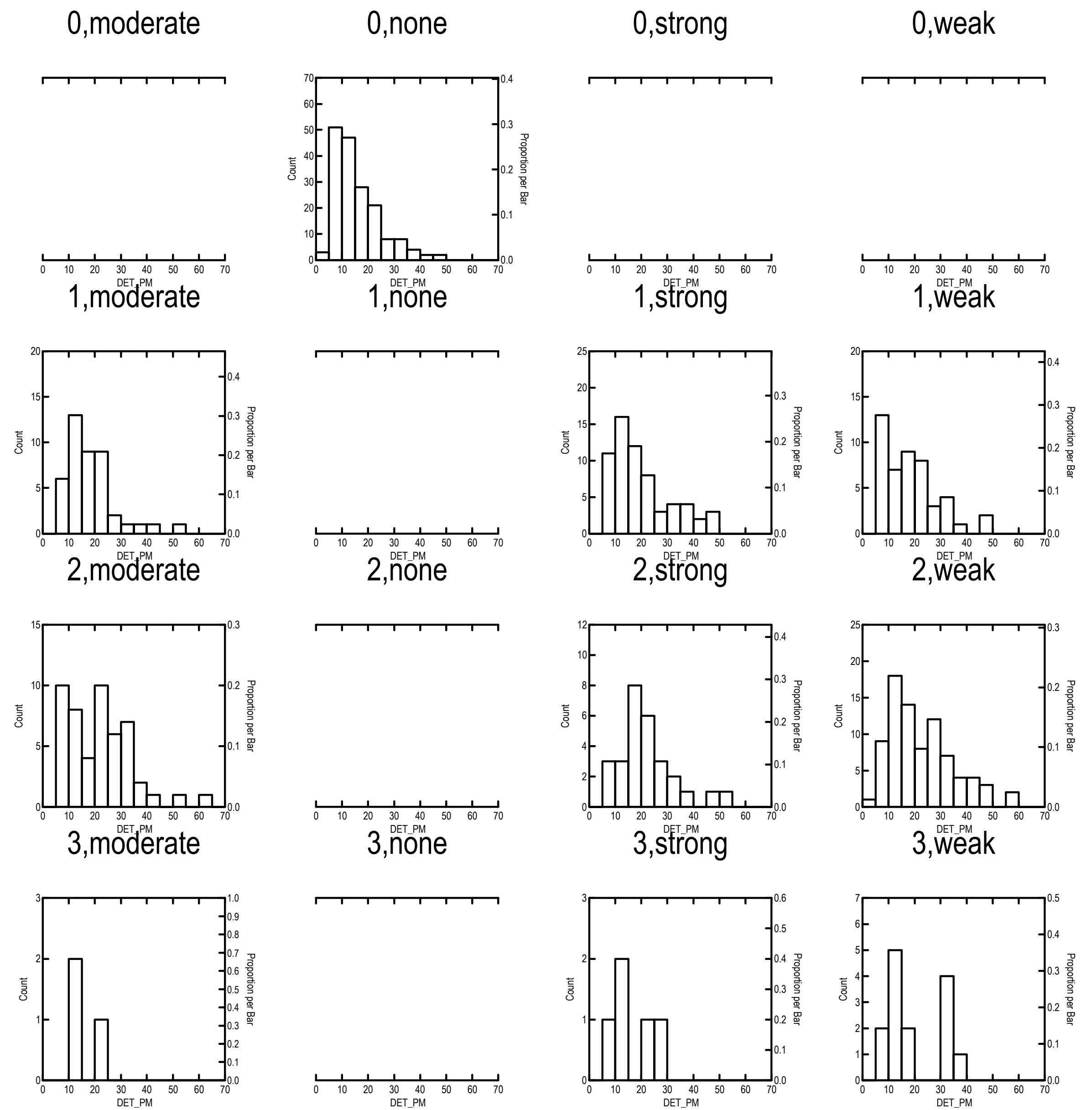

Figure A3-15. $PM_{2.5}$ concentrations ($\mu g/m^3$) at Detroit during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb) and inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb). Blank plot indicates no occurrence.

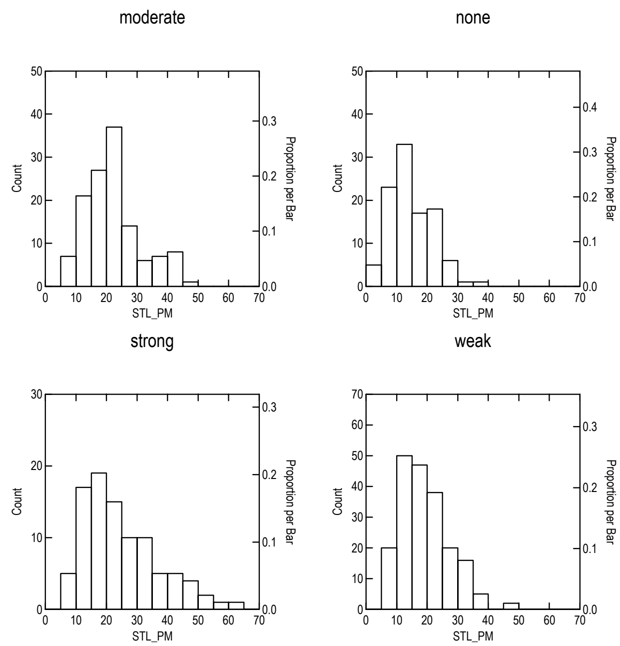

Figure A3-16. $PM_{2.5}$ concentrations ($\mu g/m^3$) at St. Louis during May-September, 1999-2002, by inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb).

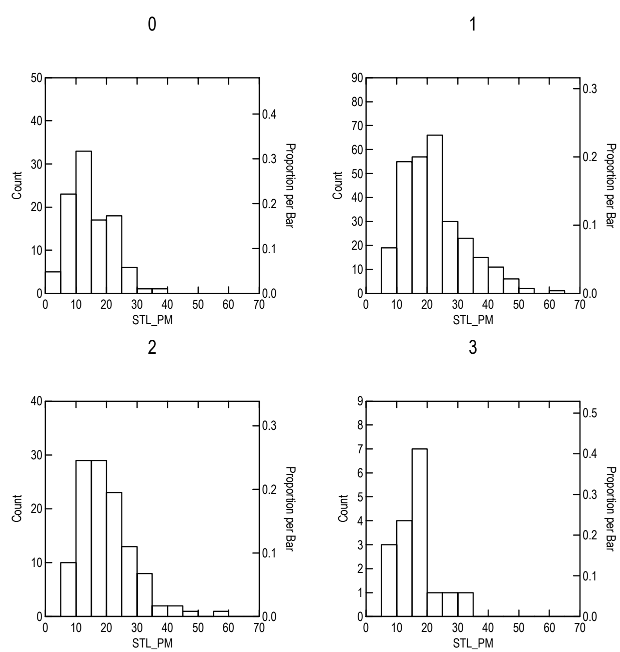

Figure A3-17. $PM_{2.5}$ concentrations ($\mu g/m^3$) at St. Louis during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb).

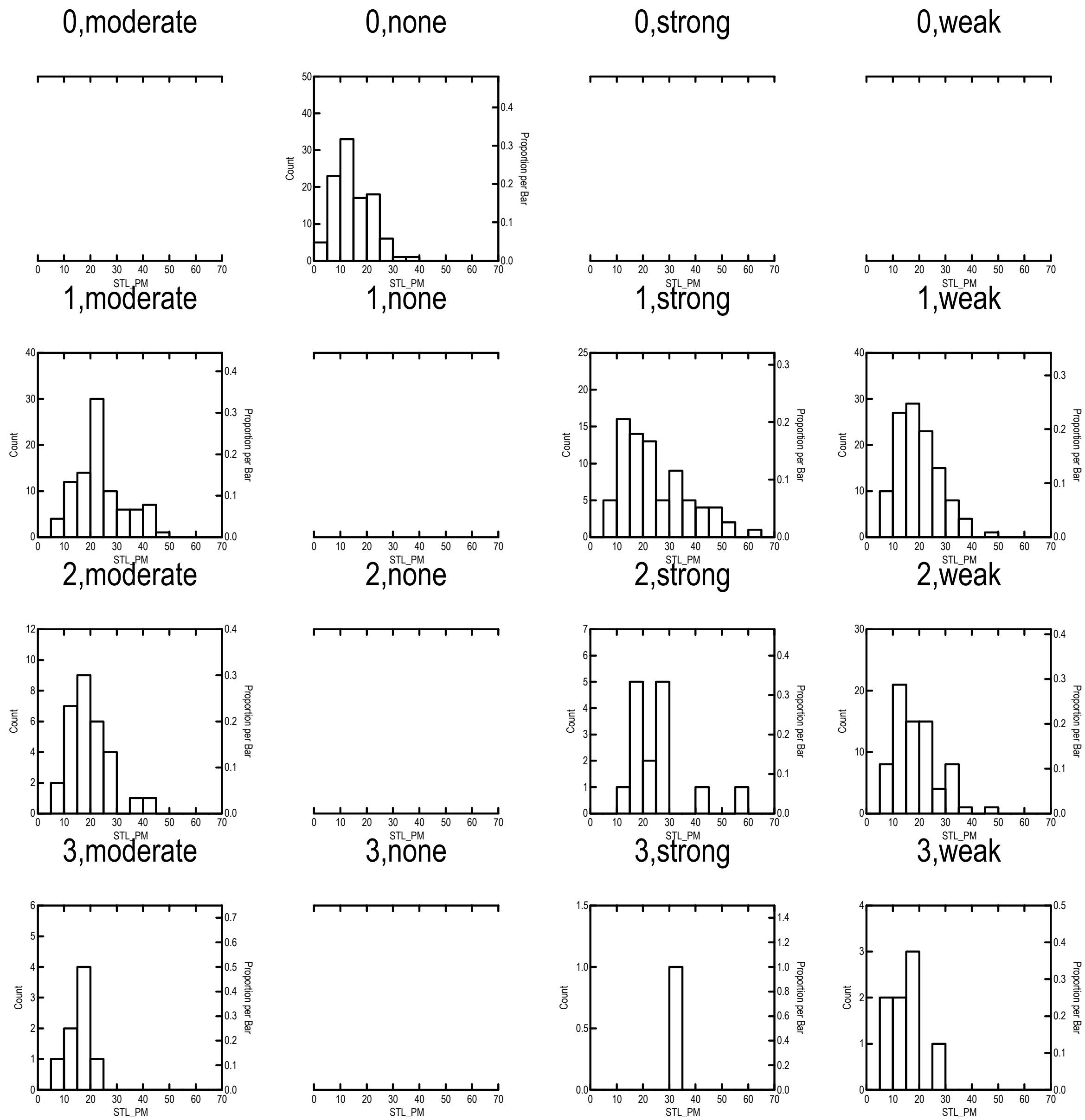

Figure A3-18. $PM_{2.5}$ concentrations ($\mu g/m^3$) at St. Louis during May-September, 1999-2002, by inversion height (0 = no inversion present, 1 = inversion below 950 mb, 2 = inversion between 950 mb and 900 mb, 3 = inversion above 900 mb) and inversion strength (none = no inversion present, weak = 0 to 4°C inversion below 925 mb, moderate = 4 to 6°C inversion below 925 mb, strong = greater than 6°C inversion below 925 mb). Blank plot indicates no occurrence.

Attachment 4

Change in $PM_{2.5}$ Concentrations and Frequency of Synoptic Type by AQI Category

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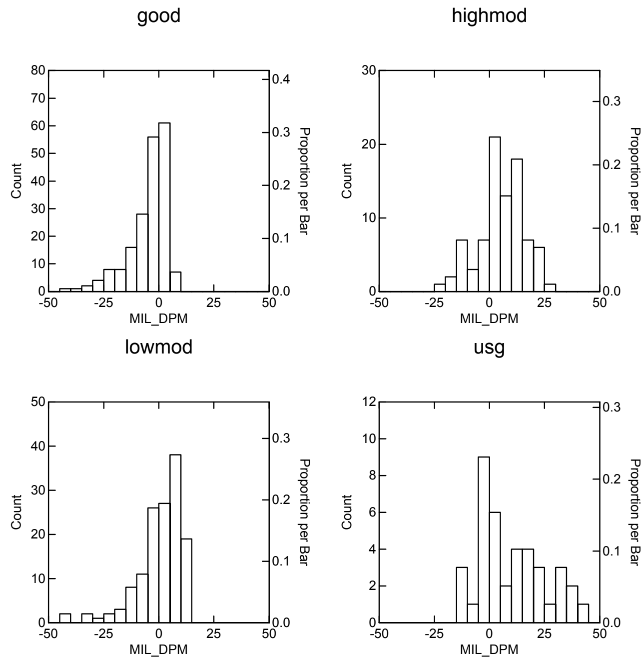

Figure A4-1. Changes in $PM_{2.5}$ concentrations from the previous day at Milwaukee by previous day's AQI category, May-September ,1999-2002 (lowmod = low moderate, 15-25 µg/m3; highmod = high moderate, 25-40 µg/m3).

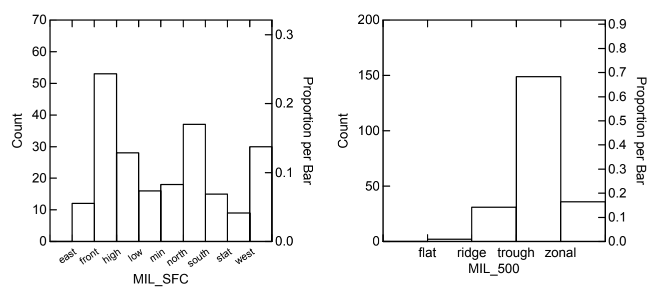

Figure A4-2. Number of instances of surface type and 500-mb type at Milwaukee with AQI of Good.

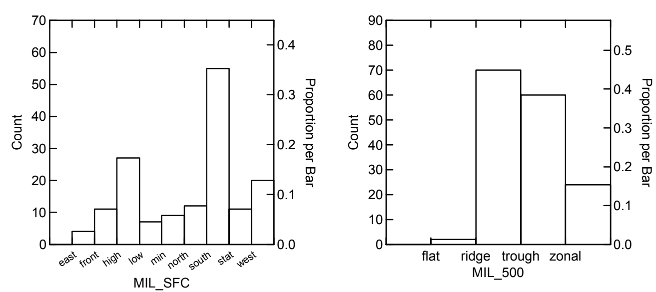

Figure A4-3. Number of instances of surface type and 500-mb type at Milwaukee with AQI of low Moderate.

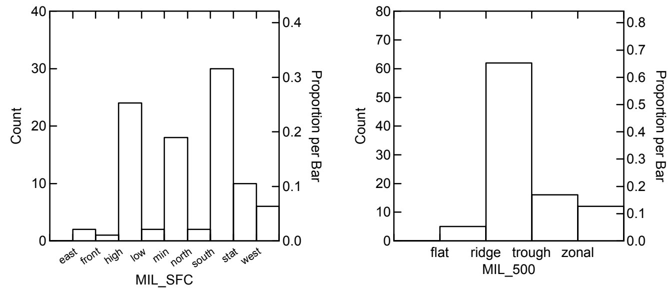

Figure A4-4. Number of instances of surface type and 500-mb type at Milwaukee with AQI of high Moderate.

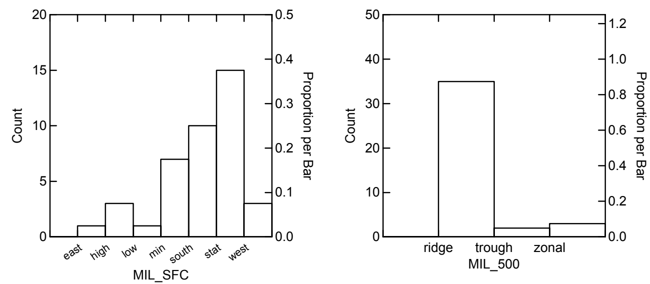

Figure A4-5. Number of instances of surface type and 500-mb type at Milwaukee with AQI of USG.

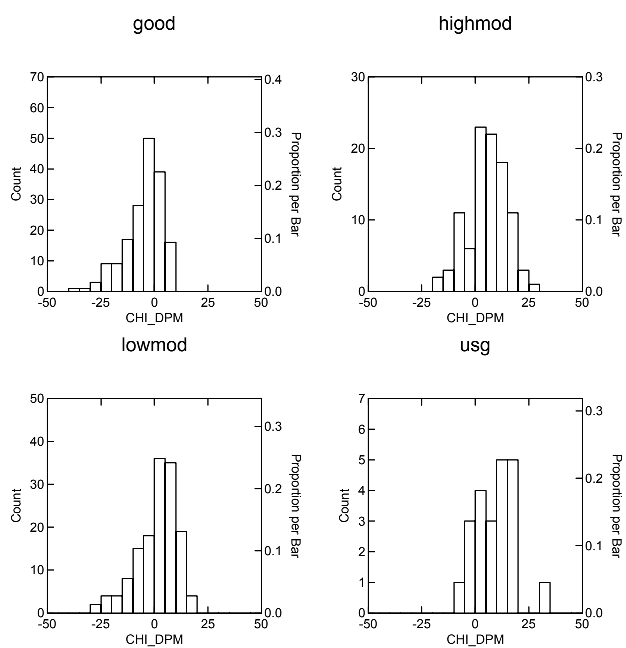

Figure A4-6. Changes in $PM_{2.5}$ concentrations from the previous day at Chicago by previous day's AQI category, May-September, 1999-2002 (lowmod = low moderate, 15-25 µg/m3; highmod = high moderate, 25-40 µg/m3).

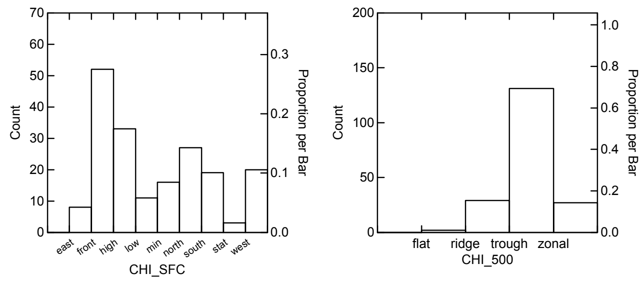

Figure A4-7. Number of instances of surface type and 500-mb type at Chicago with AQI of Good.

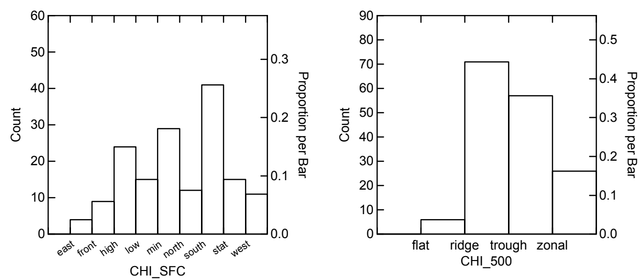

Figure A4-8. Number of instances of surface type and 500-mb type at Chicago with AQI of low Moderate.

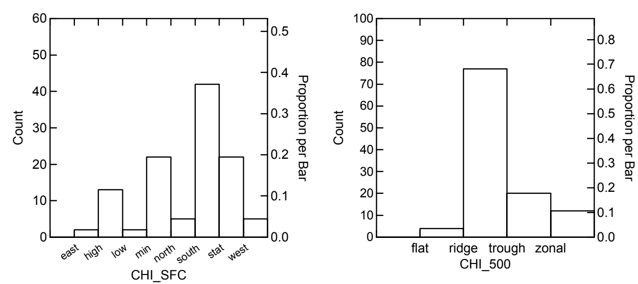

Figure A4-9. Number of instances of surface type and 500-mb type at Chicago with AQI of high Moderate.

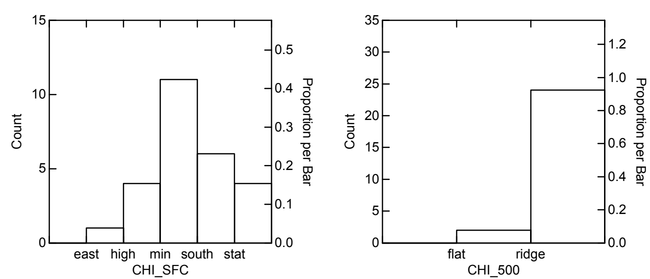

Figure A4-10. Number of instances of surface type and 500-mb type at Chicago with AQI of USG.

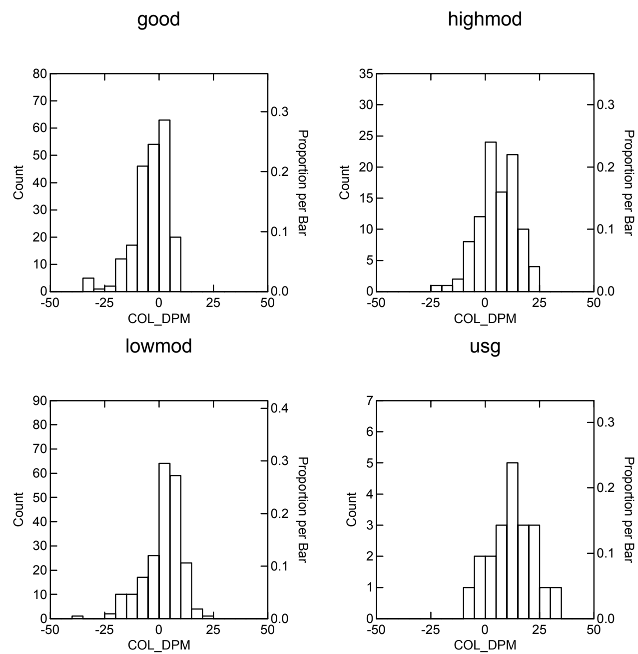

Figure A4-11. Changes in $PM_{2.5}$ concentrations from the previous day at Columbus by previous day's AQI category, May-September, 1999-2002 (lowmod = low moderate, 15-25 µg/m3; highmod = high moderate, 25-40 µg/m3).

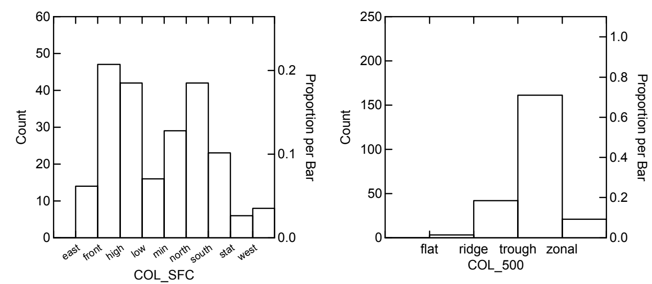

Figure A4-12. Number of instances of surface type and 500-mb type at Columbus with AQI of Good.

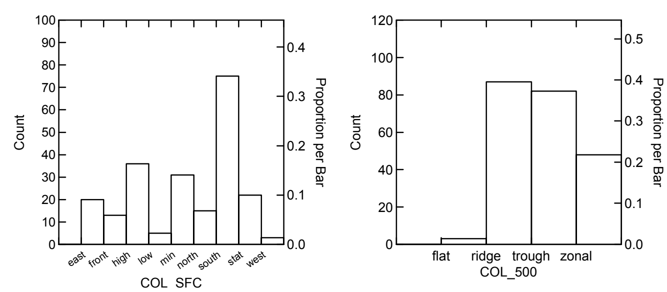

Figure A4-13. Number of instances of surface type and 500-mb type at Columbus with AQI of low Moderate.

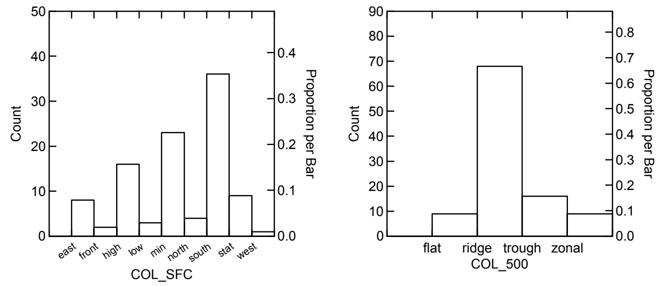

Figure A4-14. Number of instances of surface type and 500-mb type at Columbus with AQI of high Moderate.

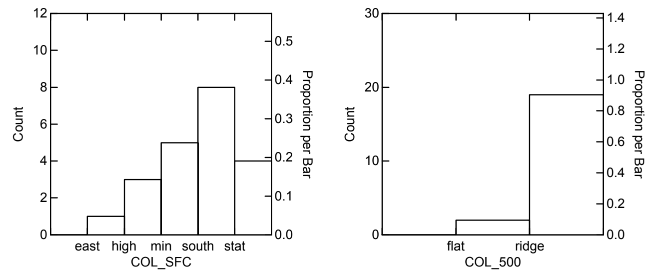

Figure A4-15. Number of instances of surface type and 500-mb type at Columbus with AQI of USG.

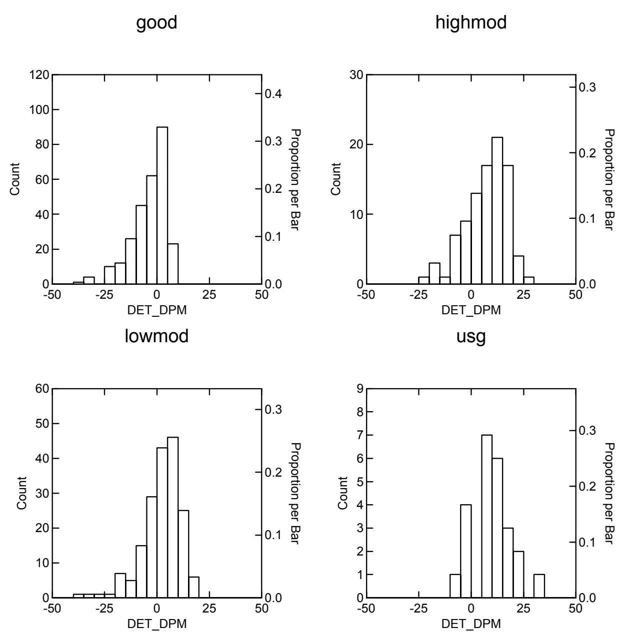

Figure A4-16. Changes in $PM_{2.5}$ concentrations from the previous day at Detroit by previous day's AQI category, May-September, 1999-2002 (lowmod = low moderate, 15-25 µg/m3; highmod = high moderate, 25-40 µg/m3).

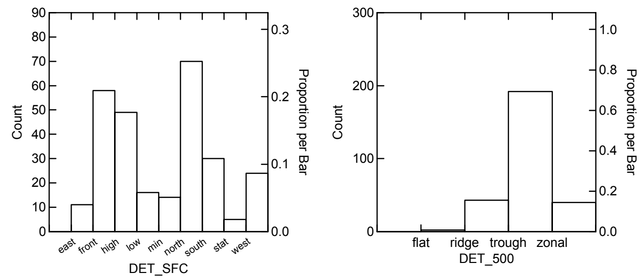

Figure A4-17. Number of instances of surface type and 500-mb type at Detroit with AQI of Good.

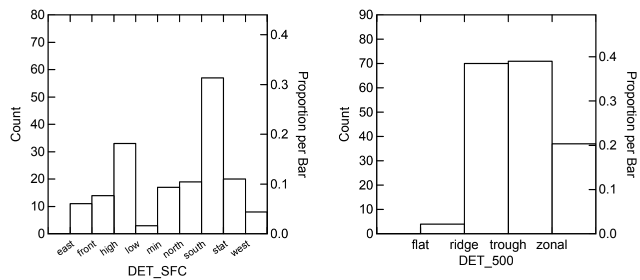

Figure A4-18. Number of instances of surface type and 500-mb type at Detroit with AQI of low Moderate.

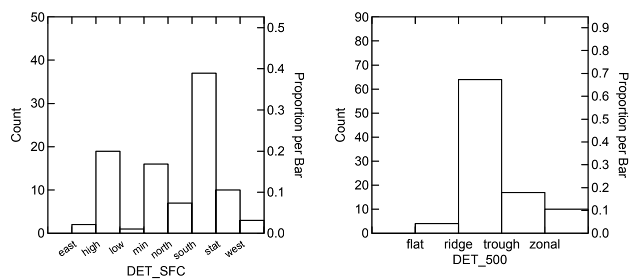

Figure A4-19. Number of instances of surface type and 500-mb type at Detroit with AQI of high Moderate.

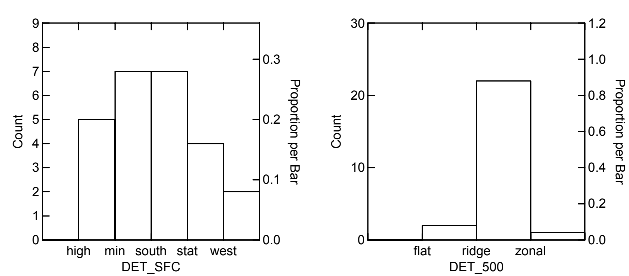

Figure A4-20. Number of instances of surface type and 500-mb type at Detroit with AQI of USG.

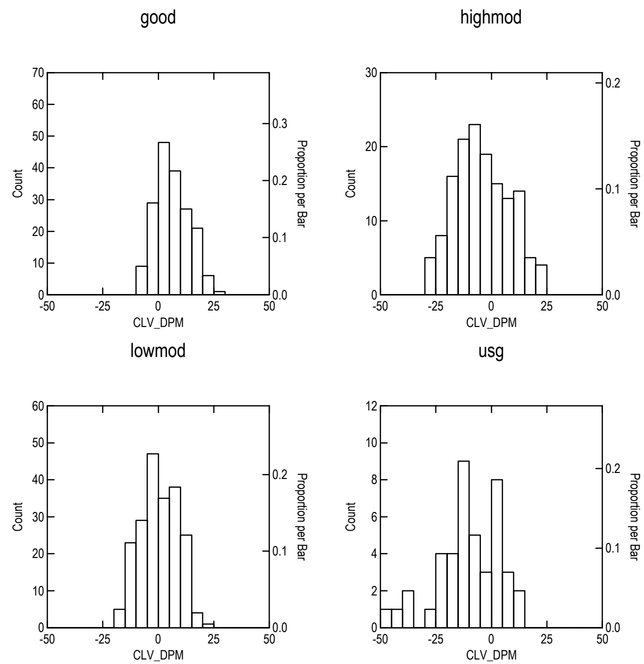

Figure A4-21. Changes in $PM_{2.5}$ concentrations from the previous day at Cleveland by previous day's AQI category, May-September, 1999-2002 (lowmod = low moderate, 15-25 µg/m3; highmod = high moderate, 25-40 µg/m3).

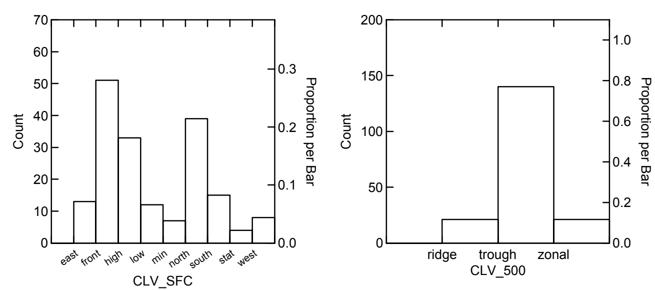

Figure A4-22. Number of instances of surface type and 500-mb type at Cleveland with AQI of Good.

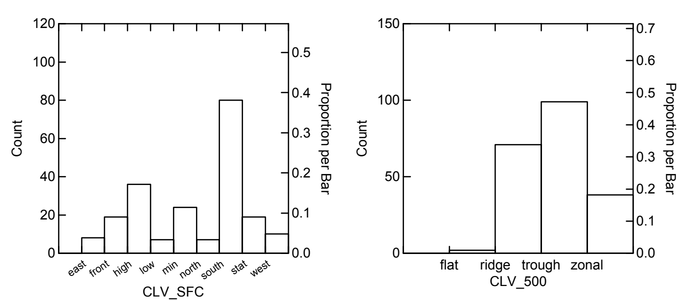

Figure A4-23. Number of instances of surface type and 500-mb type at Cleveland with AQI of low Moderate.

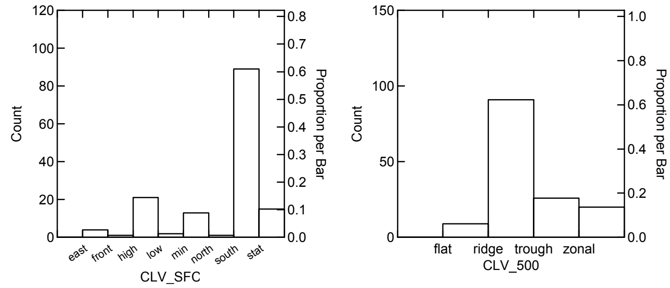

Figure A4-24. Number of instances of surface type and 500-mb type at Cleveland with AQI of high Moderate.

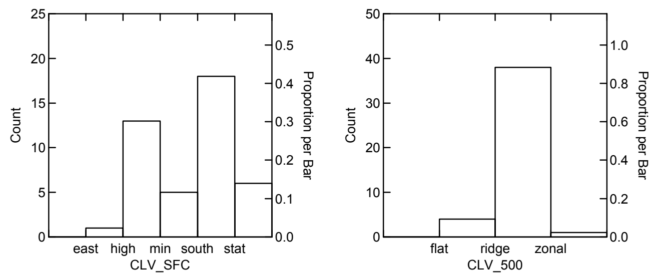

Figure A4-25. Number of instances of surface type and 500-mb type at Cleveland with AQI of USG.

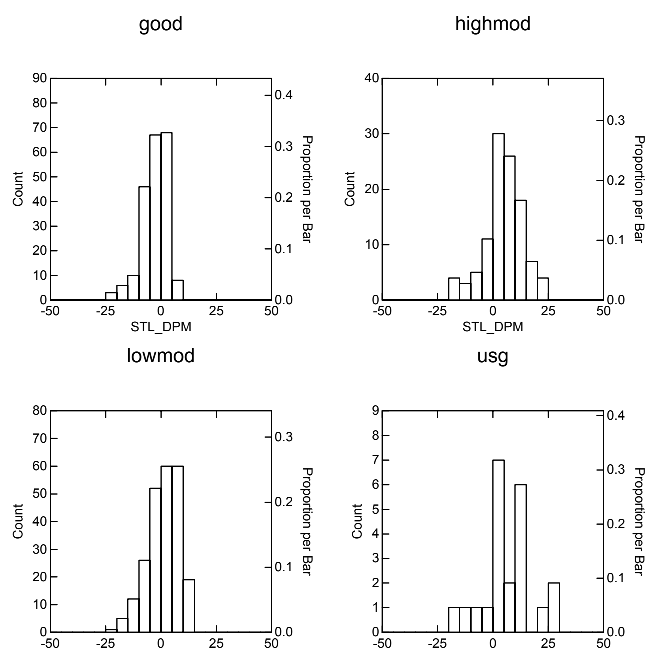

Figure A4-26. Changes in $PM_{2.5}$ concentrations from the previous day at St. Louis by previous day's AQI category, May-September, 1999-2002 (lowmod = low moderate, 15-25 µg/m3; highmod = high moderate, 25-40 µg/m3).

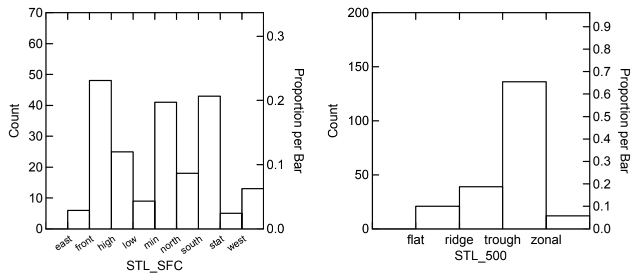

Figure A4-27. Number of instances of surface type and 500-mb type at St. Louis with AQI of Good.

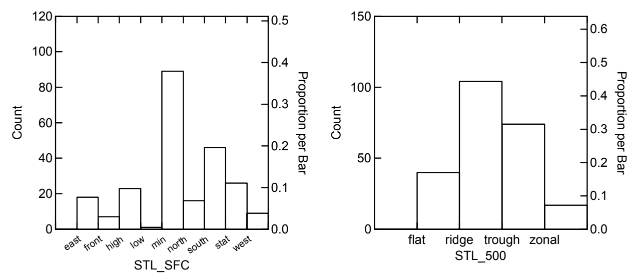

Figure A4-28. Number of instances of surface type and 500-mb type at St. Louis with AQI of low Moderate.

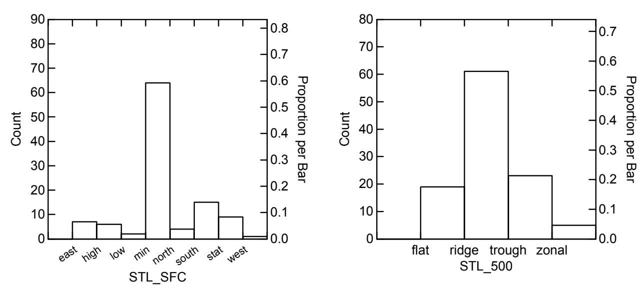

Figure A4-29. Number of instances of surface type and 500-mb type at St. Louis with AQI of high Moderate.

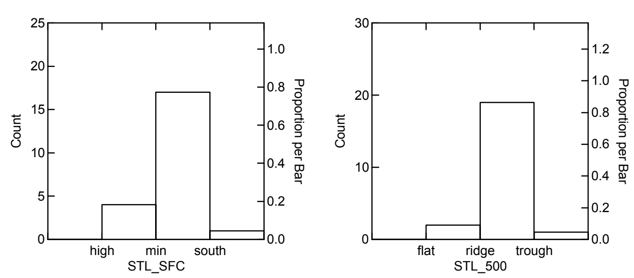

Figure A4-30. Number of instances of surface type and 500-mb type at St. Louis with AQI of USG.

Attachment 6

Change in $PM_{2.5}$ Concentration by Change in Upper-Air Synoptic Type

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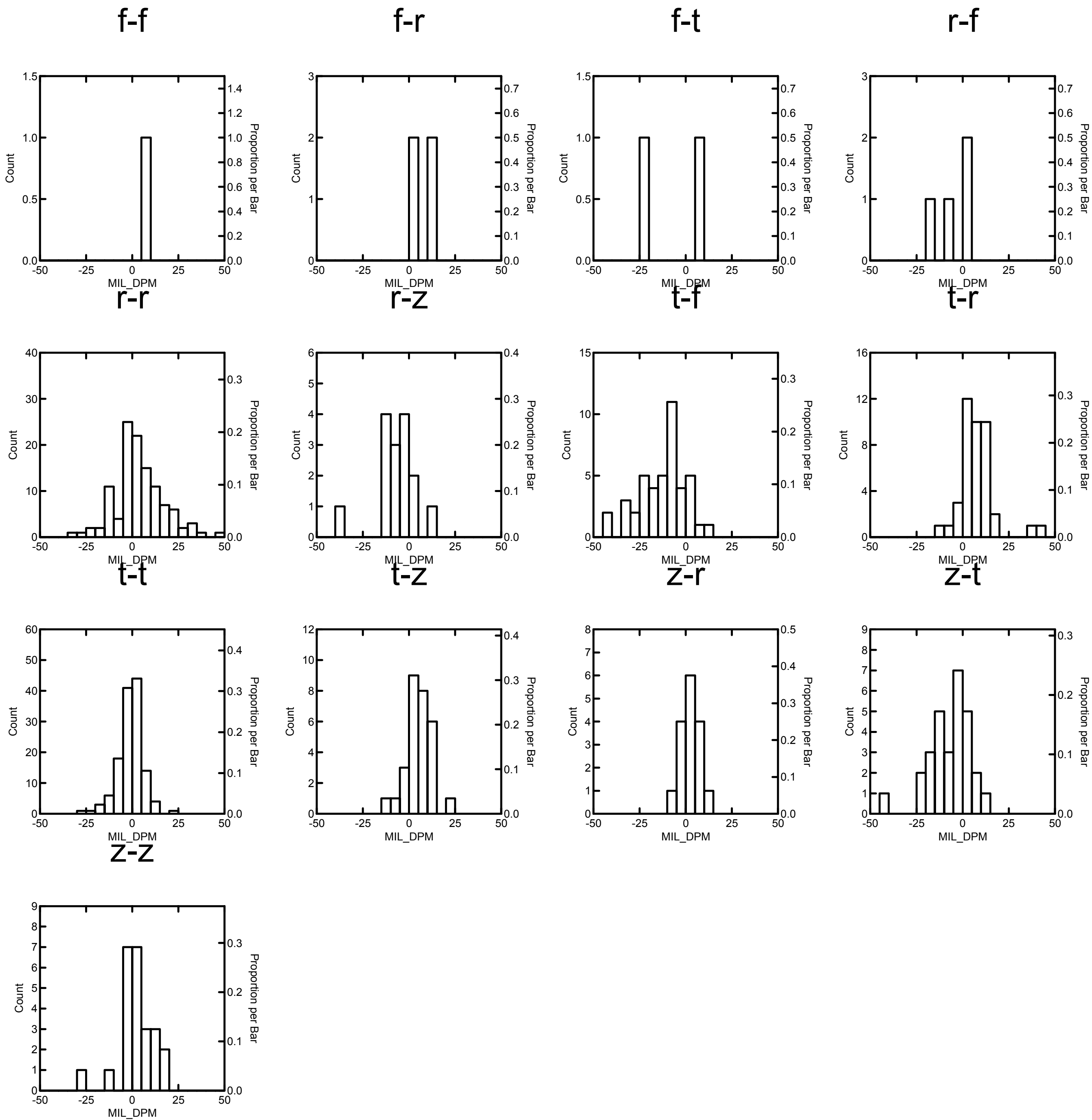

Figure A6-1. Changes in concentrations of $PM_{2.5}$ at Milwaukee by two-day 500-mb combinations, such as a flat to flat regime in successive days in the upper left of the figure. (f = flat, z = zonal, t = trough and r = ridge).

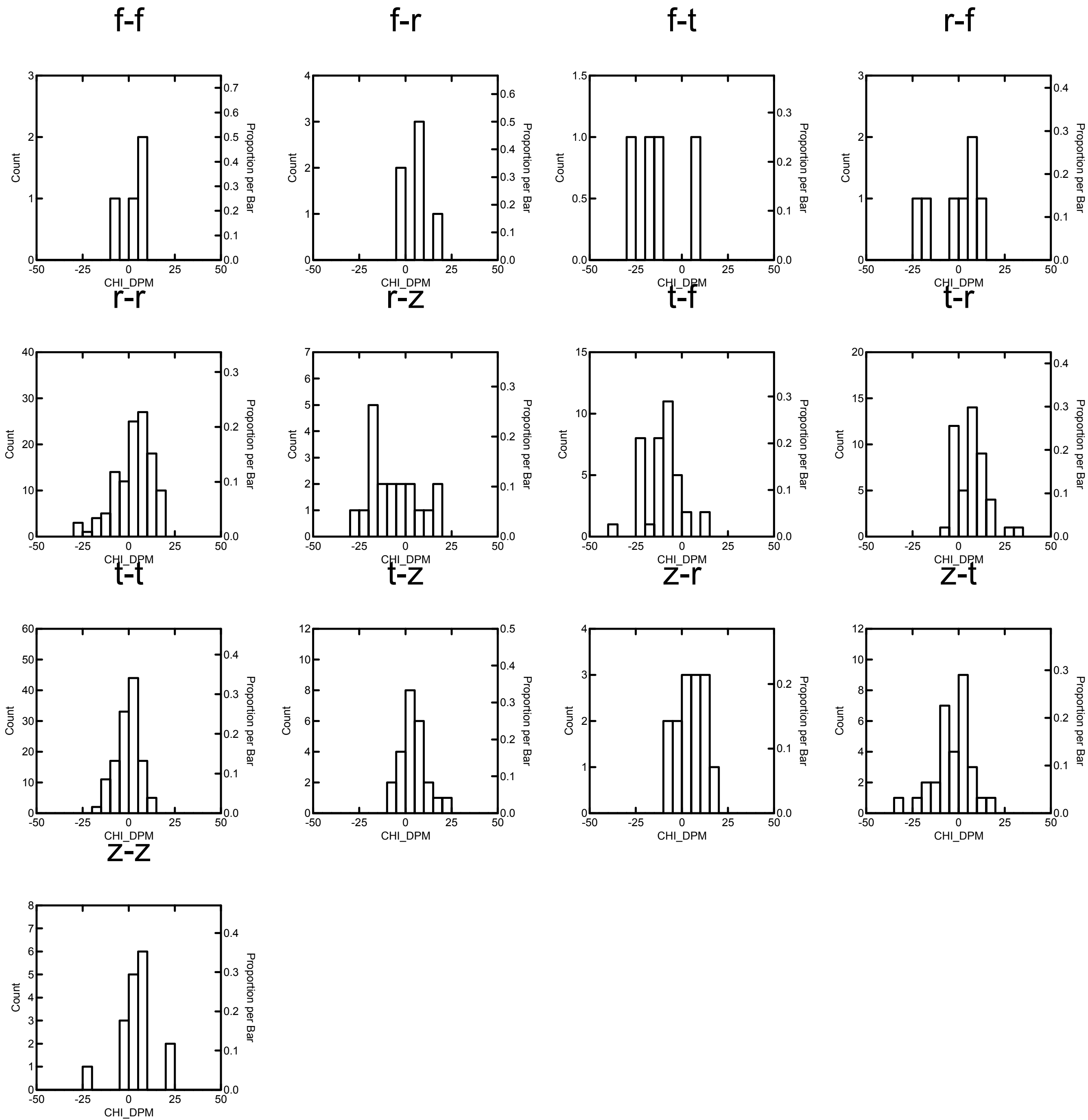

Figure A6-2. Changes in concentrations of $PM_{2.5}$ at Chicago by two-day 500-mb combinations, such as a flat to flat regime in successive days in the upper left of the figure. (f = flat, z = zonal, t = trough and r = ridge).

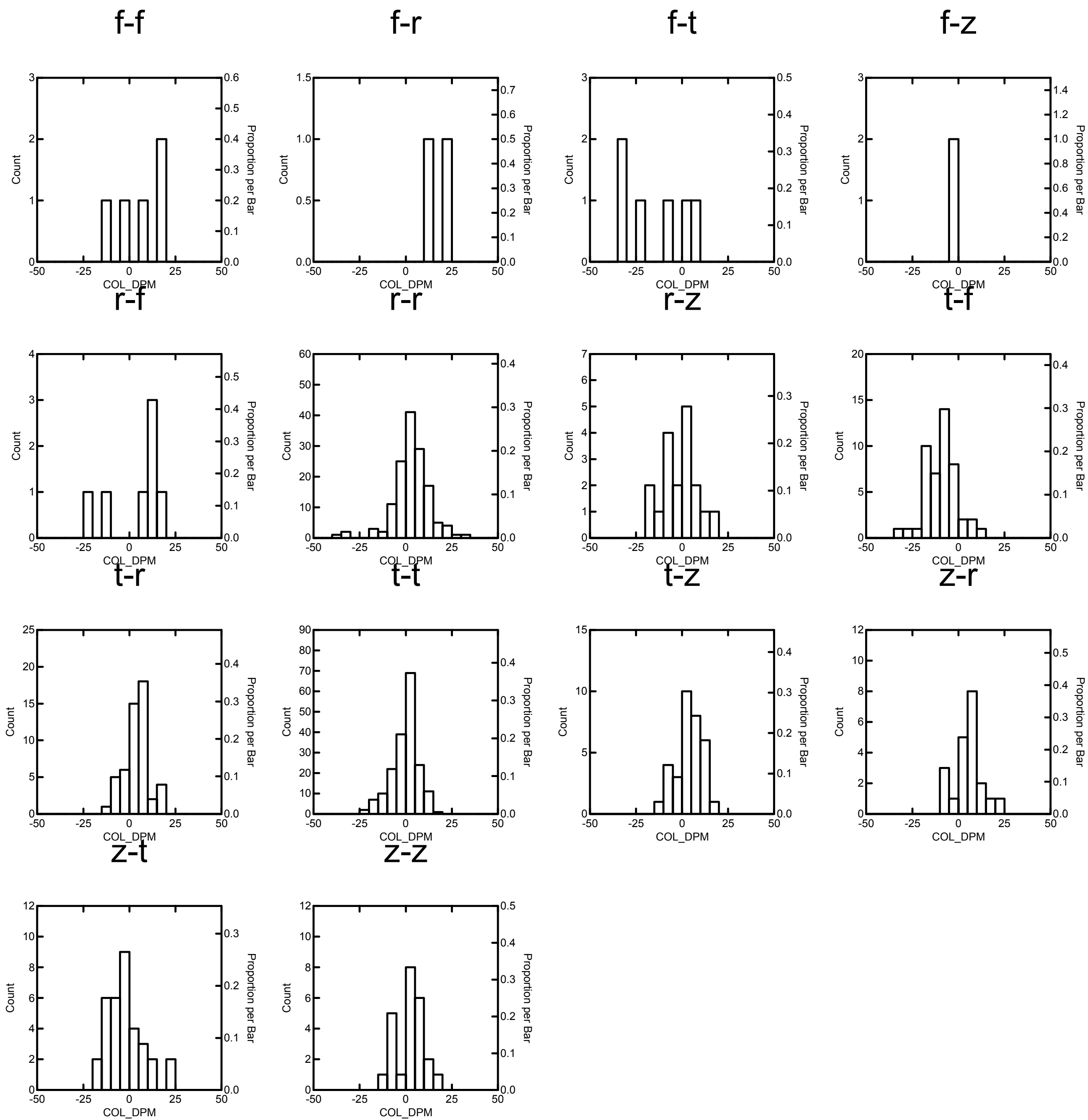

Figure A6-3. Changes in concentrations of $PM_{2.5}$ at Cleveland by two-day 500-mb combinations, such as a flat to flat regime in successive days in the upper left of the figure. (f = flat, z = zonal, t = trough and r = ridge).

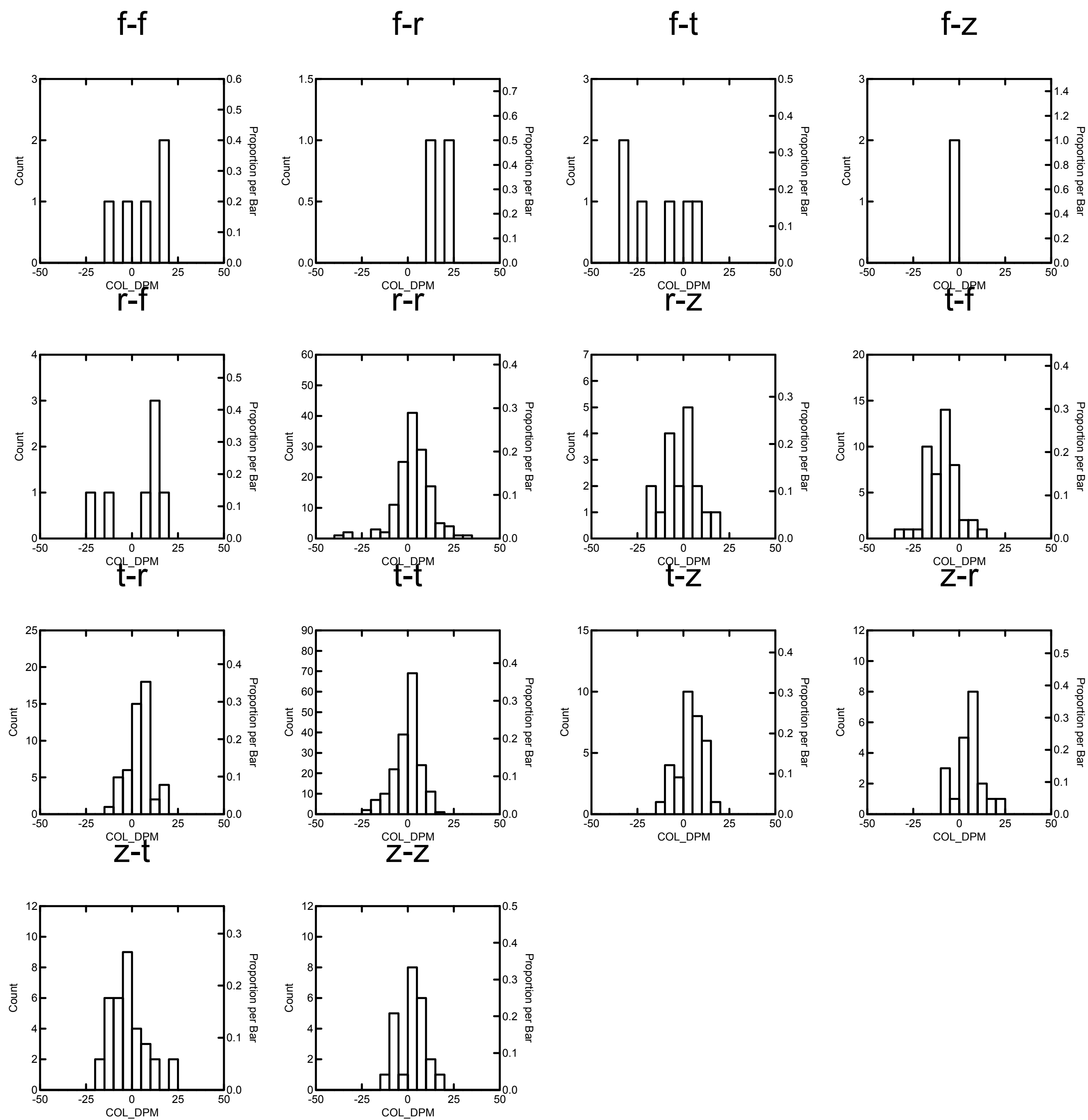

Figure A6-4. Changes in concentrations of $PM_{2.5}$ at Columbus by two-day 500-mb combinations, such as a flat to flat regime in successive days in the upper left of the figure. (f = flat, z = zonal, t = trough and r = ridge).

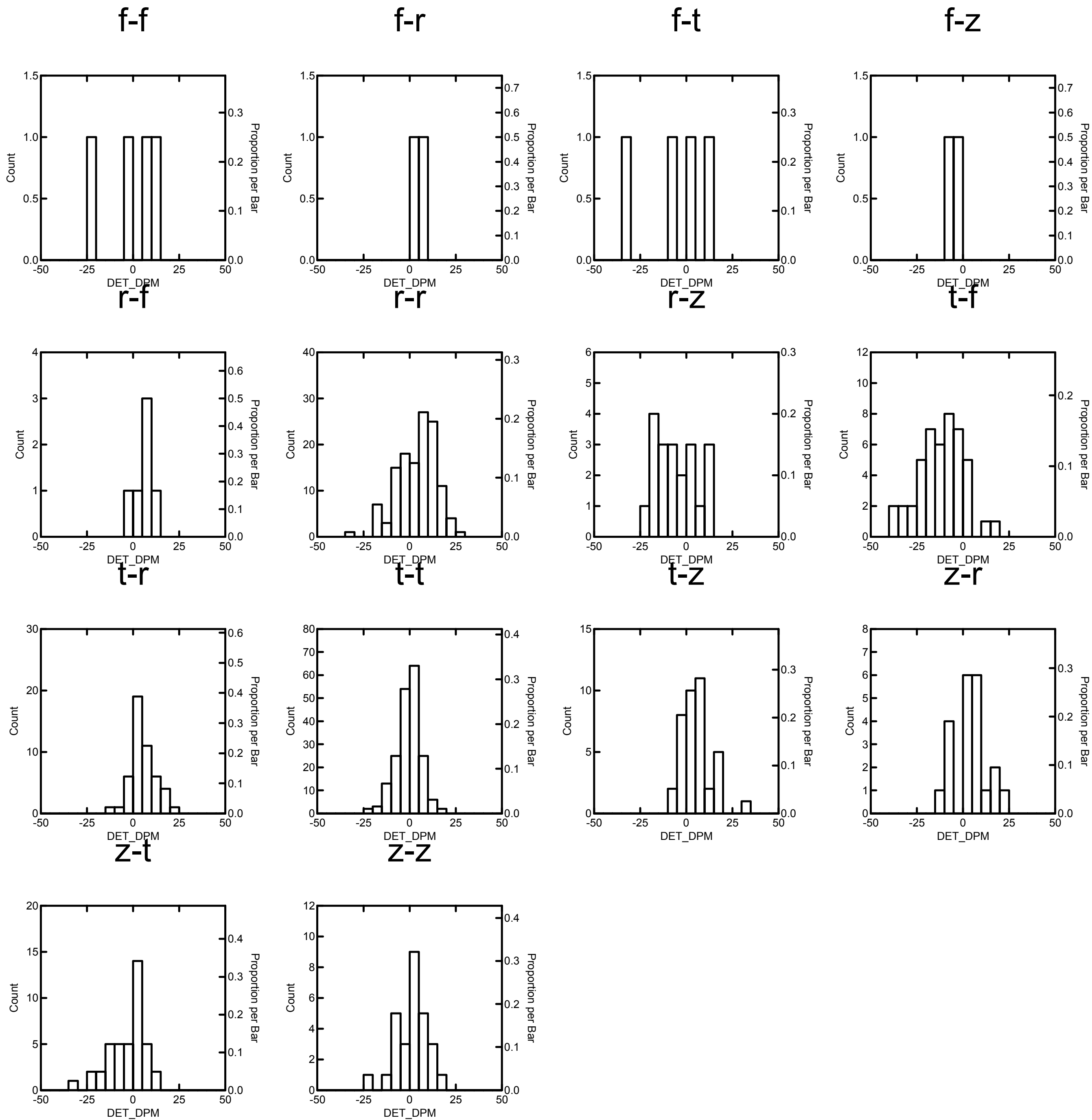

Figure A6-5. Changes in concentrations of $PM_{2.5}$ at Detroit by two-day 500-mb combinations, such as a flat to flat regime in successive days in the upper left of the figure. (f = flat, z = zonal, t = trough and r = ridge).

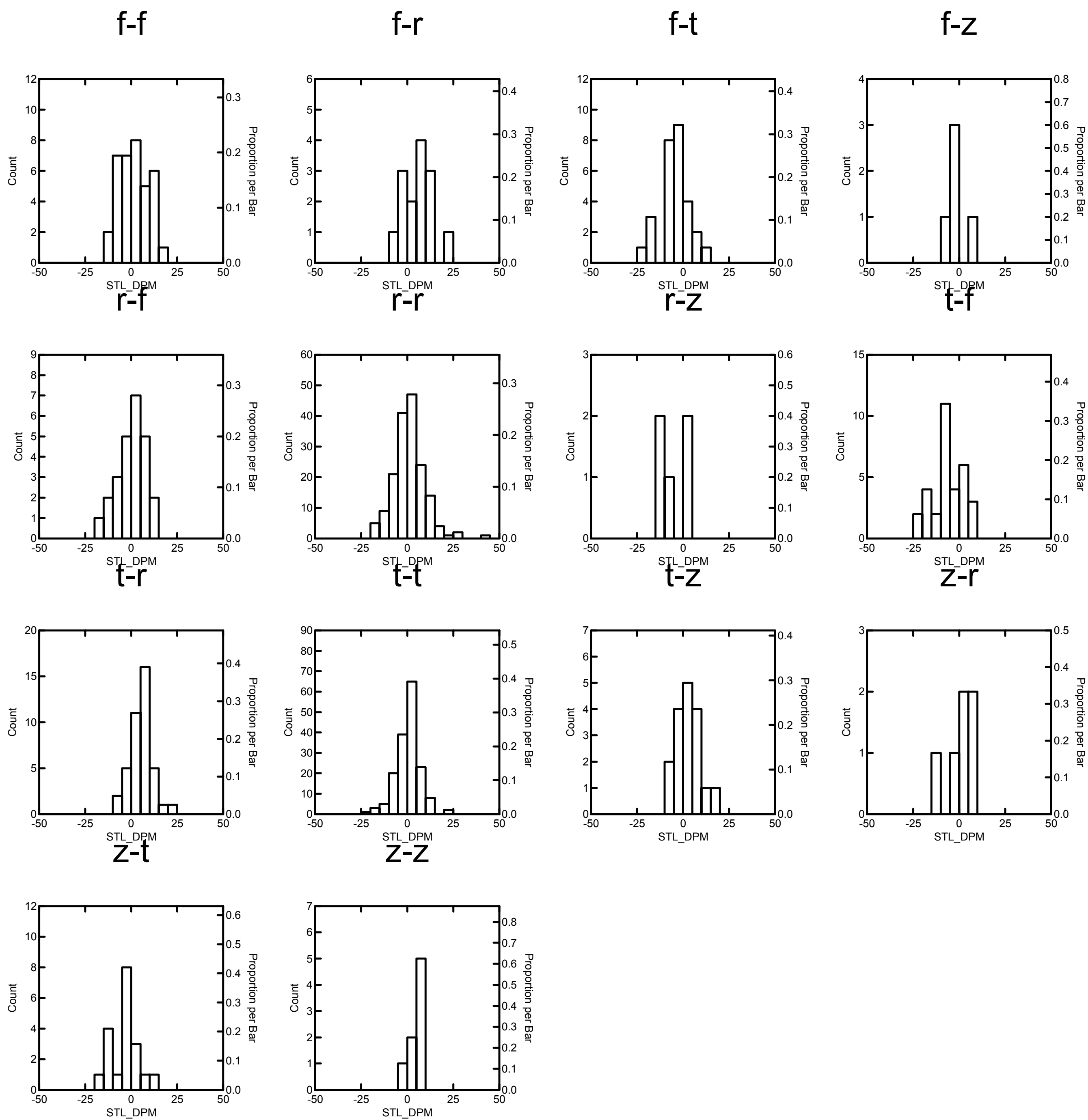

Figure A6-6. Changes in concentrations of $PM_{2.5}$ at St. Louis by two-day 500-mb combinations, such as a flat to flat regime in successive days in the upper left of the figure. (f = flat, z = zonal, t = trough and r = ridge).

Attachment 7

Change in $PM_{2.5}$ Concentration by Change in Inversion Type

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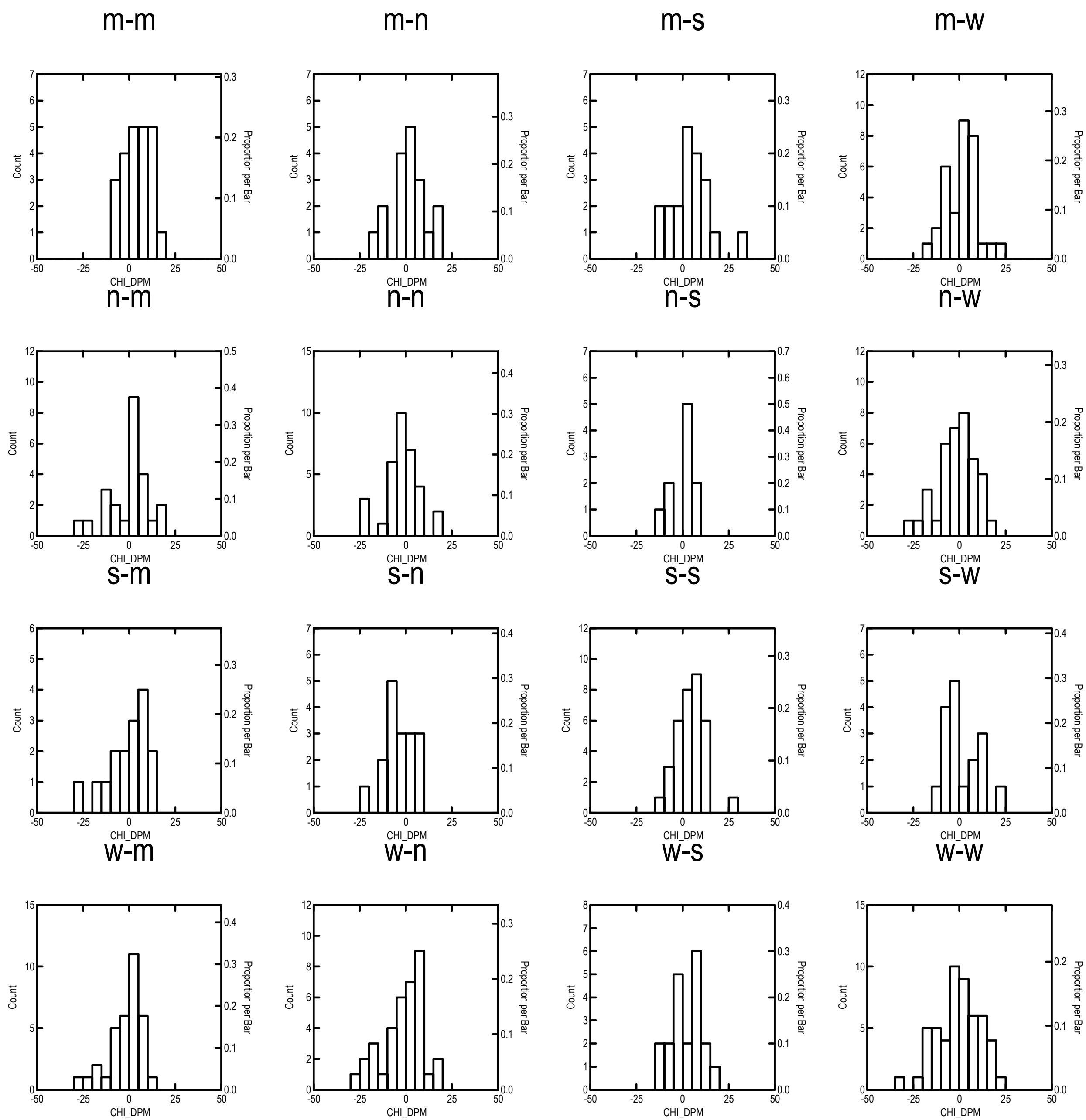

Figure A7-1. Changes in concentrations of $PM_{2.5}$ at Chicago by two-day inversion strength combinations, such as a moderate inversion to a moderate inversion in successive days in the upper left of the figure. (n = none, w = weak, m = moderate, s = strong).

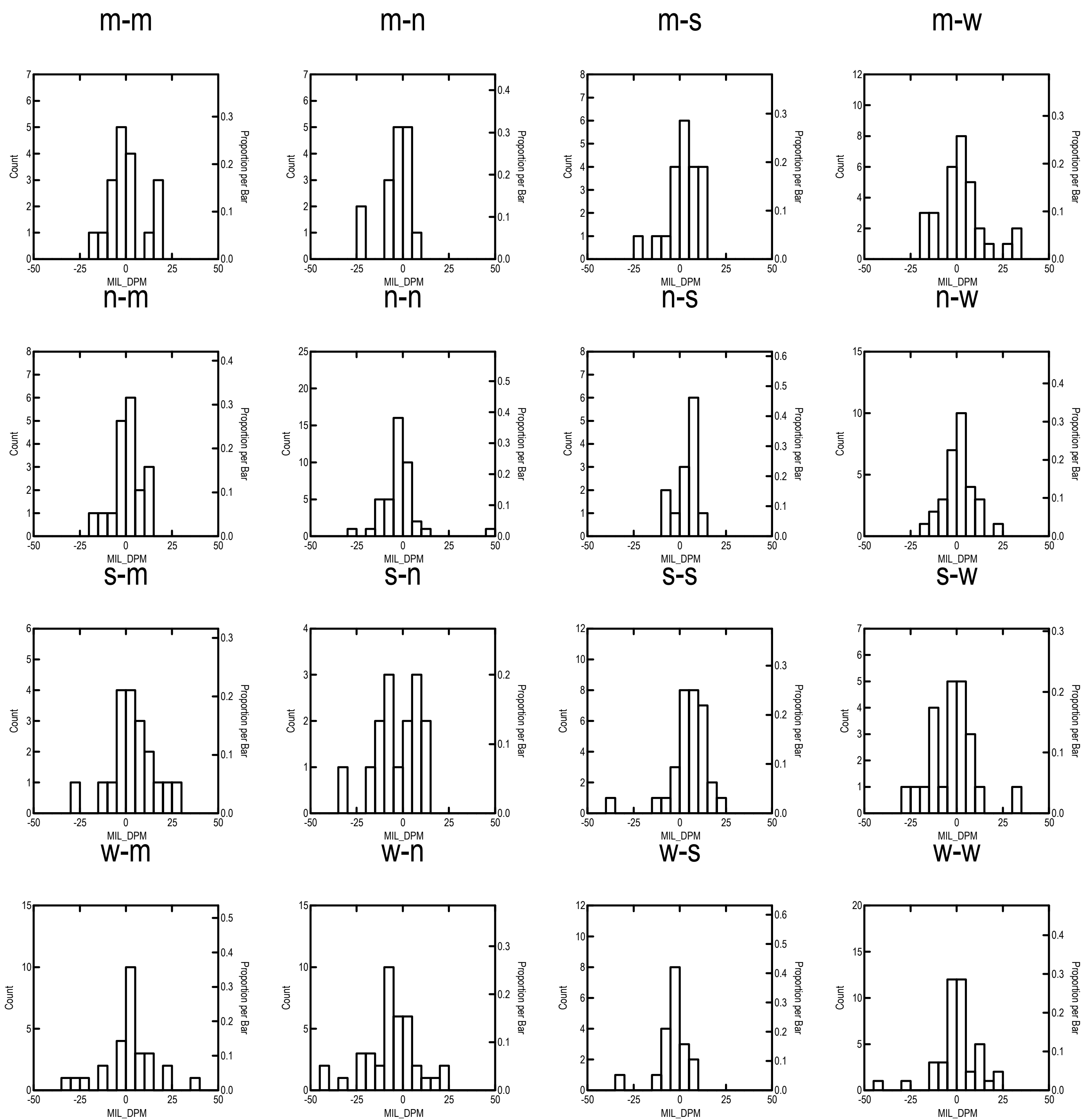

Figure A7-2. Changes in concentrations of $PM_{2.5}$ at Milwaukee by two-day inversion strength combinations, such as a moderate inversion to a moderate inversion in successive days in the upper left of the figure. (n = none, w = weak, m = moderate, s = strong).

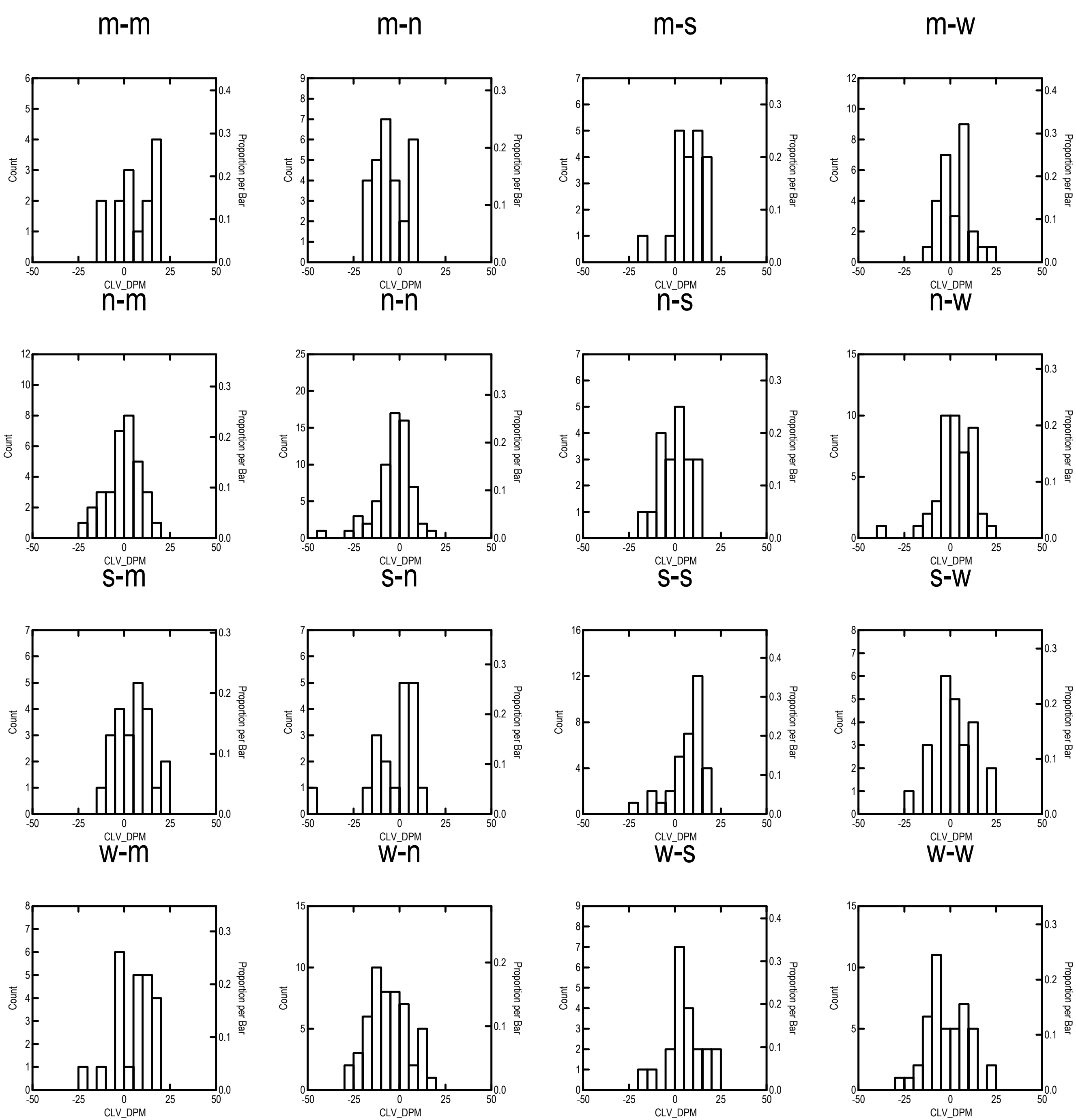

Figure A7-3. Changes in concentrations of $PM_{2.5}$ at Cleveland by two-day inversion strength combinations, such as a moderate inversion to a moderate inversion in successive days in the upper left of the figure. (n = none, w = weak, m = moderate, s = strong).

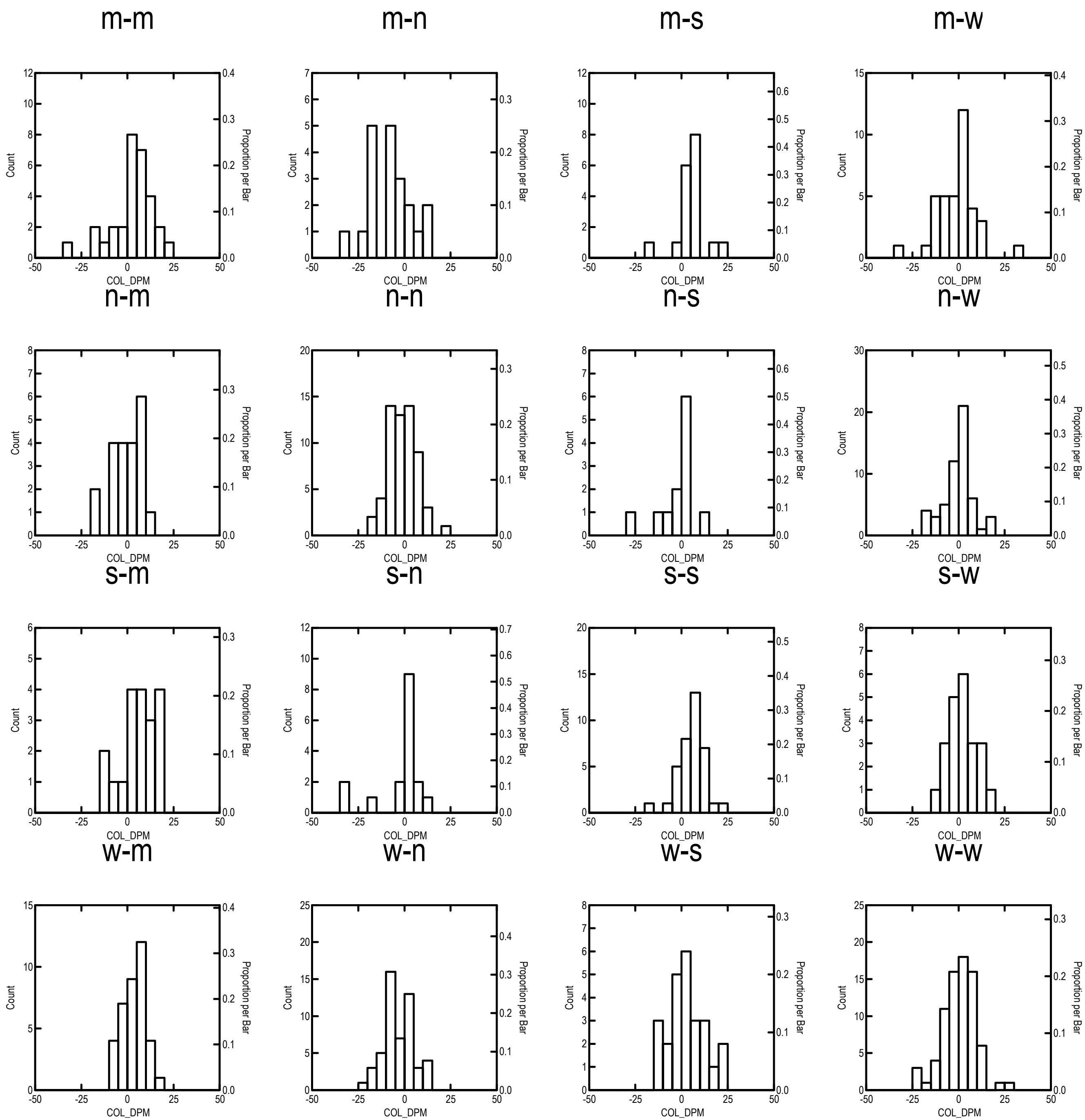

Figure A7-4. Changes in concentrations of $PM_{2.5}$ at Columbus by two-day inversion strength combinations, such as a moderate inversion to a moderate inversion in successive days in the upper left of the figure. (n = none, w = weak, m = moderate, s = strong).

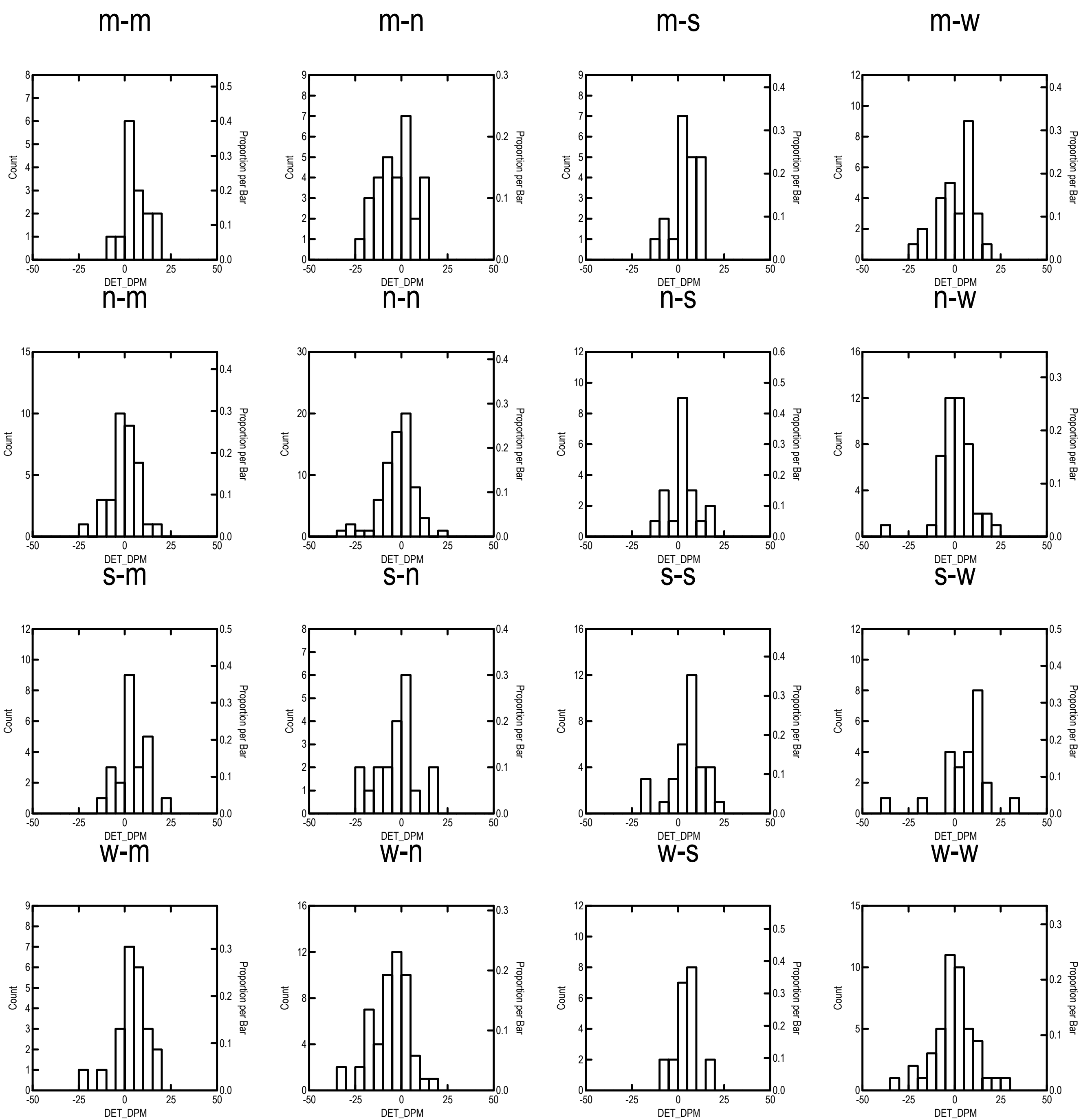

Figure A7-5. Changes in concentrations of $PM_{2.5}$ at Detroit by two-day inversion strength combinations, such as a moderate inversion to a moderate inversion in successive days in the upper left of the figure. (n = none, w = weak, m = moderate, s = strong).

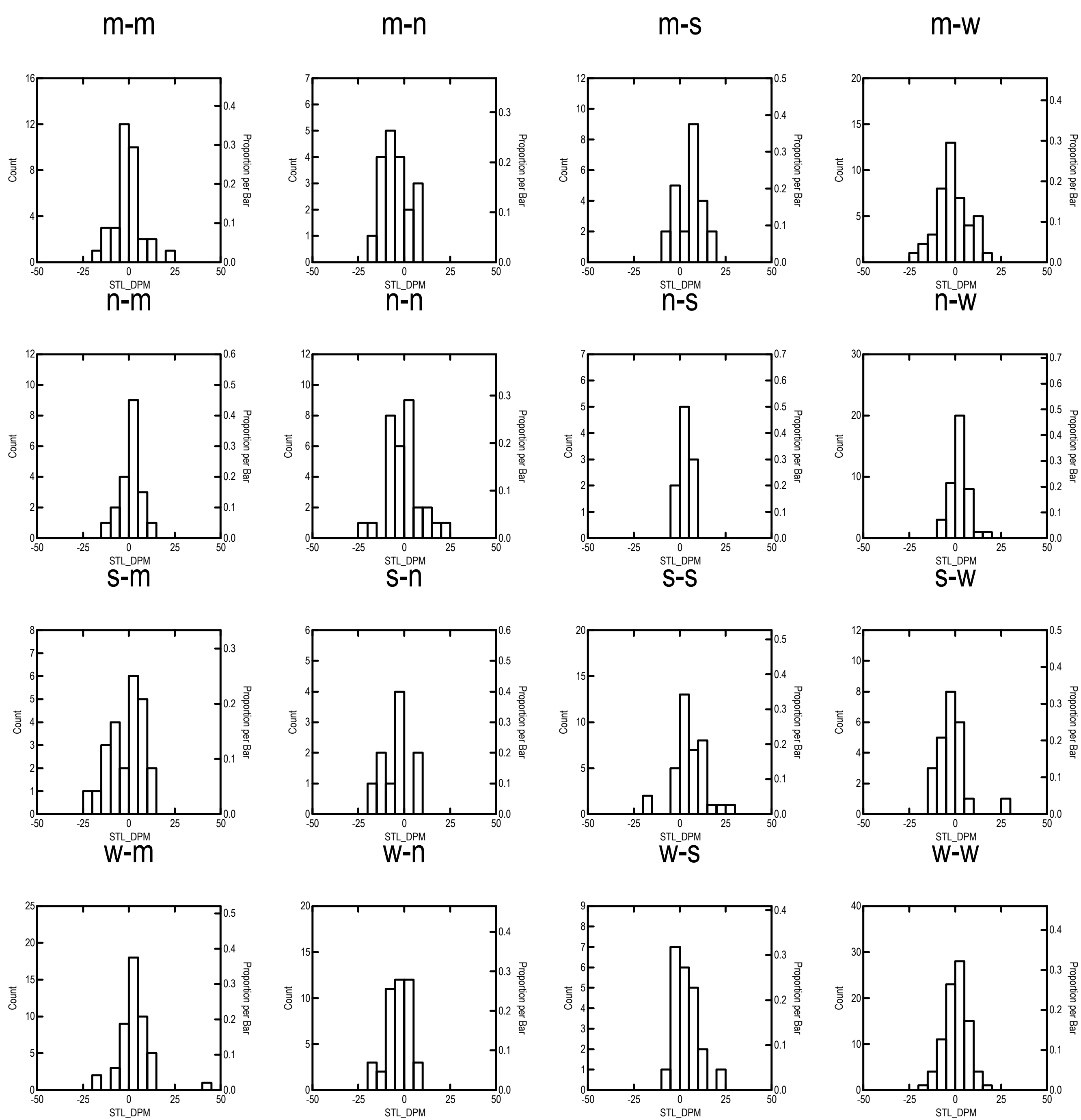

Figure A7-6. Changes in concentrations of $PM_{2.5}$ at St. Louis by two-day inversion strength combinations, such as a moderate inversion to a moderate inversion in successive days in the upper left of the figure. (n = none, w = weak, m = moderate, s = strong).