

APPENDIX B

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Relating Summer Ambient Particulate Sulfur, Sulfur Dioxide, and Light Scattering to Gaseous Tracer Emissions from the Mohave Power Project

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ABSTRACT

Project MOHAVE was initiated in 1992 to examine the role of emissions from the 1580 MW coal-fired Mohave Power Project (MPP) on haze at the Grand Canyon National Park (GCNP), located about 130km north-northeast of the power plant. Statistical relationships were analyzed between summertime ambient concentrations of a gaseous perfluorocarbon tracer released from MPP and ambient sulfur dioxide, particulate sulfur, and light scattering to evaluate whether MPP's emissions could be transported to the GCNP and then impact haze levels there. Spatial analyses indicated that particulate sulfur levels were strongly correlated across the monitoring network indicating that particulate sulfur levels in this region were influenced by distant regional emission sources. A significant particulate sulfur contribution from a point source such as MPP would result in a non-uniform pattern downwind. There was no suggestion of this in the data. Furthermore, correlations between the MPP tracer and ambient particulate sulfur and light scattering at locations in the Park were virtually zero for averaging times ranging from 24-hours to 1-hour. Hour-by-hour MPP tracer levels and light scattering were individually examined, and still virtually no positive correlations were detected. Finally, agreement between tracer and particulate sulfur did not improve as a function of meteorological regime implying that, even during cloudy monsoonal days when more rapid conversion of sulfur dioxide to particulate sulfur would be expected, there was no evidence for downwind particulate sulfur impacts. Despite the fact that MPP was a large source of SO₂ and tracer, neither time series nor correlation analyses were able to detect any meaningful relationship between MPP's SO₂ and tracer emission "signals" to particulate sulfur or light scattering.

IMPLICATIONS

Using simple statistical analyses, qualitative insight was obtained into the contributions of the Mohave Power Project's emissions to sulfur dioxide, particulate sulfur, and light scattering as a prelude to applying more quantitative source/receptor models. The results from these statistical analyses did not reveal any statistically significant relationships between either particulate sulfur or light scattering and the tracer released from MPP. From this it is concluded that MPP makes a small enough contribution to regional particulate sulfur and light scattering that its effects are dominated by those from other emission sources in the region.

INTRODUCTION

The Mohave Power Project (MPP) is a 1580MW coal-fired power plant located 130km southwest of the western boundary of the Grand Canyon National Park (GCNP). In 1992 a comprehensive air monitoring and meteorological data collection program was carried out under

the name of Project MOHAVE (Measurements Of Haze And Visual Effects)¹. The goal of Project MOHAVE was to characterize and quantify the impacts of emissions from MPP on haze at the Grand Canyon National Park. This goal was accomplished by deploying a network of air quality and meteorological sampling stations to characterize the pollutant and meteorological conditions in the MPP-GCNP region of the southwestern US. Figure 1 provides the locations of MPP and several key air quality monitoring locations discussed in this paper. 35 ambient monitoring sites were operated during the 1991-1992 yearlong field study. A major component of Project MOHAVE involved the release and sampling of an inert perfluorocarbon tracer, ocPDCH – termed the MPP tracer in this paper, from the 153m MPP stack over a continuous 50-day period during the summer experiment (July 12-August 31, 1992).

The basic objective examined in this paper was to determine if positive statistical relationships were evident in the data between MPP tracer and particulate sulfur and light scattering. If such relationships were found, then these results could suggest that MPP's emissions are transported and chemically converted in the atmosphere to form secondary sulfates, which affect regional haze levels.

EXPERIMENTAL METHODS

During the summer season experiment, the University of California at Davis (UCD) collected 24-hour averaged aerosol data following the IMPROVE (Interagency Monitoring of Protected Visual Environments) protocol at 35 regional sites. Samples were collected with a cut point of $2.5\mu\text{m } D_p$. Particulate sulfur samples were analyzed by PIXE. Sulfur dioxide samples were also collected using potassium carbonate-impregnated filters behind particulate matter filters in the IMPROVE sampler. During the summer experiment samples were collected daily commencing at 7am MST. A few sites also collected 12-hr samples. Continuous light scattering data collected by nephelometers were also available from the Meadview site, which is near the western end of the GCNP.

The MPP tracer was continuously emitted over a 50-day period from the MPP stack. This tracer was released at a rate proportional to the level of power production to maintain a constant tracer to SO_2 stack emission ratio. The average summer experiment emission ratio was: 73.3 g SO_2 per mg MPP Tracer (455,000 moles SO_2 per mole of MPP tracer). Tracer was sampled over 24-hour periods at 30 sites, and 12-hr data were also available from the Meadview and Hopi Pt. Sites in the GCNP. In addition, 15-minute samples were collected over a three-week period at Meadview and were used to construct 1-hour averages. Tracer samples were analyzed by electron capture gas chromatography².

In this paper a series of graphical plots and descriptive statistics were used to explore relationships between MPP tracer levels and levels of particulate sulfur, sulfur dioxide, and light scattering at a subset of monitoring locations near MPP for averaging times ranging from 1 hour to 24 hours. Monitoring locations selected were located “upwind” or to the south of MPP as well as “downwind” or to the north of MPP. Farber et al.³ showed that during the 1992 summer experiment the winds were from the southerly quadrant about 80% of the time. The 50-days were also grouped using a synoptic meteorological classification scheme as discussed in Farber et al.³

to determine the influence of meteorological factors on these relationships. Table 1 provides a listing of the monitoring stations used to conduct the analyses in this paper.

RESULTS

An exploratory analysis compared the data from a number of Project MOHAVE monitoring stations to determine whether any statistical correlations for MPP tracer to particulate sulfur, sulfur dioxide, and light scattering exist among these stations. Figure 2 provides a scatter matrix of 24-hour averages of particulate sulfur data collected for a coincident set of days. From visual inspection of this figure, it is readily apparent that particulate sulfur correlates well at nearly all stations. This is true for station pairs where one station is “downwind” of MPP and the other “upwind” of MPP such as ESSE/MEAD, YUCCA/DOSP, PARK/COCO, ESSE/COCO, and ESSE/OVBE as well as for station pairs whose stations were both upwind or downwind of MPP. As shown in Table 2, r-values are generally in the range of 0.7 to 0.9 at all locations with statistically significant r-values for all station pairs at the 95%-ile level. Of the 36 station pairs, 7 pairs had r-values exceeding 0.9 while 18 pairs had r-values exceeding 0.8. (It should be noted that due to missing data for the various pollutants, station pairs may be different in Tables 2, 3, and 4).

Interestingly, the mean particulate sulfur at sites upwind of MPP was virtually the same as the mean value at the downwind stations (when HOPO is excluded due to elevation and distance considerations). Despite the fact that the monitoring stations are separated spatially by 400km and by 2000m in elevation, these results are consistent with the view that the sulfate distributions over the study area have a generally similar regional character. This regional character is likely due to the strong influences of more distant source regions to the west (i.e., southern California) and south (northern Mexico) and by meteorological and chemical conditions that affect all stations more or less similarly. Figure 3 presents a time series of particulate sulfur during this period which also serves to further illustrate that particulate sulfur levels at nearly all monitoring sites exhibit similar temporal behavior although the concentration magnitudes may differ from site to site. This is true regardless of the particulate sulfur concentration level.

Figure 4 provides a scatter matrix for sulfur dioxide, which indicates much less agreement among station pairs than shown in Figure 2. The r-values are generally less than 0.5 as shown in Table 3, and fewer pairs are statistically significant. Even for station pairs that are “downwind of MPP”, the r-values are less than 0.6. Mean SO₂ concentrations were higher at the downwind sites than at the upwind sites.

The complex terrain surrounding MPP serves to complicate the transport and dispersion of the plume along preferred plume trajectories such that the MPP SO₂ plume unevenly impacts many locations. Small changes in wind direction can move the plume trajectory into any one of several nearby north-south oriented ridge-valleys. In addition, the effect of other SO₂ emission sources also complicates the spatial relationships. These results suggest that ambient SO₂ is not regionally homogeneous compared to particulate sulfur. Instead, the patterns suggest a more localized influence of SO₂ at some of the sites. This is an expected result since MPP is a substantial source of SO₂ in this region. Figure 5 provides a time series for sulfur dioxide. The

highest SO₂ levels, by far, occur at the Cottonwood Cove (COCO) site, which is 47km directly downwind of MPP.

Figure 6 provides the scatter matrix for the MPP tracer. Again, we see an overall lack of spatial correspondence between the tracer levels at any of the station pairs. Table 4 indicates that the r-values are generally less than 0.3 at most location pairs with several near zero, and only a few values are statistically significant. The only significant correlation occurred for the ESSE/PARK station pair both of which are located upwind of MPP, and likely reflects some random fluctuations of the tracer background since tracer levels at these two locations are low. As with SO₂, mean MPP tracer concentrations are higher at the downwind sites than at the upwind sites. Figure 7 shows the time series for the MPP tracer and reflects the lack of both spatial and temporal coherence in MPP tracer levels at the various monitoring sites.

Given this background information, an examination was next made of the relationships between particulate sulfur, sulfur dioxide, light scattering, and MPP tracer at the individual stations. Figure 8 provides a scatter plot of sulfur dioxide and MPP tracer at several locations. This figure indicates that at the downwind stations, as represented by the plotted stars, there is a statistically significant correlation between SO₂ and MPP tracer with r-values ranging from 0.5 to as high as 0.7 at Cottonwood Cove (COCO), the closest downwind location to MPP. At the Hopi Point (HOPO) site, there does not appear to be any significant relationship likely due to the fact that HOPO is located a relatively large distance from MPP (i.e., 240km), is relatively high in elevation, and is often affected by a different air mass than the lower elevation sites. The r-values at all downwind stations (with the exception of Hopi Pt.) are statistically significant at the 95%-ile level. Again, since MPP is a major SO₂ source in the region and the only source of the tracer, correspondence between the two data series should be expected.

Figure 9 provides a similar scatter plot for particulate sulfur and MPP tracer. The only downwind location with a statistically significant correlation is the Overton Beach (OVBE) site. This is an interesting and difficult to explain result. From the known transport patterns of the MP plume, the LVWA site should be at least comparatively impacted as the OVBE site. Yet, the correlation at LVWA is low and not significant. Oddly, although statistically significant correlations were also found at the upwind ESSE and YUCCA stations, their tracer levels are near zero and Figure 9 suggest that these correlations are spurious.

Figure 10 examines the relationship between light scattering (b_{scat}) and MPP tracer at Meadview. The Meadview location is of interest since it is the monitoring site closest to the western end of the GCNP. As this figure indicates, there is little correlation between the two variables and virtually none at the high tracer concentrations.

The analyses provided above deal with an averaging time of 24-hours. It is possible that over a 24-hour time period the MPP plume could impact the monitoring sites for shorter periods of time which may be masked by the 24-hour averaging period. At the Meadview site, 12-hr average particulate sulfur, SO₂, light scattering, and MPP tracer data were also available. Figure 11 provides a scatter plot of particulate sulfur and SO₂ as a function of MPP tracer for the 12-hr averaging period. For this shorter averaging time, SO₂ is again correlated with MPP tracer, having a statistically significant correlation (r) of about 0.5. Particulate sulfur is also statistically

correlated with MPP tracer, however, the correlation coefficient is very low, with the linear relationship explaining only about 16% ($r^2=0.16$) of the variability between MPP tracer and particulate sulfur. Figure 12 provides a similar plot for light scattering and MPP tracer and again shows virtually no correlation between the two variables for the 12-hour averaging period.

Finally, an examination was made of 1-hour average light scattering and MPP tracer data to assess whether any transient increases in light scattering could be associated with the presence of MPP tracer. Figure 13 provides a plot of these data. As is readily seen from this figure, there is no apparent relationship between the two variables even for this short averaging period. Unfortunately, there were no 1-hour average particulate data available for added comparisons.

In a recent analysis, White et al.⁴ examined available high time resolution data consisting of hourly averaged light extinction, methylchloroform, and water vapor concentrations at the Meadview location over a 3 week period during the study when the high time resolution tracer data were collected. This analysis examined transient haze events at the GCNP, which occurred during short-time averaging periods. Although hourly light scattering did not correlate with the MPP tracer as noted earlier, light extinction did track concentrations of methylchloroform and water vapor concentration, which served as tracers of opportunity for air from Southern California and southern Arizona/northern Mexico, respectively. Multiple linear regression of light extinction on MPP tracer, methylchloroform, and water vapor concentrations accounted for 74% of the observed variance, with methylchloroform and water vapor concentration the significant explanatory variables. The residual, representing extinction decoupled from the regional methylchloroform and water vapor concentrations, exhibited no evident relationship with the MPP tracer. That is, the MPP tracer independent variable added no explanatory power to the light extinction relationship.

A final set of analyses was done to examine whether the particulate sulfur/MPP tracer relationship at the downwind sites varied as a function of meteorological conditions. Farber, et al.⁵ described three principal summer synoptic meteorological regimes that influence the air quality of the southwestern United States. These patterns are described in Table 5. Each day of the summer 1992 intensive measurement period was classified according to one of the meteorological regimes shown in Table 5. With this daily classification, plots were then made of particulate sulfur vs MPP tracer for the 5 downwind sites. This classification resulted in a roughly equal number of days in each class. From Figure 14, we did not see any significantly different r-values when sorted by meteorological condition as compared to the r-values shown in Figure 9 although the r-values for the monsoonal meteorological class are marginally higher than the Figure 9 values. This suggests that even for “cloudy” monsoonal days when there might be a greater tendency toward sulfate production, there was scant evidence for downwind MPP particulate sulfur impacts. This result may not be surprising since the base of these convective clouds are at the top of the mixed layer. The MPP plume spends relatively little time in these clouds, and thus disperses in a generally drier environment.

CONCLUSIONS

In addressing the objective of this paper, the MPP plume was readily definable by the tracer, which in turn was statistically related to ambient sulfur dioxide concentrations. However,

the various analyses did not reveal any statistically significant relationships between the MPP tracer and ambient particulate sulfur concentrations or light scattering. The combination of the complexities of meteorology-terrain interactions, the influence of regional emission sources, and the uncertainties in the interaction of clouds and MPP SO₂ all combine to mask any “signal” from MPP on regional particulate sulfur and light scattering levels.

Over the course of the summer study, particulate sulfur levels were highly correlated across the Project MOHAVE network at locations both downwind and upwind of MPP. Mean particulate sulfur levels were also similar for at both upwind and downwind sites. This suggests a regional character for the spatial distribution of particulate sulfur. However, we did not see the same level of regional homogeneity for sulfur dioxide and MPP tracer throughout the network as with particulate sulfur even though MPP is a large source for sulfur dioxide and the only source of the tracer.

Correlations between SO₂, particulate sulfur and MPP tracer at Meadview located just west of the GCNP for the 12-hour averaging period remained low, and there was no correlation between light scattering and MPP tracer for any averaging period. Finally, when days were classified according to meteorological regime, there was no better agreement between particulate sulfur and MPP tracer as a function of meteorological regime. Thus, there was little evidence of MPP enhanced SO₂ conversion during these “cloudy” conditions.

The key uncertainty in the secondary particulate formation process appears to be the extent of MPP plume SO₂ interaction with clouds⁶. It is not at all surprising that there was a lack of a meaningful correlation between particulate sulfur and MPP tracer. MPP is geographically located in a dry summer climate that is occasionally interrupted by the influx of moisture from the Gulf of Mexico. Being in a dry climate, there is seldom an opportunity to form secondary particulate sulfur via the rapid aqueous phase chemical reactions involving plume-height clouds. Whatever particulate sulfur is formed in the MPP plume occurs via the much slower gas phase chemical pathways. Since the MPP plume interacts with a rural environment, oxidation conversion rates remain relatively low.

On a cautionary note, one should recall that the simple correlational analyses described above involved linear relationships. There may, however, be a non-linear relationship as might be expected in a situation involving the formation of secondary particulate formation. Nonetheless, the fact remains that neither the correlation analyses nor time series analyses showed any meaningful statistical relationships despite the fact that MPP is a large emitter of SO₂ and the only emitter of the tracer.

REFERENCES

1. Project MOHAVE Study Plan; US Environmental Protection Agency, Las Vegas, NV, 1991
2. Dietz, R. N.; “Perfluorocarbon tracer technology. *In Regional and Long-Range Transport of Air Pollution, Lectures of a course held at the Joint Research Center, Ispra, Italy*, 15-19 September 1996, Elsevier Science Publishers B. V. Amsterdam, 215-247.

3. Farber, R.; Hoffer, T. E; Green, M. C.; and Walsh, P., A., *JAWMA* **1997** 47, 383-394.
4. White, W. H., Farber, R. J., Green, M. C., Macias, E. S., Mirabella, V. A., Pitchford, M. L., and L. A. Vasconcelos, Accepted by *JAWMA*.
5. Farber, R. J.; Green, M. C.; Moran, W. A., “Meteorological Parameters Associated with Aerosol Episodes During Project MOHAVE Summer Intensive”, In *Proceedings of the 90th Annual Meeting of the AWMA*; Toronto, Canada, Paper No. 97-WA70.01, **1997**.
6. Project MOHAVE Final Report, March 1999, submitted to the US Environmental Protection Agency.

Table 1. Location of selected monitoring stations.

Station Name	Location Relative to MPP	Elevation (m-msl)
PARK (Parker, AZ)	118 km south	137
ESSE (Essex, CA)	80 km southwest	520
YUCCA (Yucca, AZ)	55 km southeast	579
COCO (Cottonwood Cove, NV)	47 km north	274
LVWA (Las Vegas Wash, NV)	112 km north	457
DOSP (Dolan Springs, AZ)	62 km north-northeast	1,007
MEAD (Meadview, AZ, located 20km from GCNP)	110 km north-northeast	902
OVBE (Overton Beach, NV)	160 km north-northeast	396
HOPO (Hopi Point, AZ, located at GCNP Visitor's Center)	275 km northeast	2,164
Mohave Power Project (source of tracer)		213

Table 2. Correlation coefficients (r) and descriptive statistics for particulate sulfur (24 coincident days).

	COCO (d)	DOSP (d)	LVWA (d)	MEAD (d)	OVBE (d)	HOPO(d)	ESSE(u)	PARK(u)	YUCCA (u)	Mean (ng/m3)	St Dev
COCO (d)	<u>0.96</u>	<u>0.89</u>	<u>0.94</u>	<u>0.93</u>	<u>0.62</u>	<u>0.87</u>	<u>0.79</u>	<u>0.76</u>	709	243	
DOSP (d)		<u>0.86</u>	<u>0.91</u>	<u>0.95</u>	<u>0.57</u>	<u>0.86</u>	<u>0.84</u>	<u>0.80</u>	568	210	
LVWA (d)			<u>0.86</u>	<u>0.91</u>	<u>0.49</u>	<u>0.81</u>	<u>0.59</u>	<u>0.55</u>	701	226	
MEAD(d)				<u>0.95</u>	<u>0.65</u>	<u>0.90</u>	<u>0.77</u>	<u>0.79</u>	561	184	
OVBE (d)					<u>0.61</u>	<u>0.89</u>	<u>0.69</u>	<u>0.73</u>	613	221	
HOPO(d)						<u>0.70</u>	<u>0.60</u>	<u>0.61</u>	385	120	
ESSE(u)							<u>0.65</u>	<u>0.68</u>	674	263	
PARK(u)								<u>0.86</u>	732	215	
YUCCA(u)									590	187	

Correlations significant at the 95th-%ile level are underlined

Table 3. Correlation coefficients (r) and descriptive statistics for sulfur dioxide (30 coincident days).

	COCO (d)	DOSP (d)	LVWA (d)	MEAD (d)	ESSE (u)	YUCCA(u)	Mean (ng/m3)	St Dev
COCO (d)		-0.08	<u>0.46</u>	0.01	0.11	-0.12	7967	3534
DOSP (d)			<u>0.44</u>	<u>0.73</u>	<u>0.68</u>	<u>0.40</u>	1909	1475
LVWA(d)				<u>0.56</u>	0.33	0.12	2453	1339
MEAD (d)					<u>0.59</u>	<u>0.55</u>	1005	736
ESSE (u)						<u>0.54</u>	1555	1046
YUCCA (u)							1066	1160

Correlations significant at the 95th-%ile level are underlined

Table 4. Correlation coefficients (r) and descriptive statistics for MPP tracer (25 coincident days).

	DOSP (d)	LVWA (d)	MEAD (d)	OVBE (d)	HOPO(d)	ESSE(u)	PARK(u)	YUCCA (u)	Mean (ng/m3)	St Dev
DOSP (d)		0.00	0.35	0.30	0.24	0.23	0.23	0.17	1.86	1.26
LVWA (d)			0.28	0.06	0.17	0.24	0.22	-0.23	1.13	0.87
MEAD(d)				0.19	0.11	0.28	0.32	-0.18	1.25	0.76
OVBE (d)					0.32	0.34	0.34	0.04	1.17	0.72
HOPO(d)						0.07	-0.08	0.32	0.24	0.15
ESSE(u)							<u>0.78</u>	0.36	0.51	1.36
PARK(u)								0.35	0.10	0.05
YUCCA(u)									0.17	0.12

Correlations significant at the 95th-%ile level are underlined

Table 5. Dominant summer synoptic weather patterns in the southwestern US.

Pattern	Description	Most Frequent Time of Occurrence
Thermal Low (monsoon)	Thermal low in the mixed layer with southwesterly flow but with moist and unstable southeasterly flow aloft	Mid-July to September
Summer Trough	Strong southwest flow in the mixed layer and aloft; often moisture is present	April to early July and September to October
Dry Ridge	Southwest flow in the mixed layer with dry westerly flow aloft	Most common in May

Figure Captions

Figure 1. Map of the Project MOHAVE study area.

Figure 2. Scatter plot of 24-hour average particulate sulfur (24 coincident days).

Figure 3. Time series of 24-hour average particulate sulfur.

Figure 4. Scatter plot of 24-hour average sulfur dioxide (30 coincident days).

Figure 5. Time series of 24-hour average sulfur dioxide.

Figure 6. Scatter plot of 24-hour average MPP tracer (25 coincident days).

Figure 7. Time series of 24-hour average MPP tracer.

Figure 8. Scatter plot of 24-hour average sulfur dioxide and MPP tracer.

Figure 9. Scatter plot of 24-hour average particulate sulfur and MPP tracer.

Figure 10. Scatter plot of 24-hour average light scattering (bscat) and MPP tracer at Meadview.

Figure 11. Scatter plot of 12-hour average particulate sulfur, sulfur dioxide and MPP tracer at Meadview.

Figure 12. Scatter plot of 12-hour average light scattering (bscat) and MPP tracer at Meadview.

Figure 13. Scatter plot of 1-hour average light scattering (bscat) and MPP tracer at Meadview.

Figure 14. Scatter plot of 24-hour average particulate sulfur and MPP tracer by meteorological class.

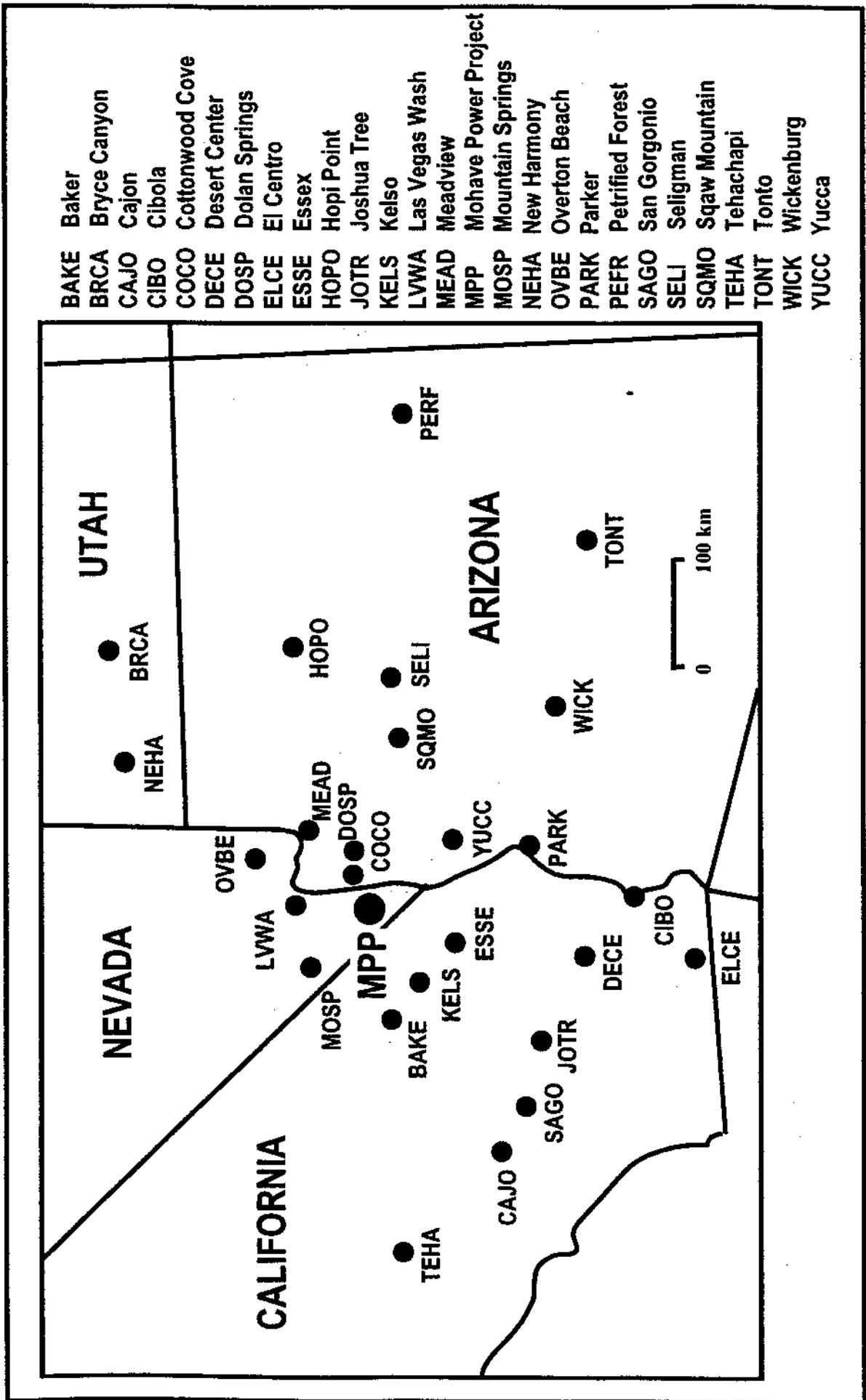


Figure 1. Map of the Project MOHAVE study area.

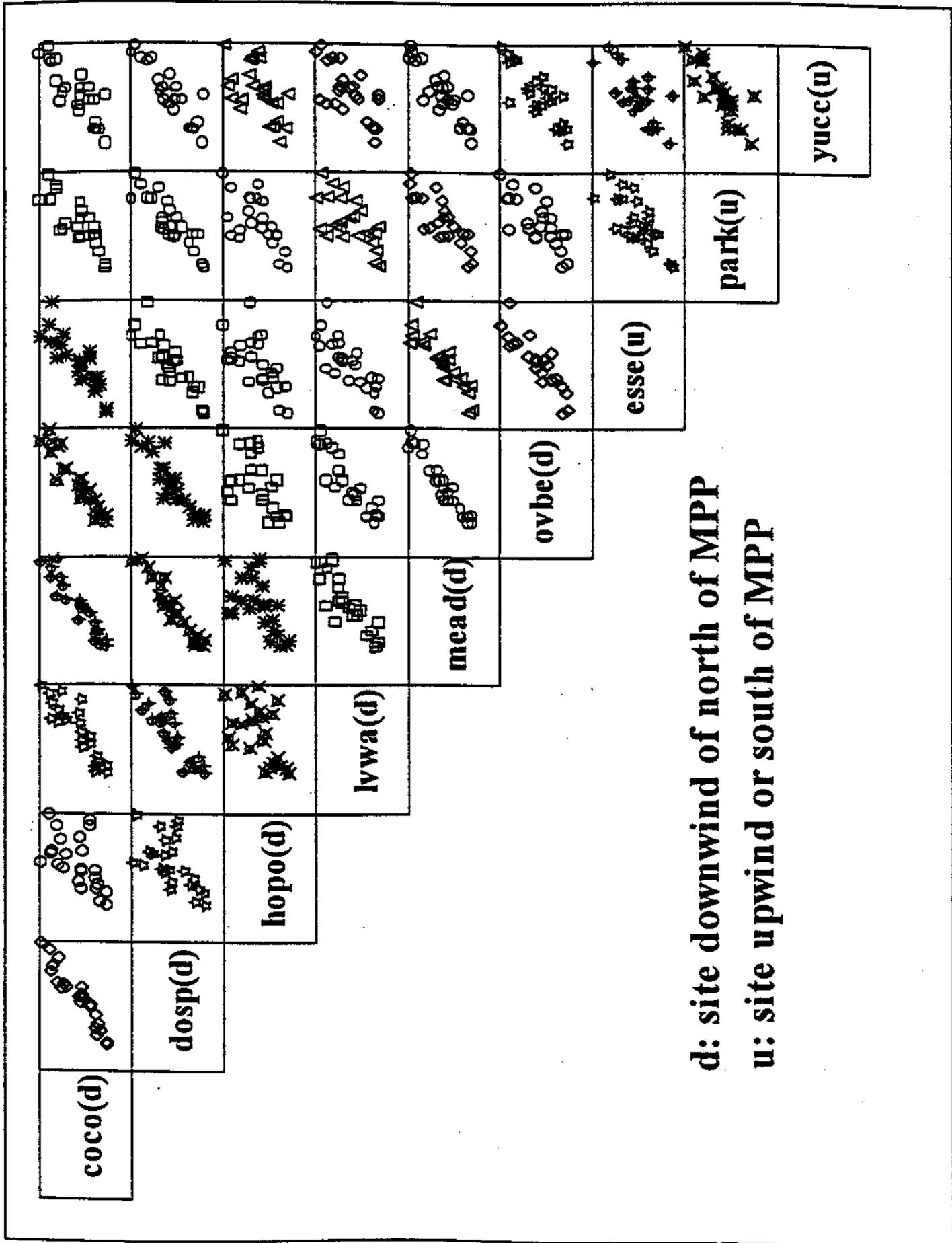


Figure 2. Scatter plot of 24-hour average particulate sulfur (24 coincident days).

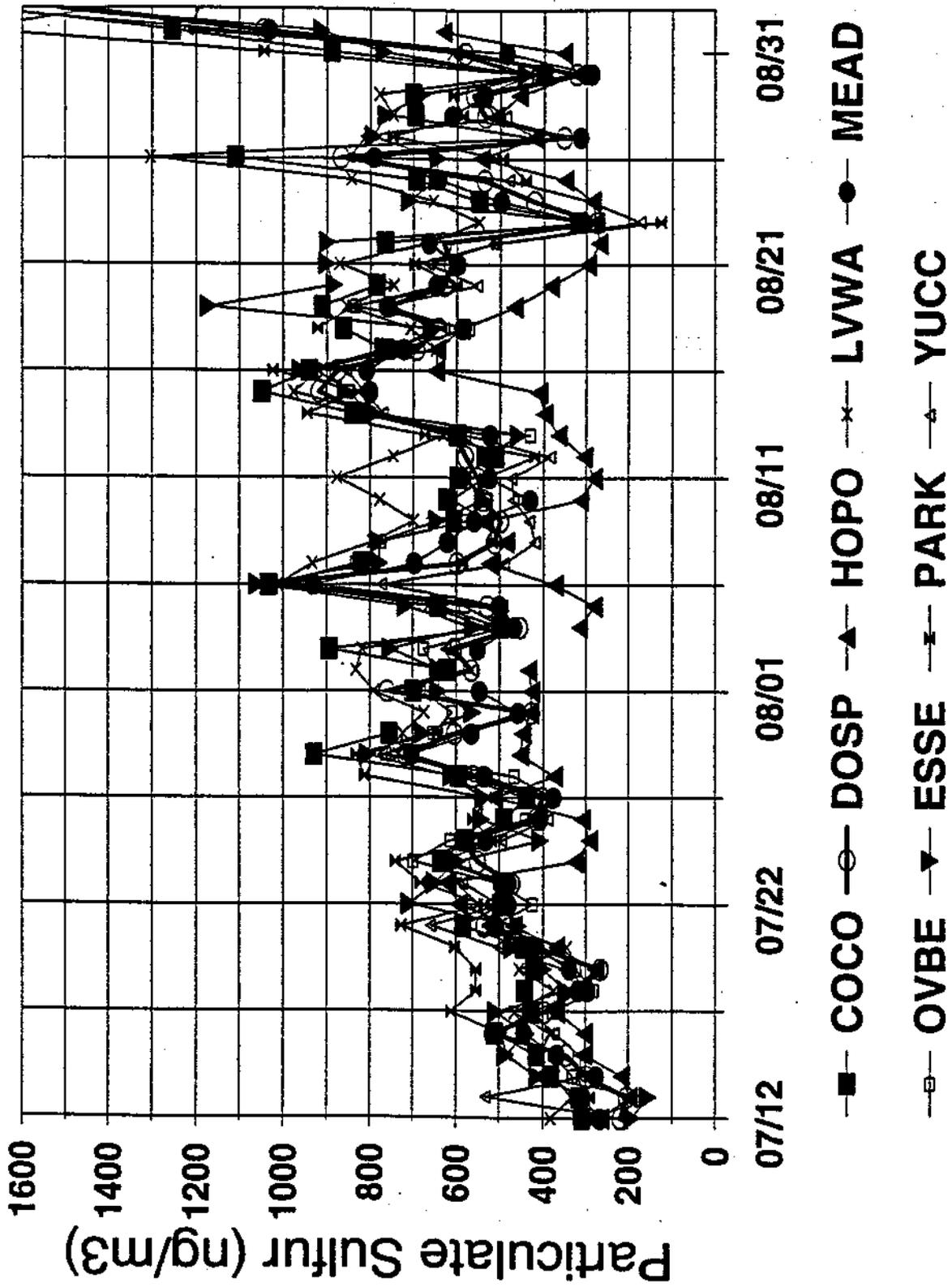


Figure 3. Time series of 24-hour average particulate sulfur.

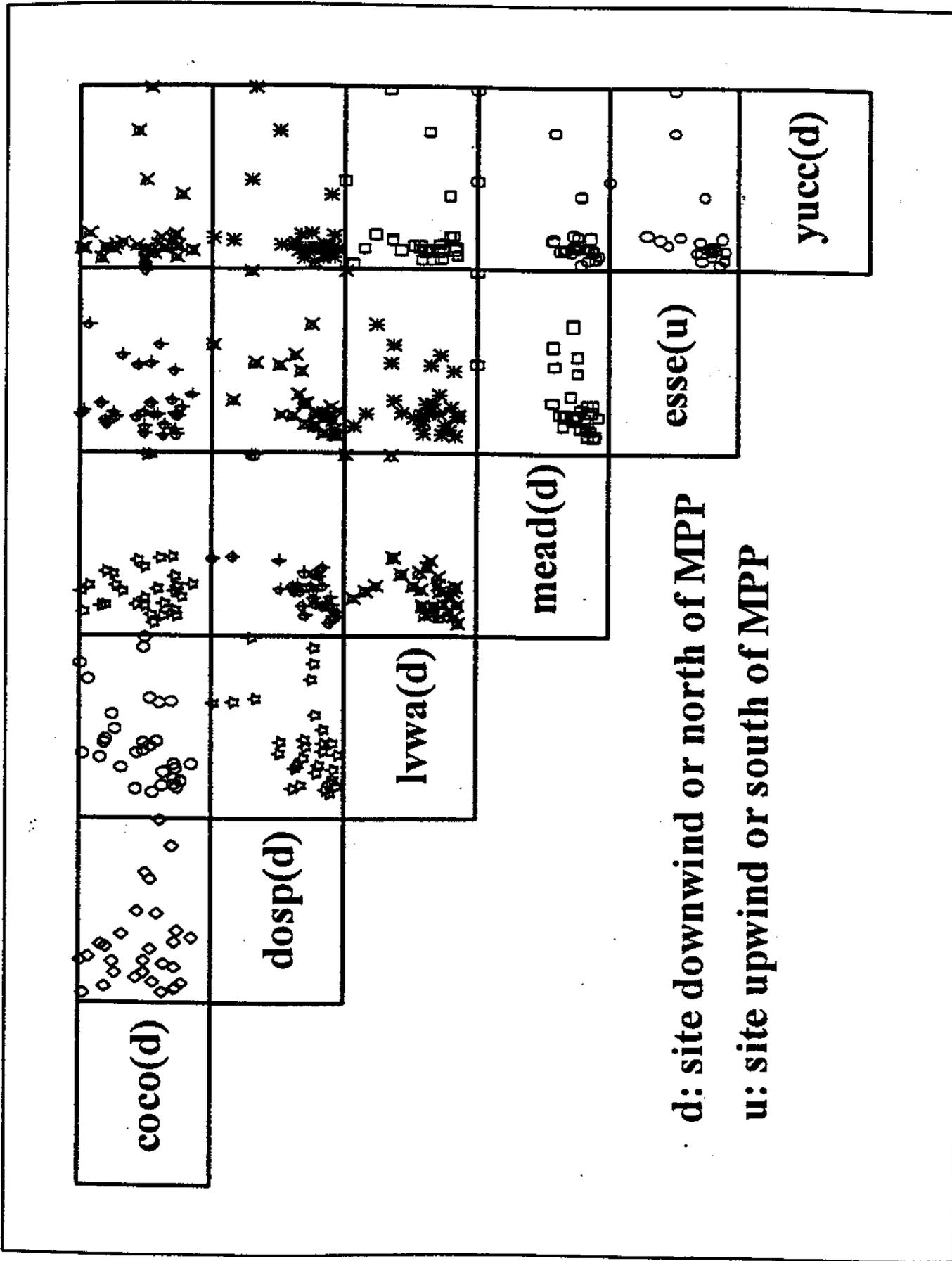


Figure 4. Scatter plot of 24-hour average sulfur dioxide (30 coincident days).

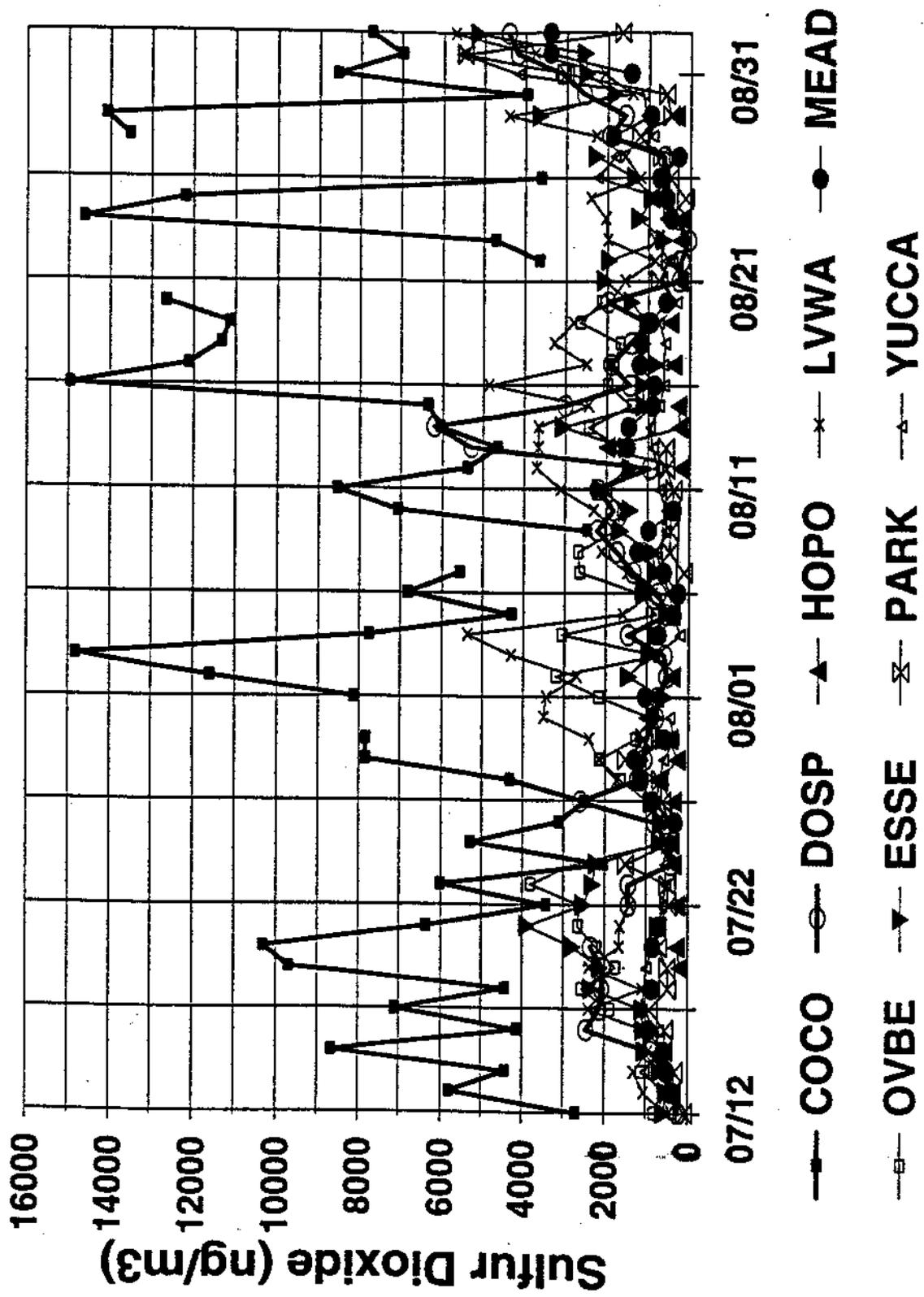


Figure 5. Time series of 24-hour average sulfur dioxide.

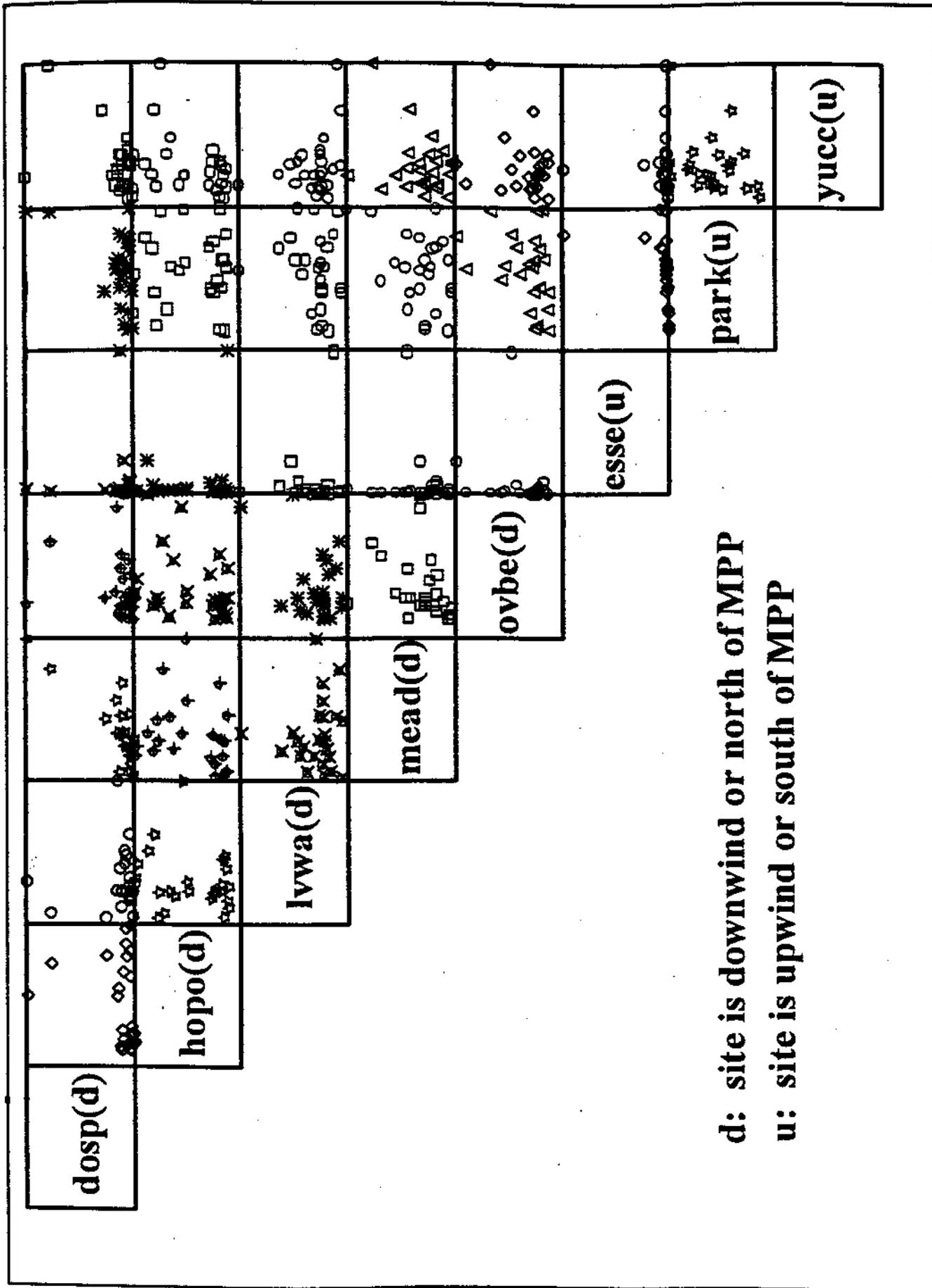


Figure 6. Scatter plot of 24-hour average MPP tracer (25 coincident days).

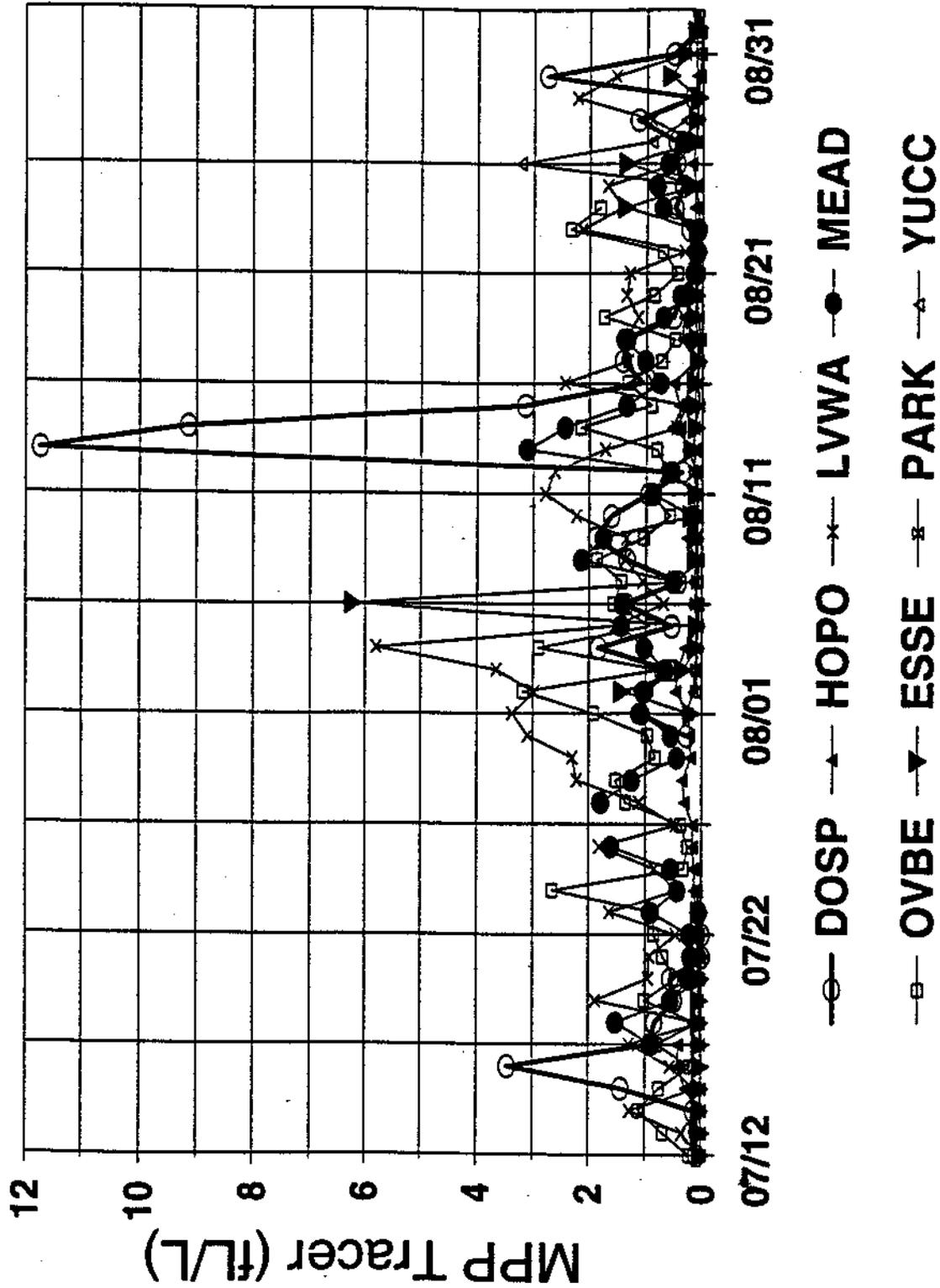
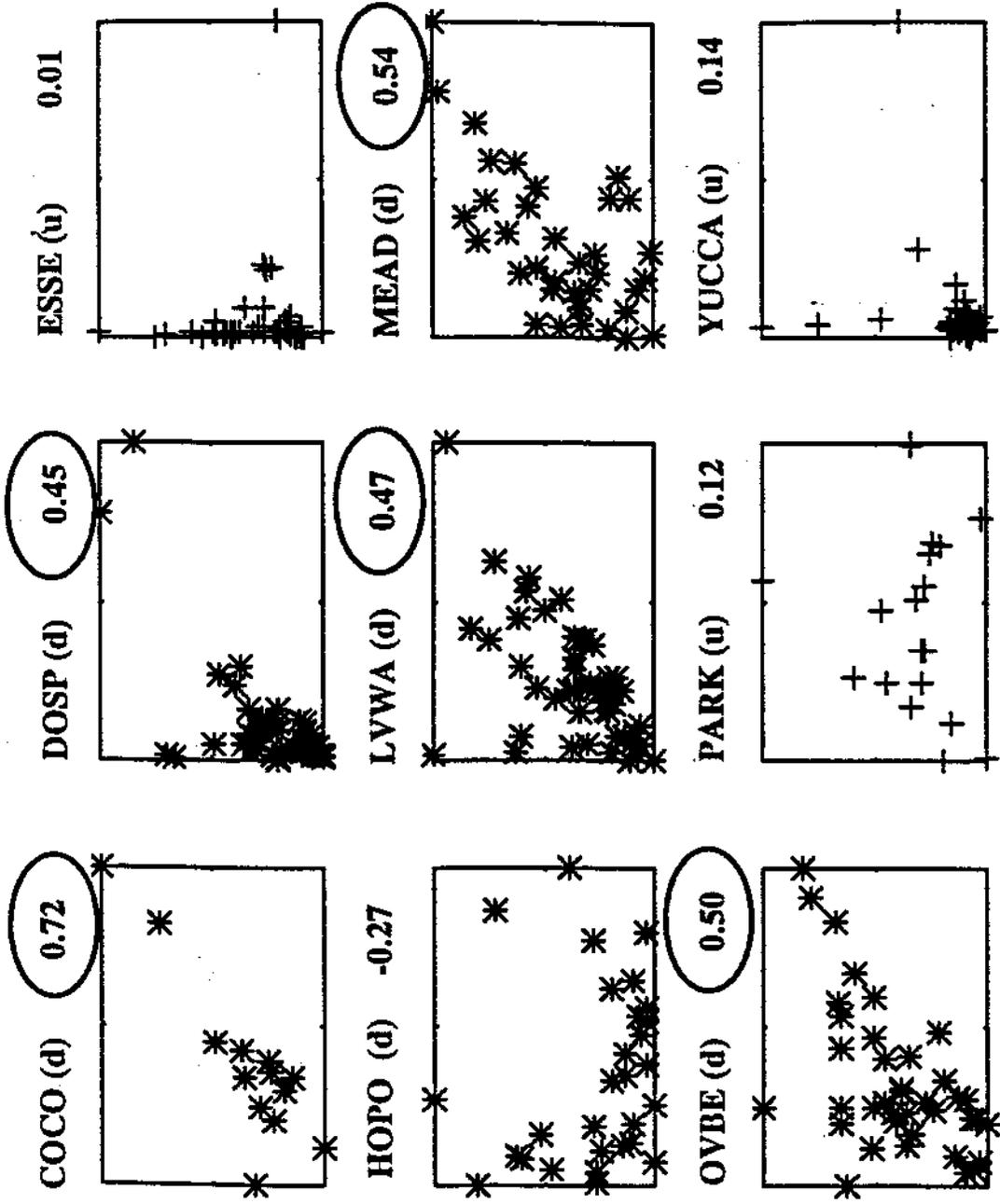


Figure 7. Time series of 24-hour average MPP tracer.

Sulfur Dioxide

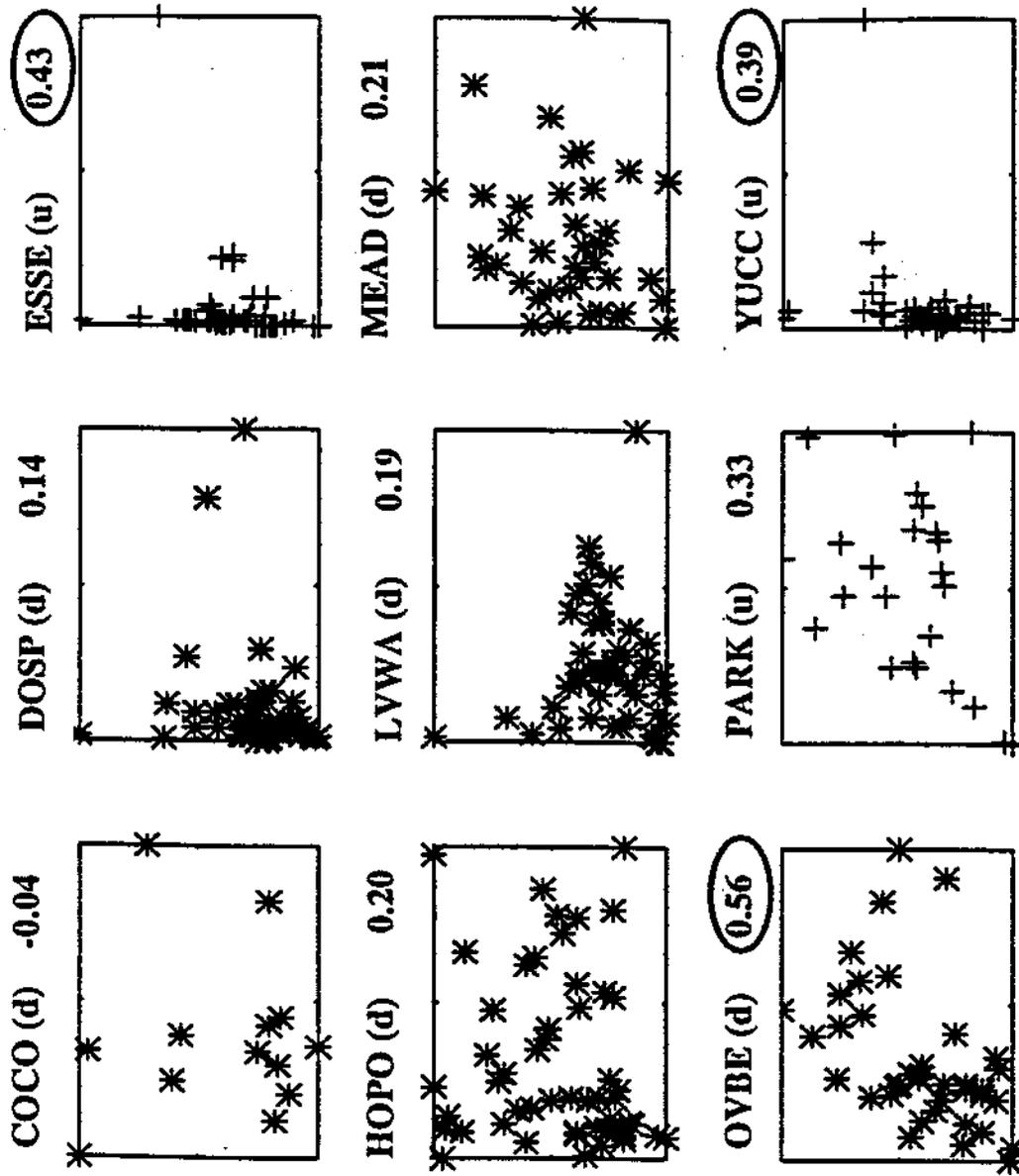


MPP Tracer

Circled r values are significant at 95% -ile level

Figure 8. Scatter plot of 24-hour average sulfur dioxide and MPP tracer.

Particulate Sulfur



MPP Tracer

Circled r values are significant at 95%-ile level

Figure 9. Scatter plot of 24-hour average particulate sulfur and MPP tracer.

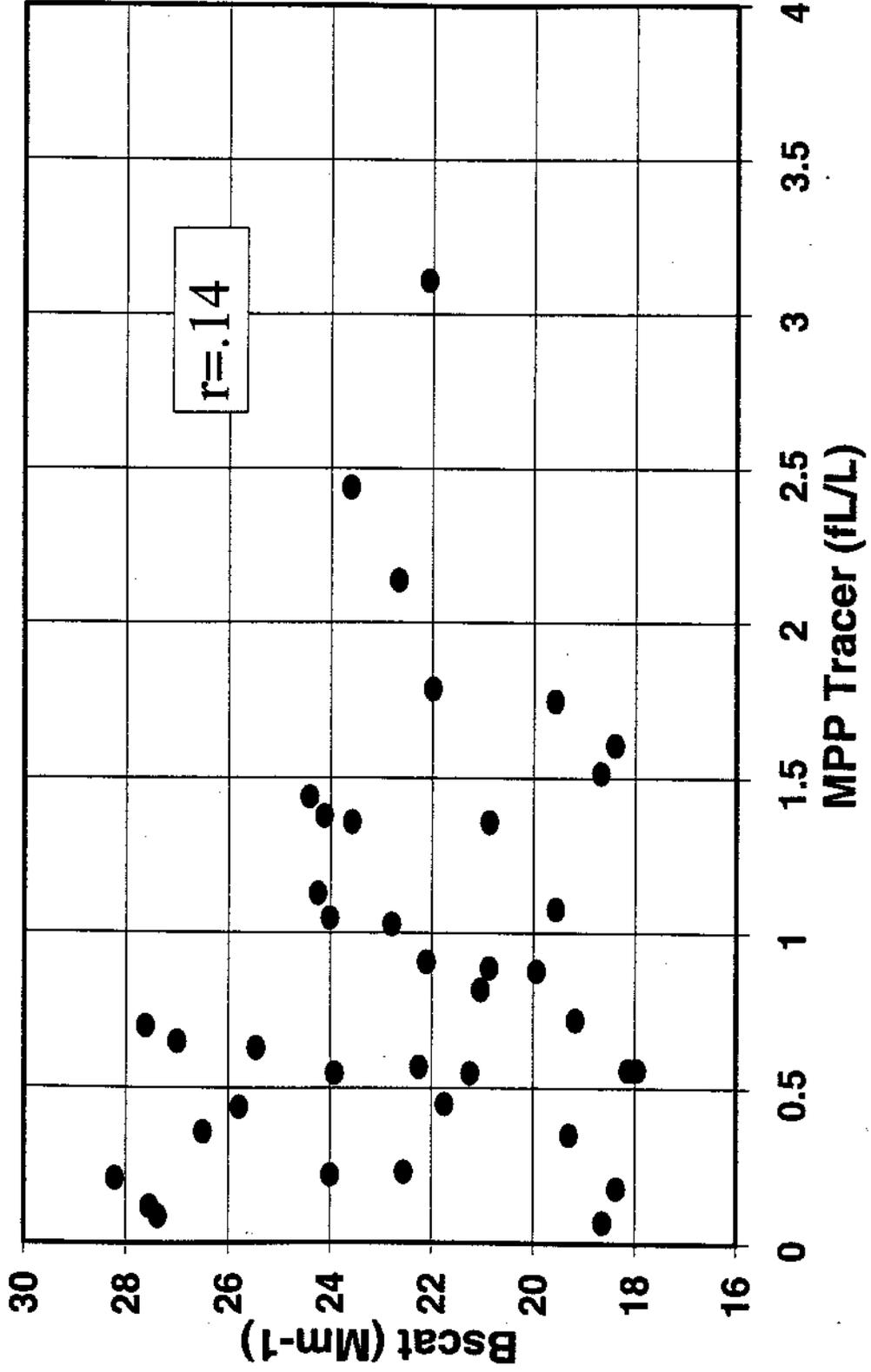


Figure 10. Scatter plot of 24-hour average light scattering (bscat) and MPP tracer at Meadview.

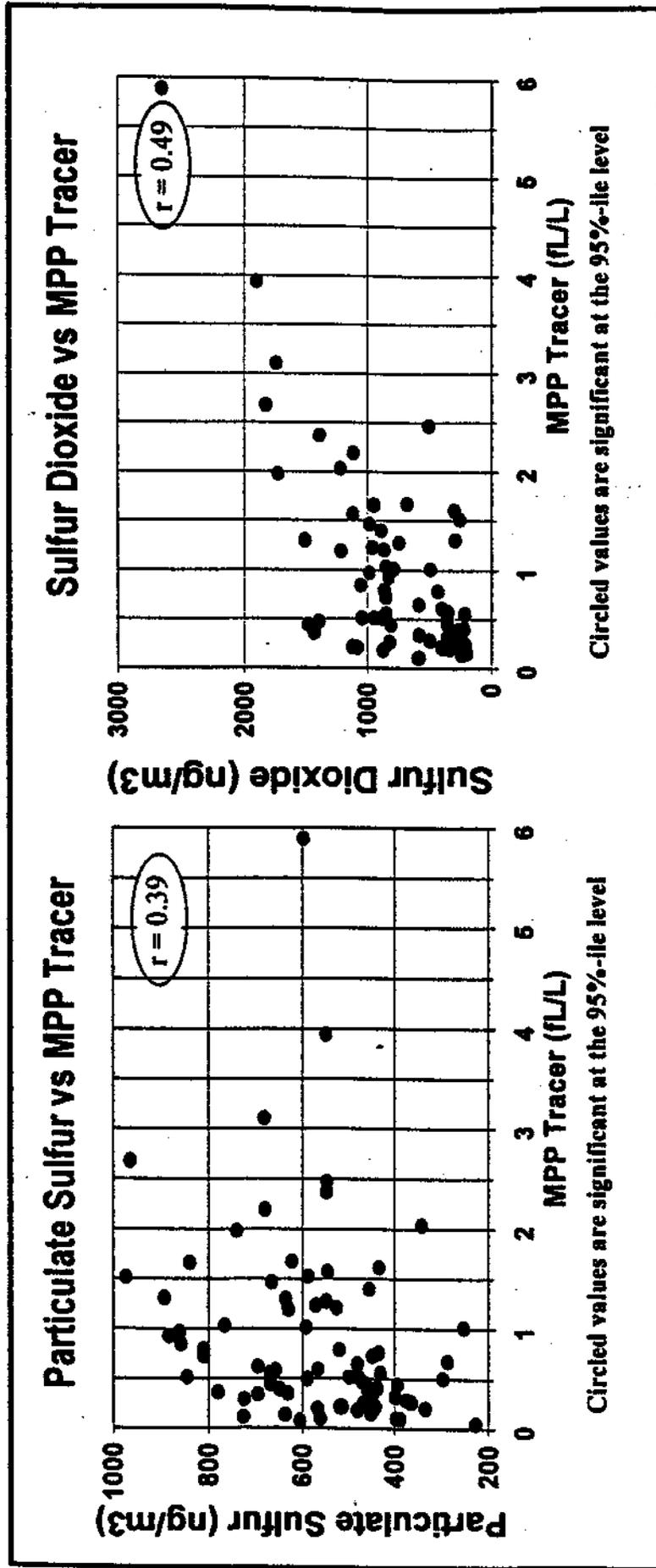


Figure 11. Scatter plot of 12-hour average particulate sulfur, sulfur dioxide and MPP tracer at Meadview.

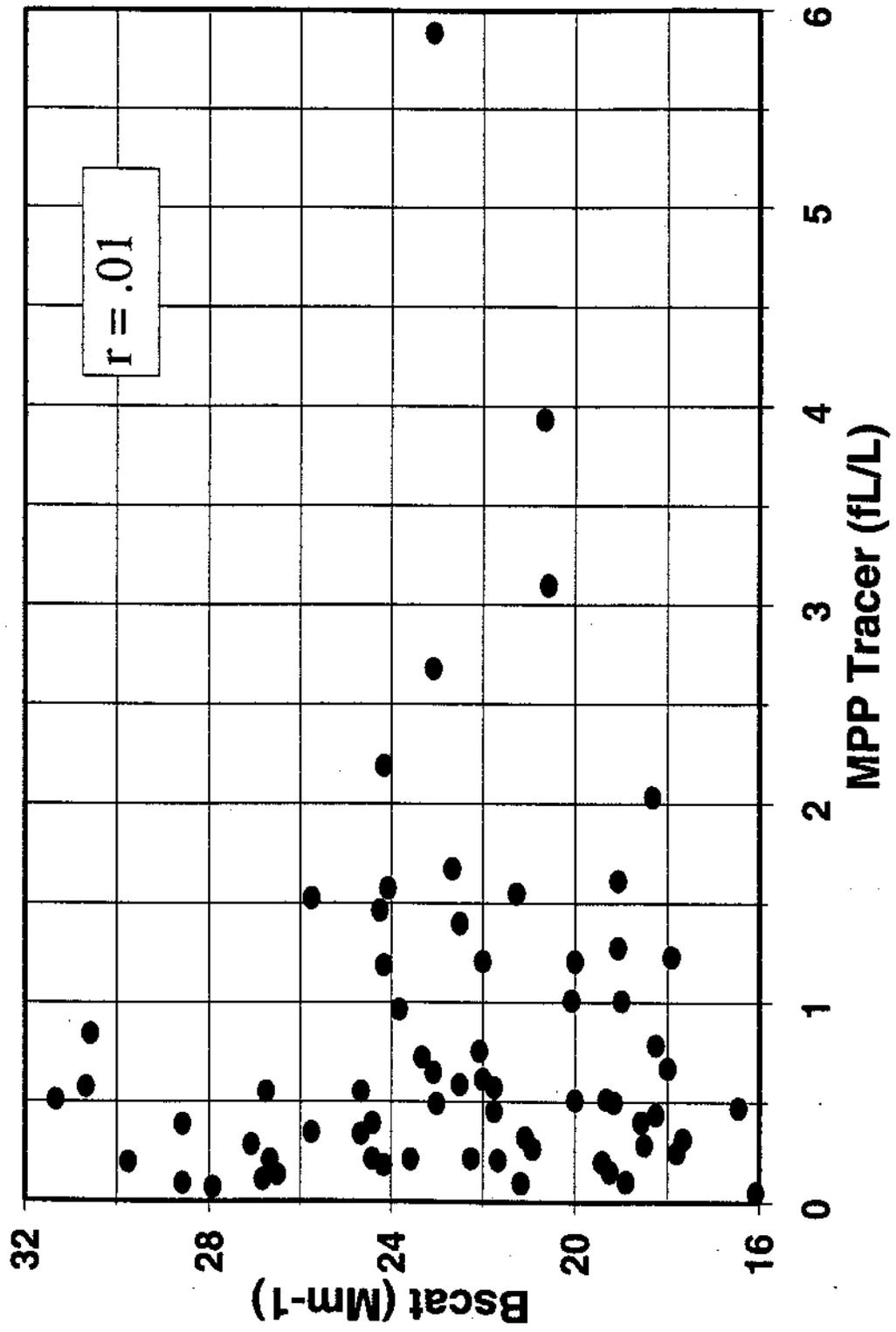


Figure 12. Scatter plot of 12-hour average light scattering (bscat) and MPP tracer at Meadview.

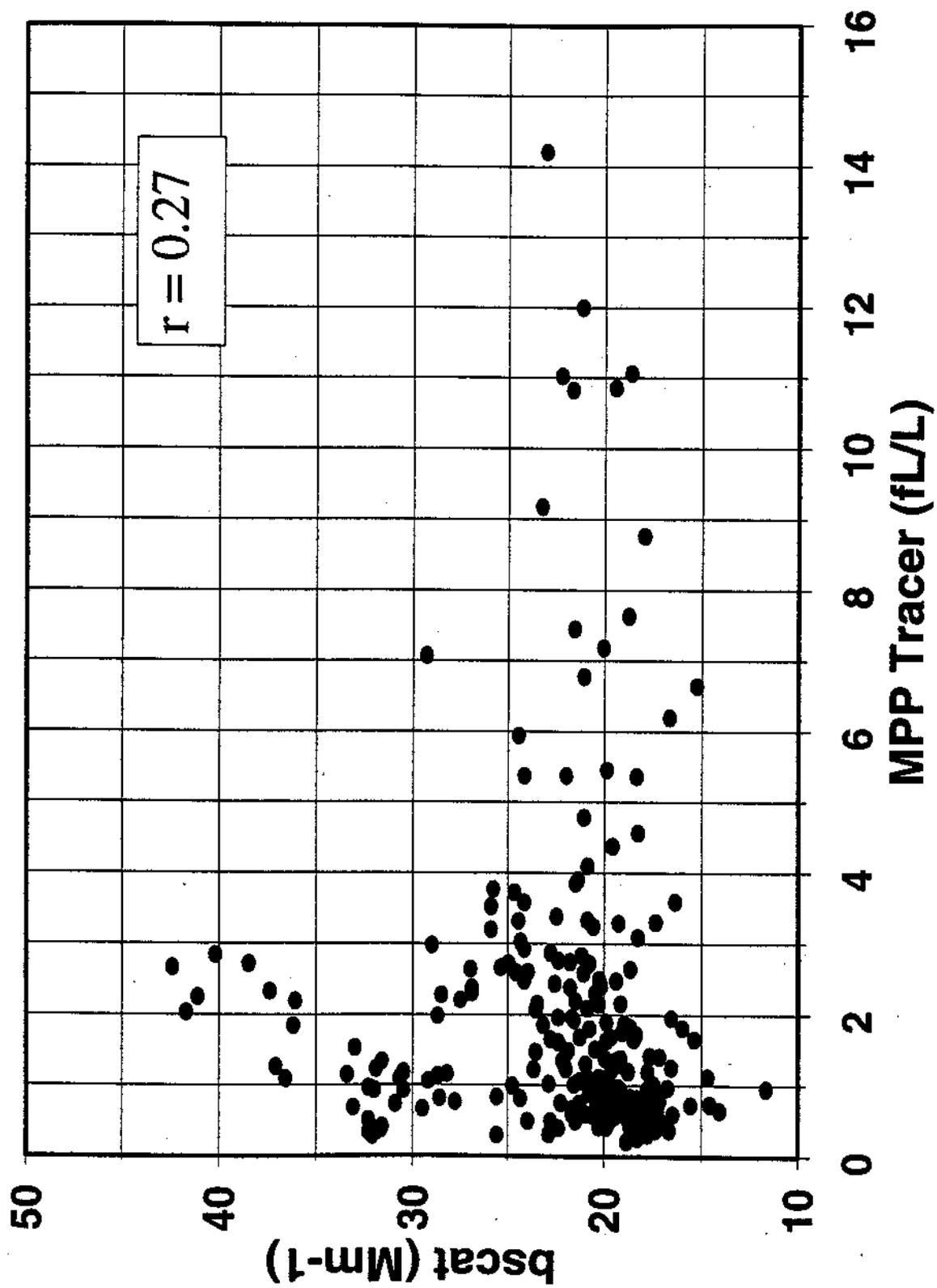


Figure 13. Scatter plot of 1-hour average light scattering (bscat) and MPP tracer at Meadview.

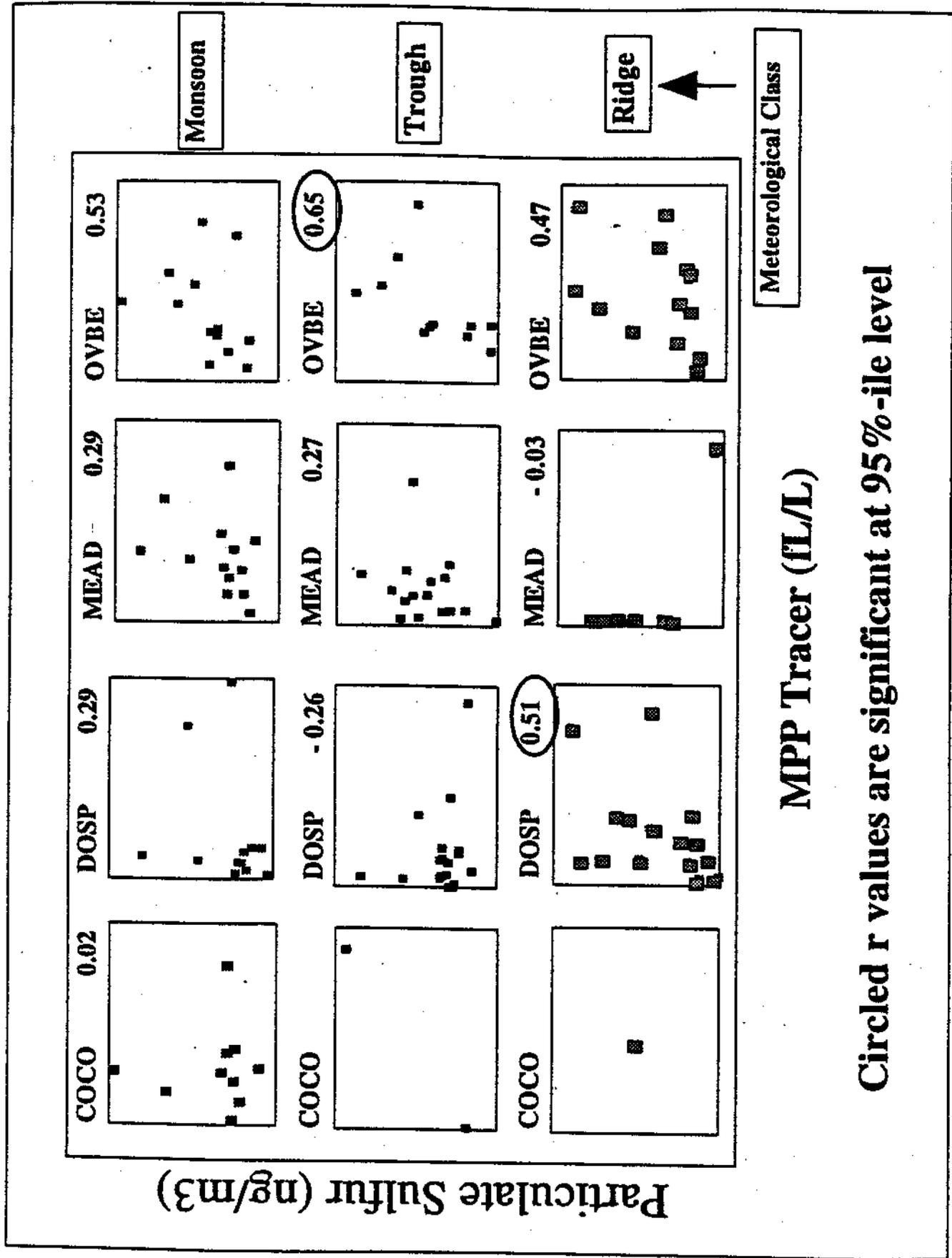


Figure 14. Scatter plot of 24-hour average particulate sulfur and MPP tracer by meteorological class.