Appendix A

A Source Apportionment Analysis of the Dearborn Speciation Trends Network Site

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Summary

The Dearborn site in Detroit, MI has some of the highest ambient fine particulate concentrations within USEPA's Region 5 with levels ranging between 16.8 to 19.8 $\mu g/m^3$ for 2001 to 2004. In order to better characterize ambient fine particulate in areas such as Detroit, USEPA established the Speciation Trends Network (STN) in 2001 and a monitoring station at Dearborn in 2002. This network measures a variety of elements, ions and carbon fractions which constitute ambient $PM_{2.5}$. One of the primary uses for this data has been to determine and estimate what types of sources affect ambient concentrations in order to implement controls and bring an area into attainment with the National Ambient Air Quality Standards. One such source apportionment tool which has been proving successful in estimating source contributions is the Positive Matrix Factorization (PMF) model. This technique decomposes the data matrix consisting of measured ambient species concentrations into a source profile and a source contribution matrix.

This work examined data from the STN site at Dearborn from May 2002 to December 2004 using PMF. The results show that nine possible sources contribute to ambient fine particulate concentrations measured at the site. These include soil, metals processing, diesel, secondary sulfates, secondary nitrates, road salt, motor vehicles, vegetative burning and industrial sources (petroleum refining and electrical utilities). Motor vehicles contribute approximately 25% of the total fine particulate with secondary sulfates and nitrates contributing 22% and 18%, respectively. When compared to other sites within the Region, the Dearborn site has higher contributions from soil, metals processing, diesel and industrial sources which may explain the higher ambient total $PM_{2.5}$ measured concentrations. The soil contribution may also be influenced by rock crushing and cement production facilities in close proximity to the site. Trajectory analyses show that many of these source categories are upwind of the Dearborn site on days when source contributions are elevated.

Introduction

With the promulgation of the National Ambient Air Quality Standards (NAAQS) for fine particulate matter, the United States Environmental Protection Agency established the national Federal Reference Method monitoring network to determine attainment status for many areas across the country. The measurements taken at the Dearborn, MI site are among the highest recorded in Region 5 with 2001 to 2004 annual averages ranging between 16.8 to 19.8 $\mu g/m^3$. The site is categorized as a neighborhood scale site located on an elementary school. The area around the monitor is heavily industrialized with the Ford Motor Company's River Rouge

manufacturing facility located just west of the site. There are also several other large industrial sources such as steel manufacturing and electrical generating facilities within a 50 mile radius. Because of the large amount of industry in the area, there are also many miles of rail freight and interstate traffic traversing the area which could also affect ambient $PM_{2.5}$ concentrations.

In order to better characterize areas such as Dearborn, the USEPA established the Speciation Trends Network (STN) in 2001. All of the STN sites collect data describing ambient concentrations for a variety of elemental species, organic and elemental carbon, as well a sulfates, nitrates and ammonium ions. Because of the higher concentrations and the relatively dense industry of the area, an STN monitor was started at the Dearborn site in the early part of 2002. One of the priorities of the STN network is to use the data collected to determine potential source contributions in an area. One such tool developed to estimate the influence of sources is Positive Matrix Factorization (PMF) which is a multivariate statistical approach. This technique decomposes the data matrix from the STN into source profile and contribution matrices. There is no need to have a set of measured source profiles on hand as is the case with the Chemical Mass Balance (CMB) method. However, PMF does require a large amount of data since the results center around the mean of the data's distribution unlike the CMB model which is calculated on a day by day basis.

Methodology

Positive Matrix Factorization is a multivariate statistical approach which decomposes the concentration based measurement matrix into a source profile and source contribution matrix, respectively, and can be represented by the following equation.

$$X=GF+E$$

where :
- X is the matrix of measured species concentrations over time
- G is the source contribution matrix
- F is the source profile matrix
- E is the matrix of random errors or differences between the model results and the original data

The above equation is solved iteratively using software designed by Pentti Paatero of the University of Helsinki in Finland. The data for the Dearborn site in the Detroit metropolitan area were polled from AQS and cover the time period of approximately May 2002 to August 2004. Measurements at this site were collected on a 1 every 6 day sampling frequency. The data were processed to compute individual species uncertainties which are used to describe one's confidence in the collected measurement. This allows the model to find a solution based on species whose measurements have a greater confidence than others. For example, species are categorized as "good", "weak" or "bad" depending on the number of concentrations reported as below the detection limit. "Bad" variables are completely omitted from the analysis and do not play any role in the solution. "Weak" variables are heavily downweighted to a point where their relative uncertainties are much higher than the "good" variables. This means that the model places little importance on using these species to find a final solution.

Therefore, the values of the "good" variables have the greatest influence on the model's final solution. A total of 106 observations and 41 "good" and "weak" variables were utilized for the analysis.

To determine where possible sources are located, the HYSPLIT trajectory model was used. Four backward trajectories per day were calculated going back in time a total of 48 hours per trajectory. The results of the analysis were summarized using an incremental probability where the trajectories were divided up into individual cells and the probability of having a trajectory pass through a cell was calculated. Each probability was then weighted according to the magnitude of the daily contribution to the mean contribution of the source. In other words, days with contributions below the mean were less than one, days near the mean were close to one and days having contributions much larger than the mean were greater than one. These values were plotted on a map to show highly likely areas where these sources may be located.

Results

Figure 1 shows the resulting identified source profiles for the Dearborn monitor.

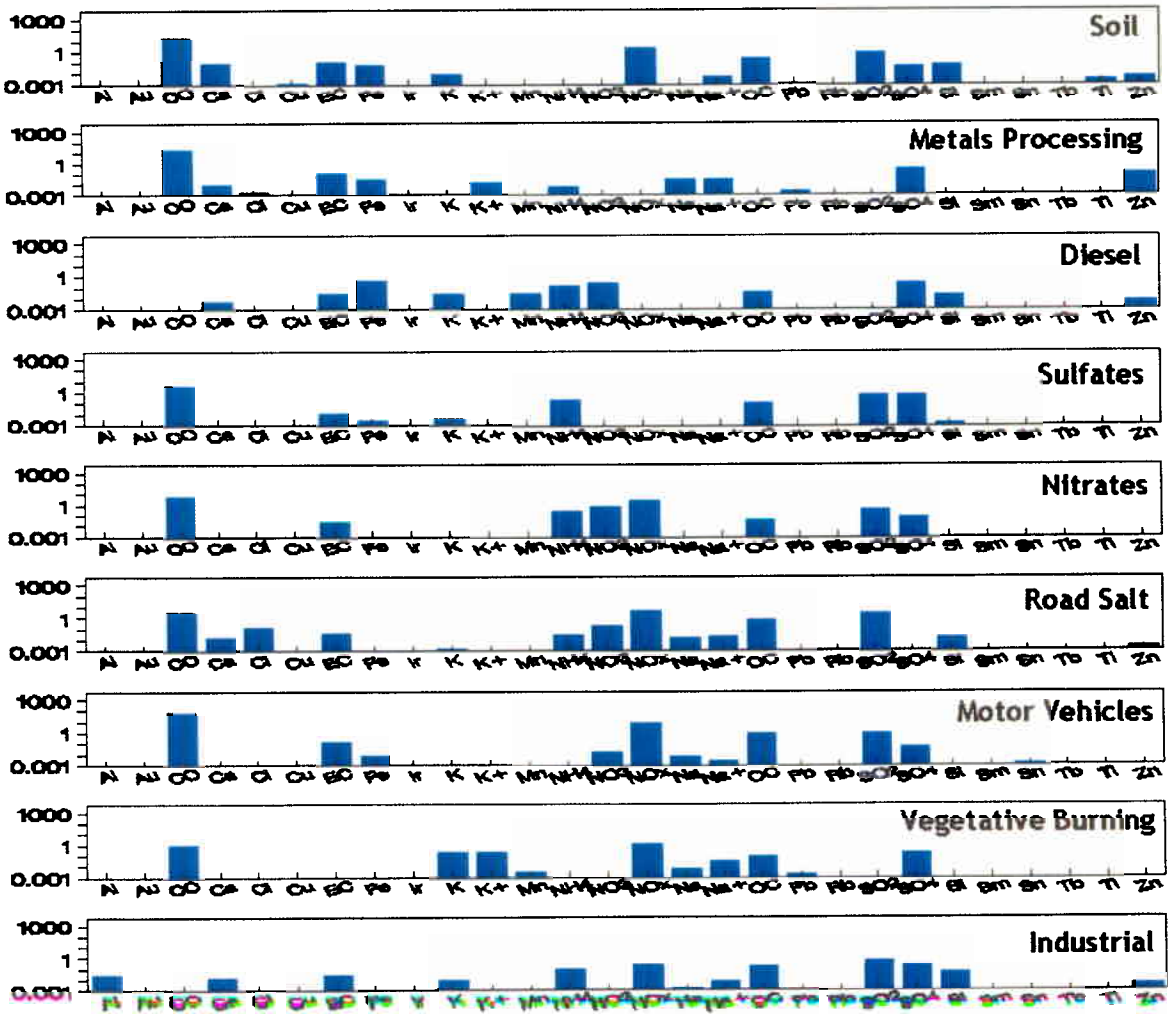


Figure 1. Source profiles for Dearborn STN site

The various source categories were identified according to specific species within each profile. Soil had the highest calcium loading along with loadings of silicon. Metals processing had the highest loadings of zinc and lead. Iron and manganese loaded the highest on the diesel along with elemental and organic carbon. The sulfate and nitrate ions loaded the highest on the secondary sulfate and secondary nitrate sources, respectively. Chlorine loaded the highest on the road salt source. The motor vehicles source had carbon monoxide and high loadings for elemental and organic carbon fractions as well as NOx. Elemental potassium and the potassium ions were the markers for vegetative burning. Finally, the industrial source was characterized using aluminum, silicon, zinc, organic and elemental carbon.

Figure 2 shows the source contributions over the time period analyzed at Dearborn.

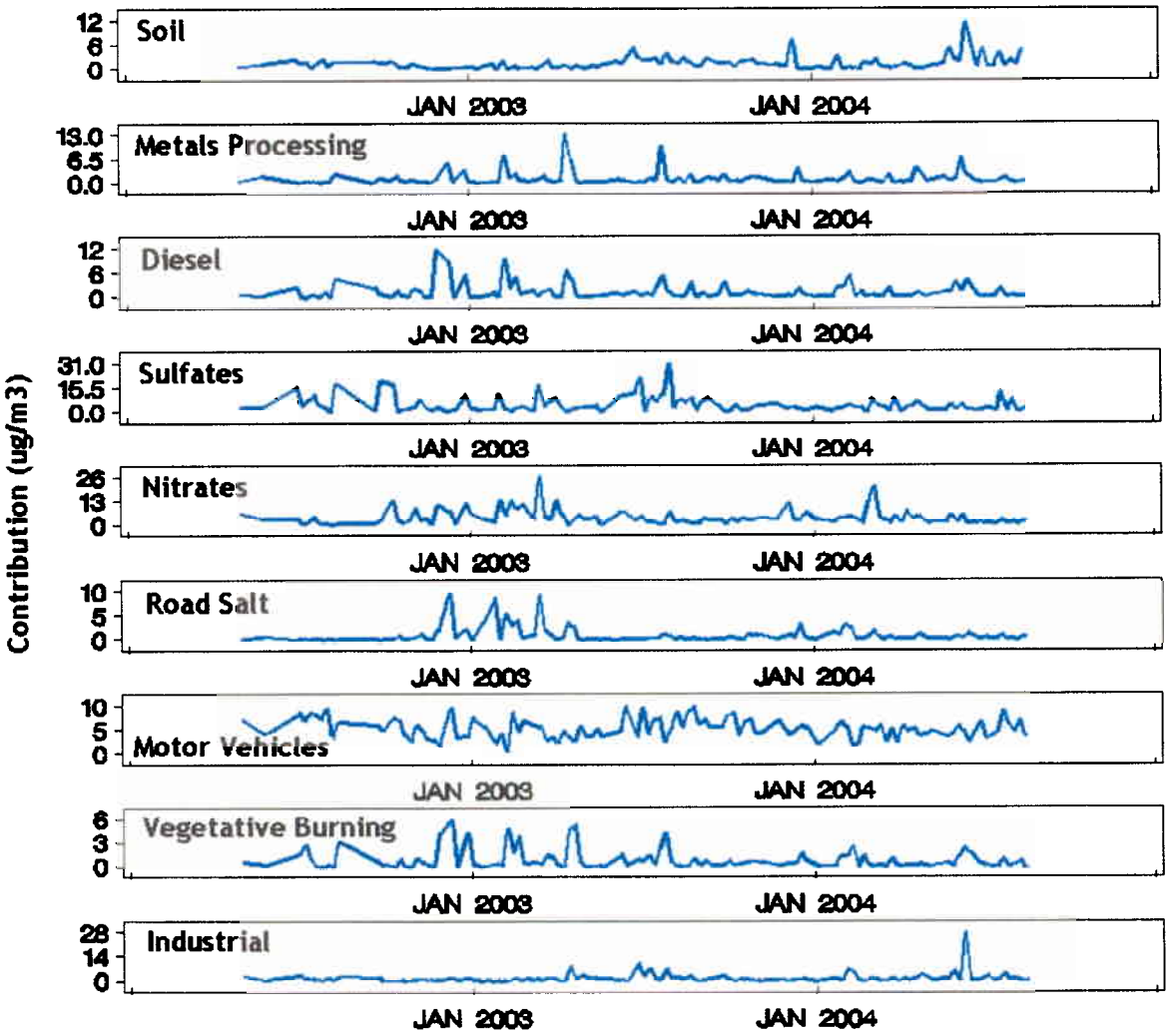


Figure 2. Source contributions for the Dearborn STN site

Table I shows the summary statistics for the source contributions at the Dearborn monitor.

Table I: Summary Statistics for the Source Contributions at the Dearborn Monitor

Source	Average ($\mu g/m^3$)	Std. Dev. ($\mu g/m^3$)	Minimum ($\mu g/m^3$)	Maximum ($\mu g/m^3$)	Percent
Soil	1.4	1.6	0.0	11.2	7%
Metals Processing	1.1	1.9	0.0	12.9	5%
Diesel	1.3	2.0	0.0	11.2	6%
Sulfate	4.6	5.1	0.0	30.3	22%
Nitrate	3.7	4.2	0.0	25.9	18%
Road Salt	0.8	1.7	0.0	9.1	4%
Vehicles	5.3	2.0	0.5	9.7	25%
Burning	0.9	1.2	0.0	5.7	4%
Industrial	1.7	3.1	0.0	27.3	8%

The above results show that the majority of the fine particulate seen at the Dearborn site is caused by secondary sulfates with secondary nitrates and motor vehicles contributing approximately the same amount. Figure 2 shows that many of the sources impacting the Dearborn site are episodic such as soil, industry, road salt and vegetative burning. Other sources such as motor vehicles contributions are more uniform throughout the year.

Table II shows the comparison between the Dearborn site and four other STN sites in Region 5.

Table II: Comparison of the Dearborn Site with Four Other STN Sites in Region 5

Source	Detroit (Dearborn)	Chicago	Detroit (Allen Park)	Indianapolis	Mayville, WI
Soil	1.4	0.6		0.3	0.4
Industrial (Utility and Petroleum Refineries)	1.7	0.2	0.7	0.7	0.5
Road Salt	0.8	0.5	0.4		
Fe/Mn (Qualified Diesel)	1.3	0.1	0.2	0.2	1.5
Vehicles	5.3	4.1	5.9	5.9	2.1
Nitrates	3.7	3.3	3.5	2.9	3.2
Sulfates	4.6	5.4	5.0	6.8	3.9
Steel (Metals Processing)	1.1	0.4	0.3	1.3	
Vegetative Burning	0.9	0.9	0.9	0.2	0.9
Copper		0.1	0.1		
Total $PM_{2.5}$	20.8	15.5	16.9	18.4	12.4

In general, the Dearborn site has some of the highest ambient concentrations in Region 5. The total PM2.5 from the source apportionment analysis shows that Dearborn is considerably higher than the other urban locations. When examining the individual source contributions between the five sites, there is a comparable influence from secondary sulfates and nitrates across all five sites suggesting that these species are regional in nature. Vegetative burning is comparable across all of the sites as well as road salt and motor vehicles. Figures 3 through 5 show maps of areas where winds passed through on their way to the monitoring site. Areas in warmer colors represent areas where the source contribution was high when compared to its individual average contribution. Cooler colors represent areas winds traveled through when the source contribution was low compared to its mean.

Figure 5. Incremental Probability Map for Vegetative Burning at Dearborn

Figure 4. Incremental Probability Map for Secondary Nitrates at Dearborn

Figure 3. Incremental Probability Map for Secondary Sulfates at Dearborn

Figure 3 shows that high sulfates are seen on days when winds pass through Indiana or Ohio. Likewise, Figure 4 shows that high nitrate concentrations occur when the winds come from areas west, southwest and east of Detroit. This phenomenon is indicative of transport from these areas to the Dearborn site. In the case of sulfates, this is due to secondary formation in the atmosphere from emissions further upwind possibly from the Ohio River Valley's power generating stations. Secondary nitrates are formed from atmospheric reactions involving NOx and ammonia emissions. The map shows that the primary transport of nitrates to Dearborn occurs when winds cross over Indiana into Ohio and the primary transportation corridor between Chicago and Toledo, OH as well as from western Ontario. The vegetative burning contributions occur with winds coming from the central Illinois and northern Indiana regions which are predominantly rural. Furthermore, there are spikes in the burning contributions during the winter which may indicate possible residential wood burning.

Figures 6 through 8 show the incremental probability maps for the diesel, steel processes and industrial source categories, respectively.

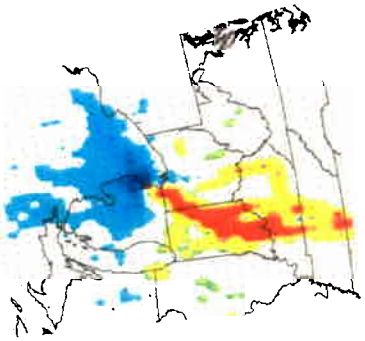


Figure 8. Incremental Probability Map for Industrial Sources at Dearborn

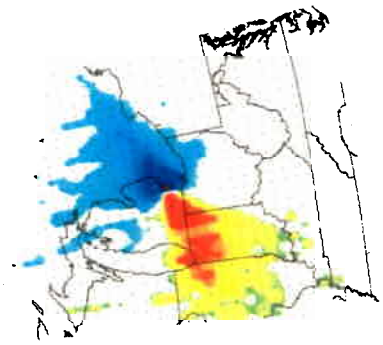


Figure 7. Incremental Probability Map for Steel Processes at Dearborn

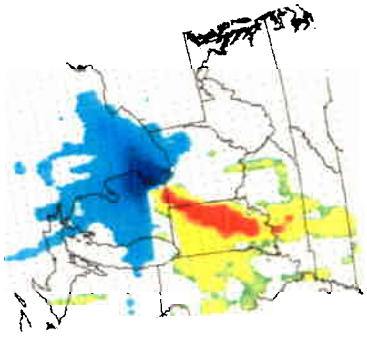


Figure 6. Incremental Probability Map for Diesel at Dearborn

The diesel map shows that on days with winds from the southwest through Indiana and into Detroit have the highest diesel contributions. The industrial and steel processing source maps show a similar picture. The area around the Dearborn monitor is heavily industrialized with steel processing facilities, various automotive manufacturing plants, power plants, major rail staging yards and interstate highways as well as international highways between the United States and Canada. Figure 9 demonstrates that the influence of local sources for the steel processing source category can be shown by plotting wind trajectories color coded for the magnitude of the contribution. The dots represent locations of sources in the Detroit Metropolitan area classified by their individual Standard Industrial Classification (SIC) codes. The size of the dot represents the distance weighted emissions from the facility. This weighting takes into account facilities which are very close to the monitoring site. For orientation purposes, major roads and interstates are also plotted. Only the days where the contribution was greater than the average contribution are displayed. All of the trajectories trace winds as they are approaching the Dearborn STN site.

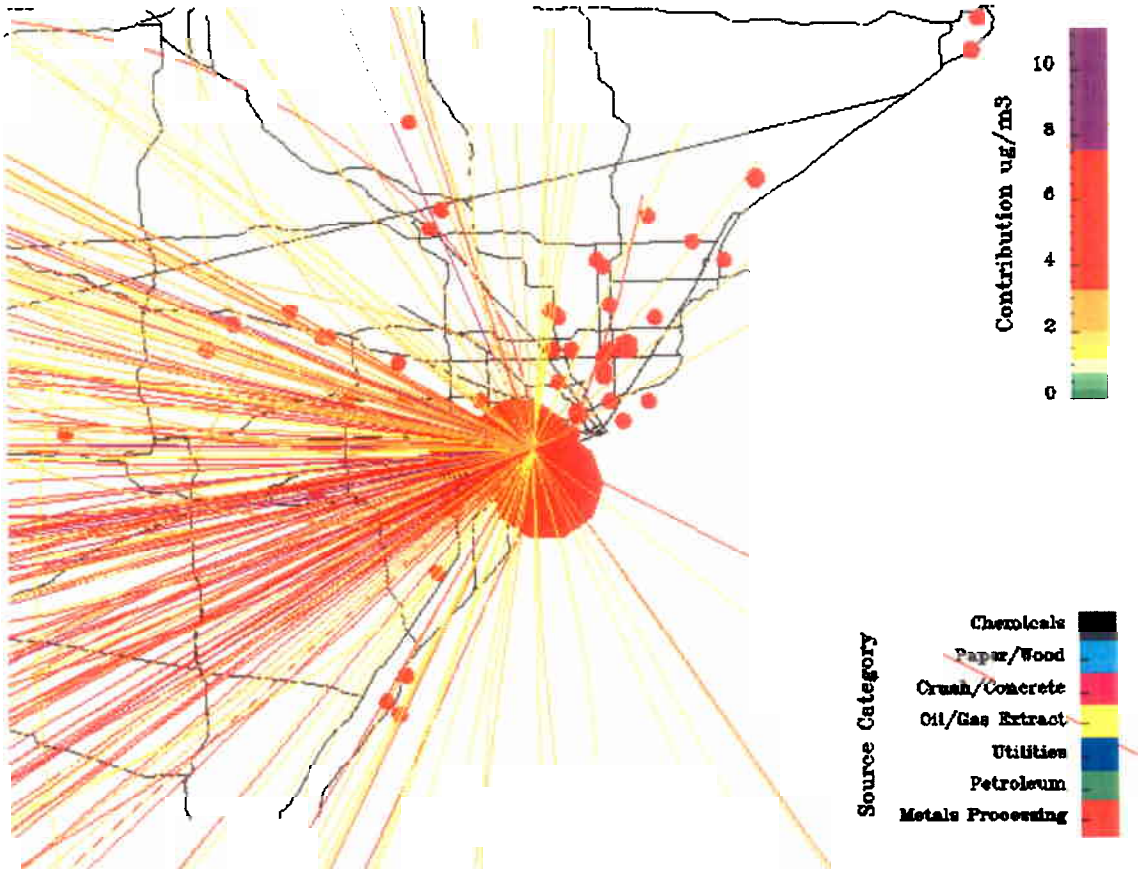


Figure 9. Pollution Trajectory Map for Steel Processes

The previous figure shows a very directional influence on the steel source contribution. Many of the trajectories pass over facilities associated with steel processing. However, on days when the contribution is in the red or purple range, the vast majority of the trajectories pass through a central steel facility directly adjacent to the monitoring site.

When examining the diesel contribution, Figure 10 shows that the contributions are somewhat less directional than the steel. This would be due to the vast network of major roads and interstates which pass around the Dearborn site. Highest diesel contributions, however, still come from the west and southwest which is consistent with the steel source.

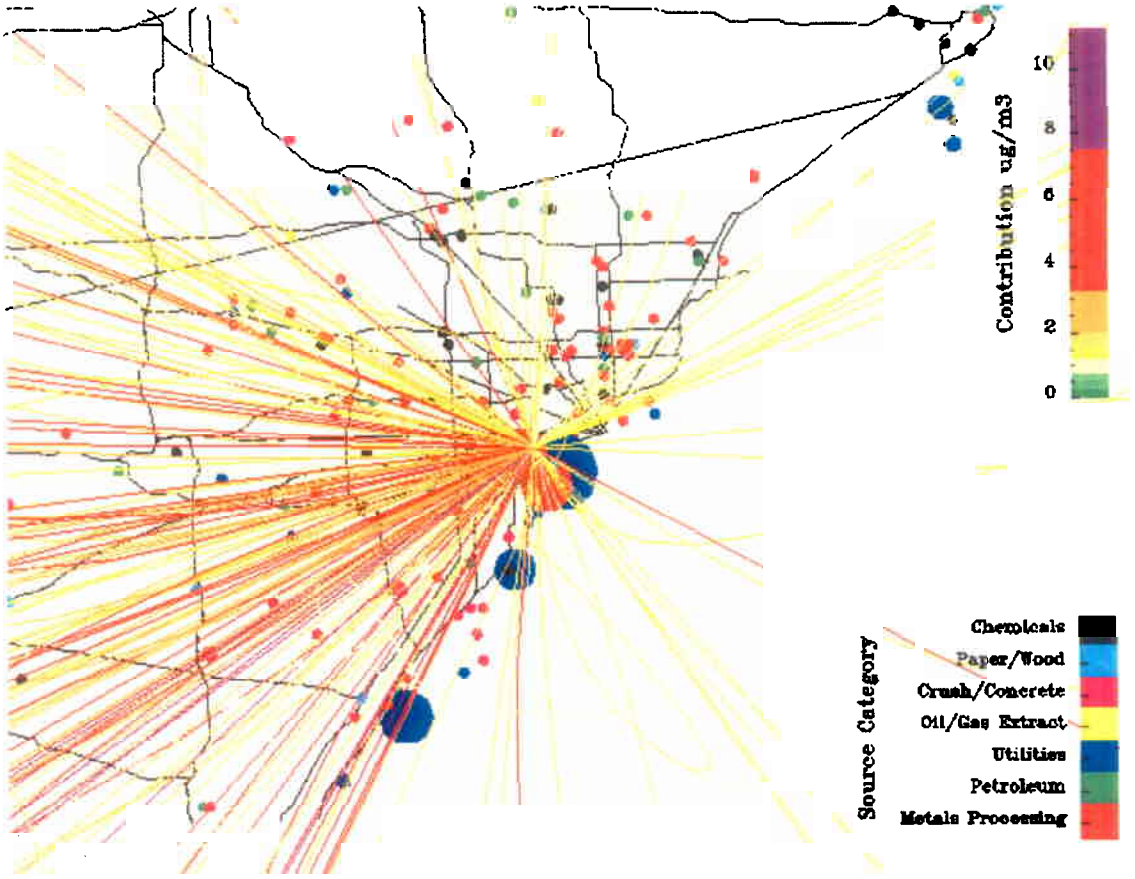


Figure 10. Pollution Trajectory Map for Diesel

Figure 11 shows the pollution rose map for the industrial source category. This category includes petroleum processing facilities such as asphalt and refining plants as well as power generating utilities.

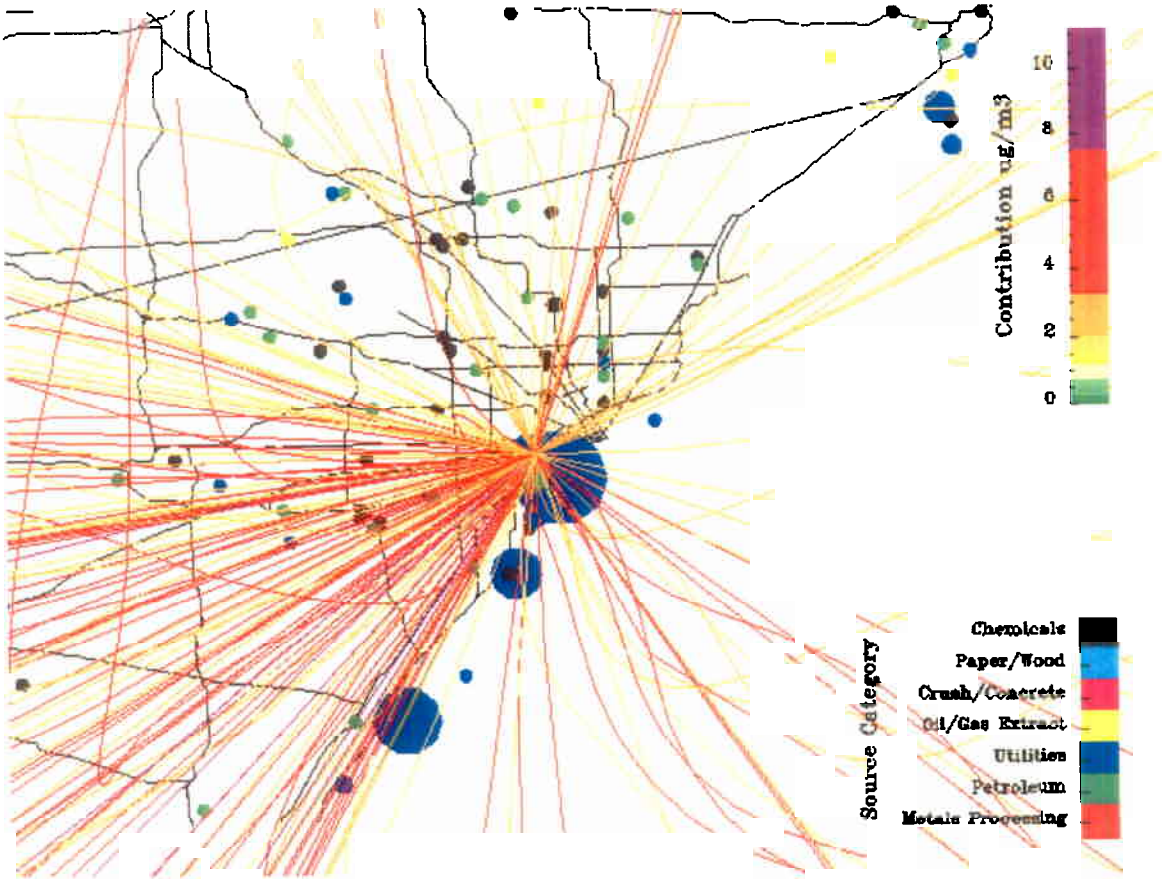


Figure 11. Pollution Trajectory Map for Industrial Sources

As can be seen in Figure 11, many of the trajectories pass over influential petroleum facilities and utilities within relatively close proximity of the monitoring site. However, due to the ability for fine particle emissions to travel large distances, utility and petroleum refining emissions from outside of the area at facilities located in northern Ohio, Indiana or central Michigan may also influence local $PM_{2.5}$ concentrations adding to the general metropolitan area's emissions.

Another source which has a larger contribution at Dearborn as compared to the other sites examined in the Region is the soil source. This particular source may be influenced by local emissions from rock crushing and concrete facilities in the metropolitan area upwind of Dearborn. Figure 12 shows on days when there was a large contribution to ambient fine particulate concentrations from soil, winds passed over rock crushing or concrete facilities upwind of Dearborn. Since crushed rocks and concrete processing emits fine particulate with similar chemical compositions, these processes could be adding to the soil component which would explain the elevated soil contribution when compared to the other four sites.

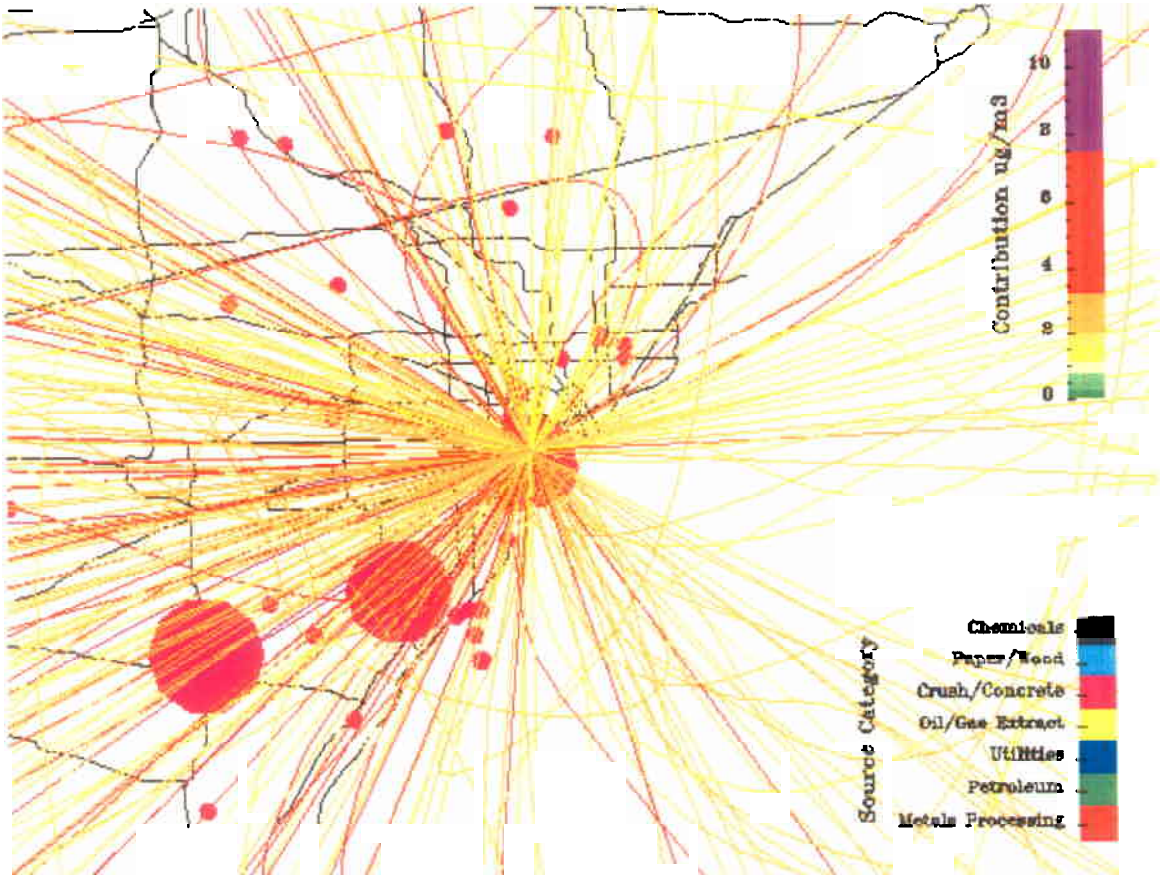


Figure 12. Pollution Trajectory Map for Soil

Conclusions

1. The Dearborn fine particulate matter monitoring location has some of the highest PM concentrations seen in Region 5.

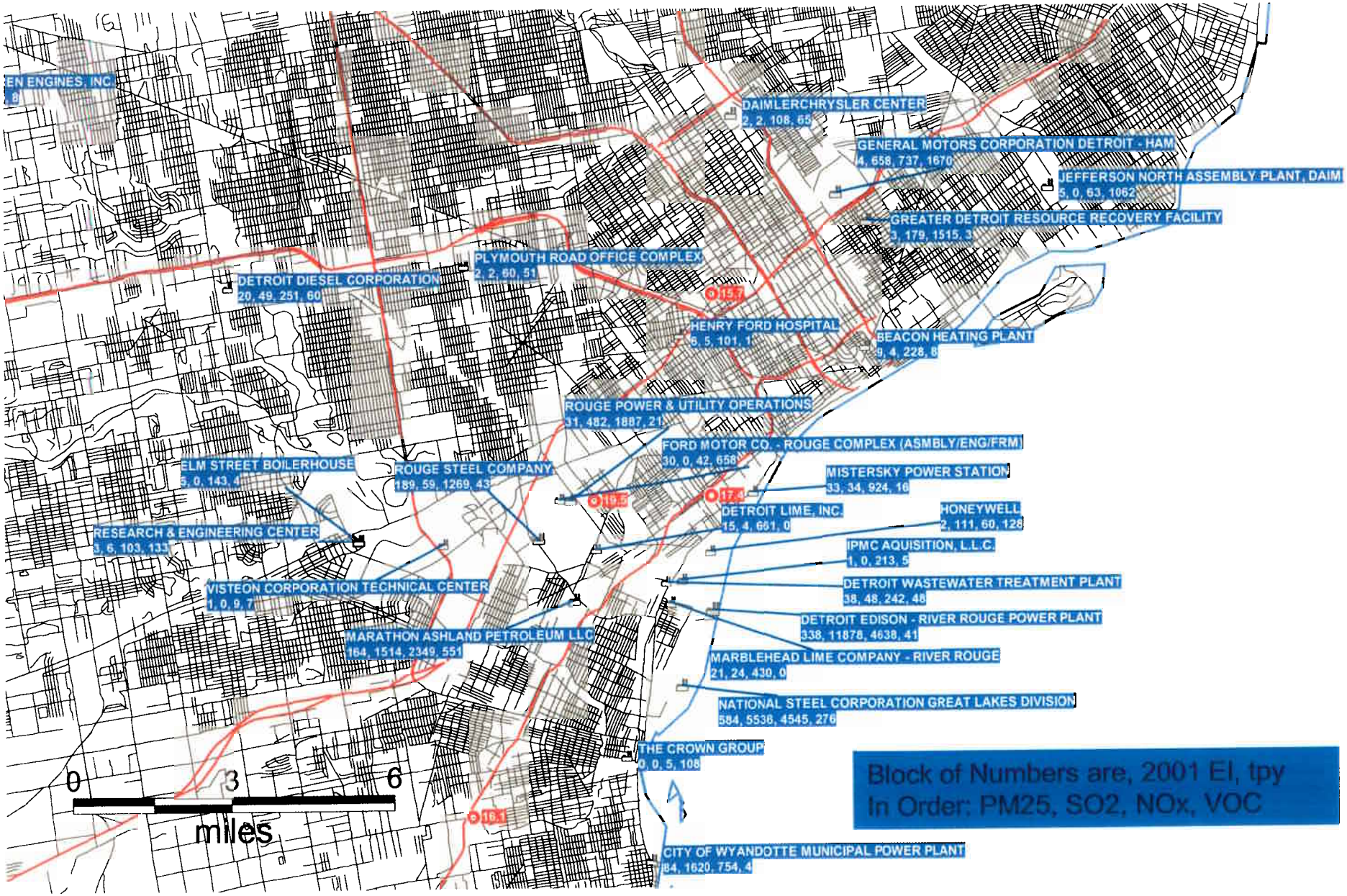
2. Regional source contributions such as from secondary sulfates and nitrates are consistent with those seen from other sites within the Region.

3. Local source contributions from motor vehicles and road salting are consistent with data from other sites in the Region.

4. Local sources of influence which may be contributing to the elevated PM concentrations at Dearborn include industrial sources such as power generation and petroleum refining facilities, steel production and processing plants and elevated diesel emissions from the various rail yards and the extensive major road network surrounding the site.

5. Local influences from rock crushing and concrete facilities may be causing elevated soil contributions in addition to the regional influence of wind blown dust entering into the Detroit Metropolitan area.

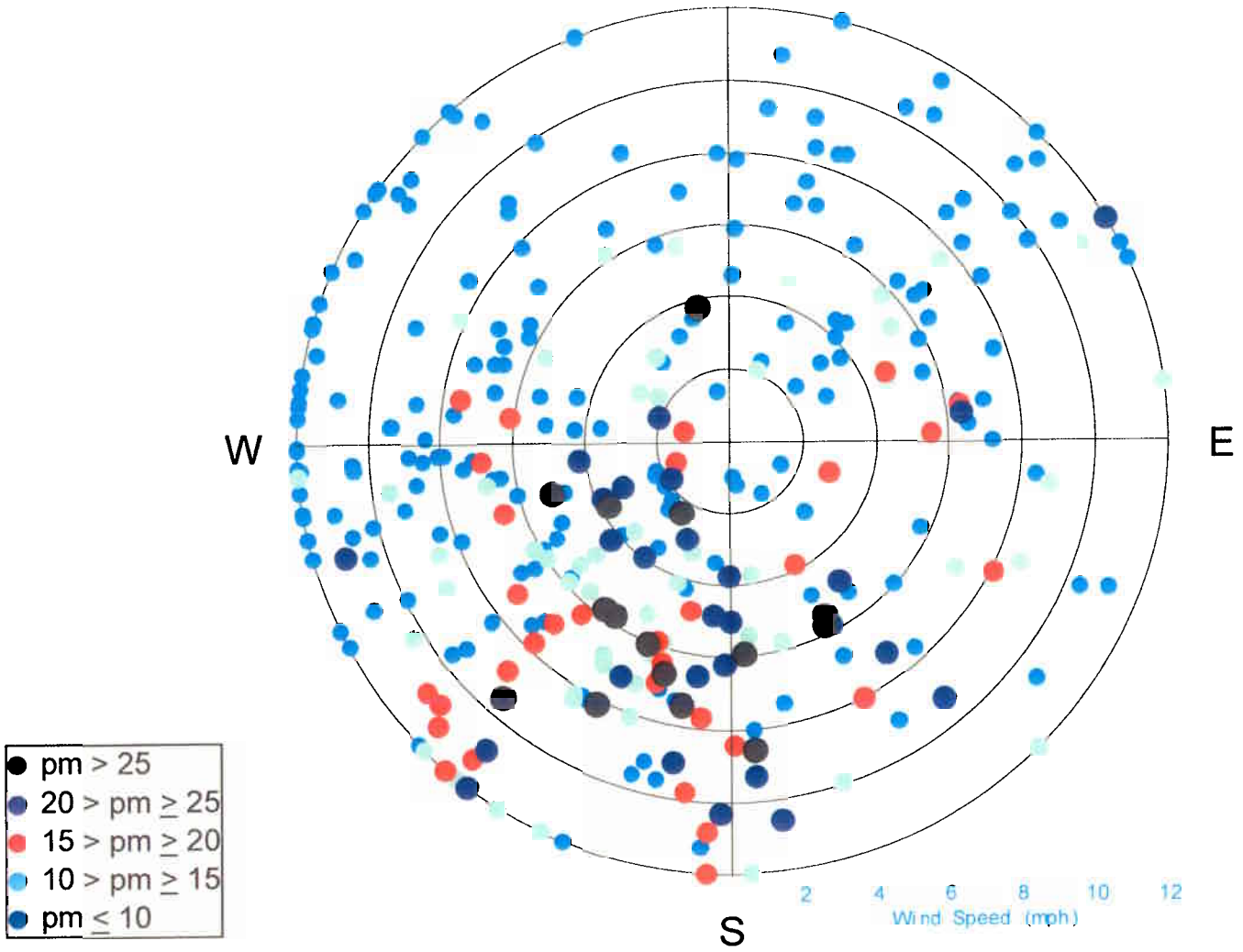
Detroit, MI



A-015
Source Map

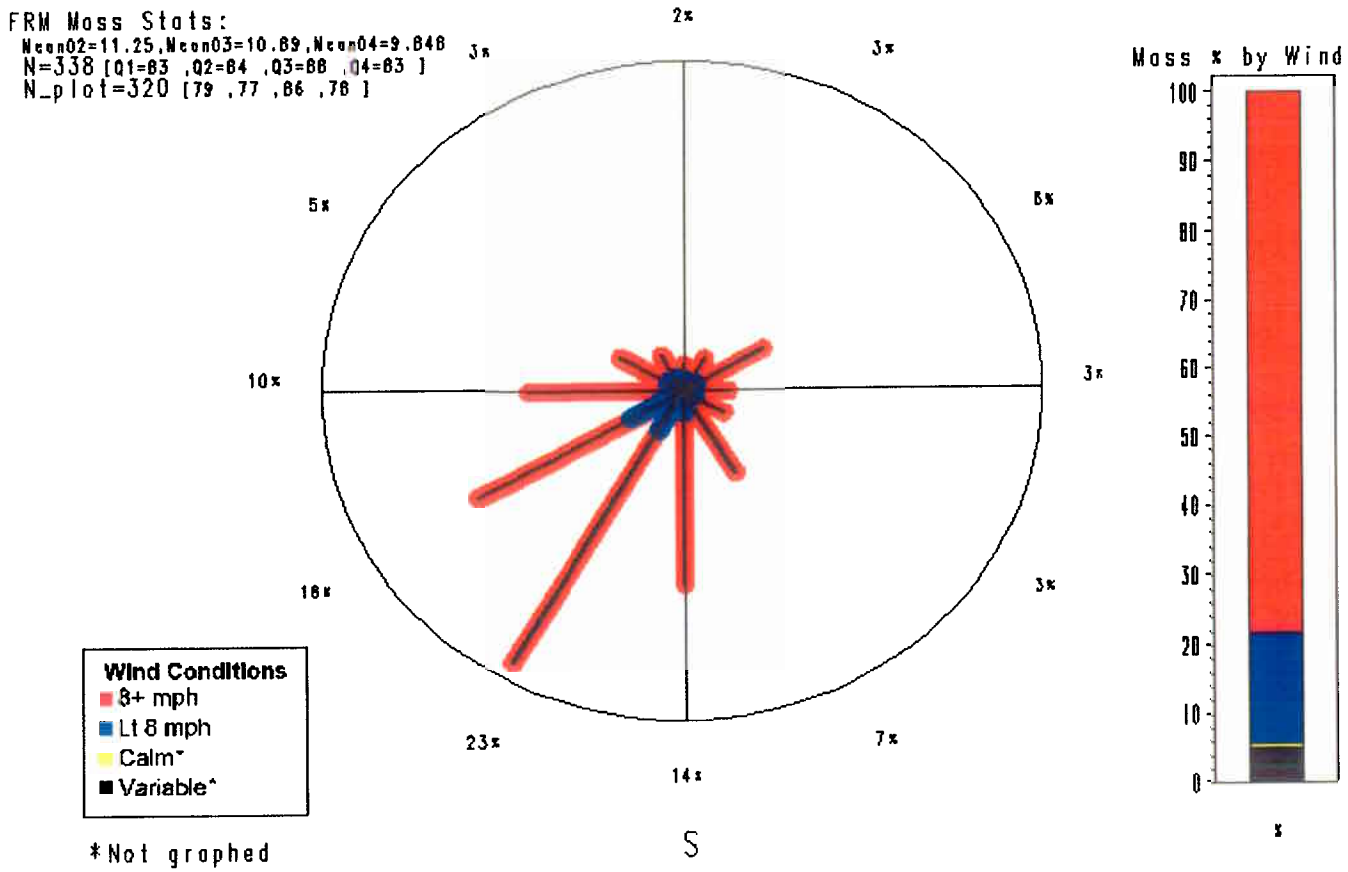
'02-'04 Bubble Pollution Roses

Area= Other Michigan; Site= 260170014



'02-'04 PM2.5 Contribution Rose for Other Michigan

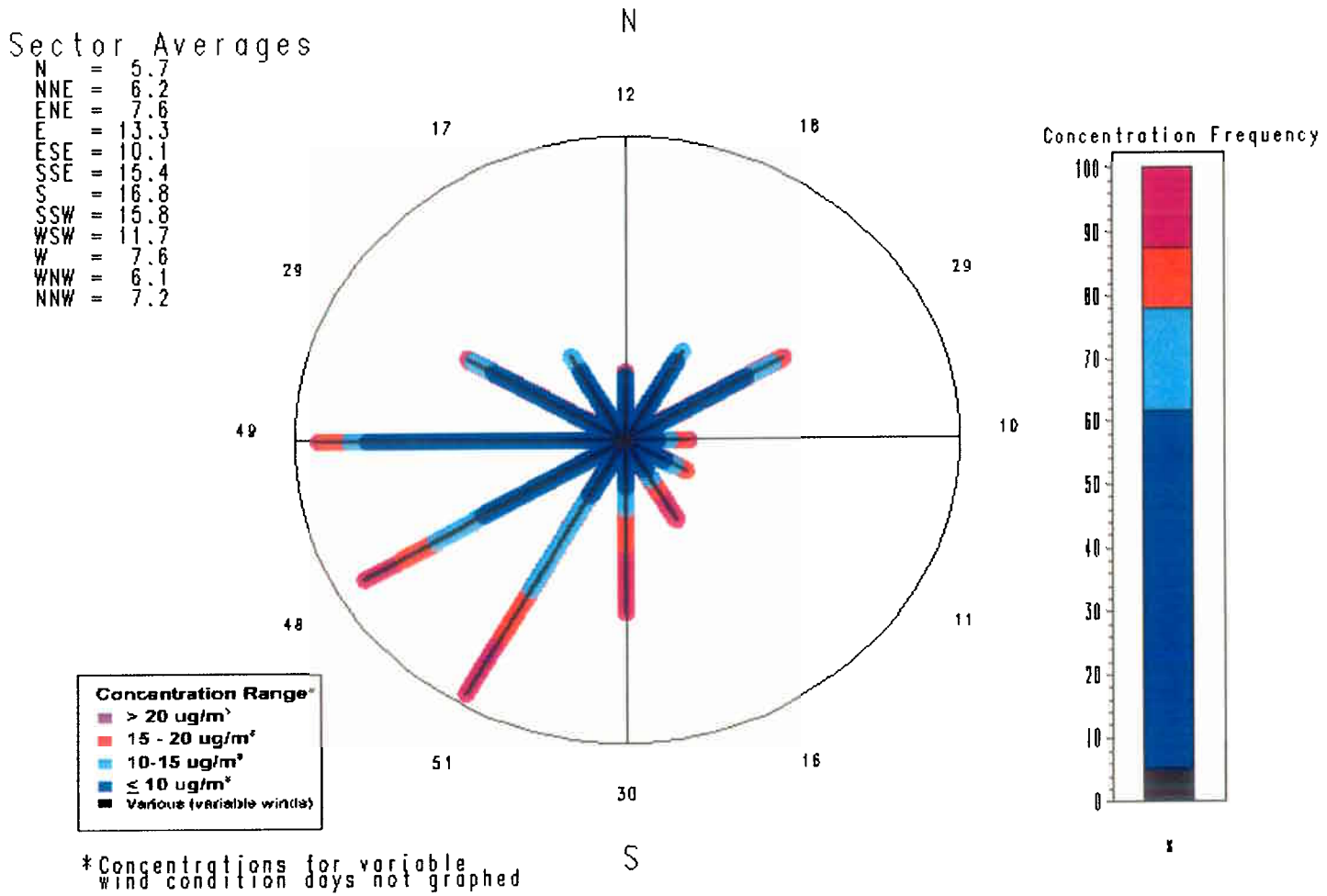
Site 260170014 [Bay, MI DV=10.7 A]



Met from 43miles (ID:14826)

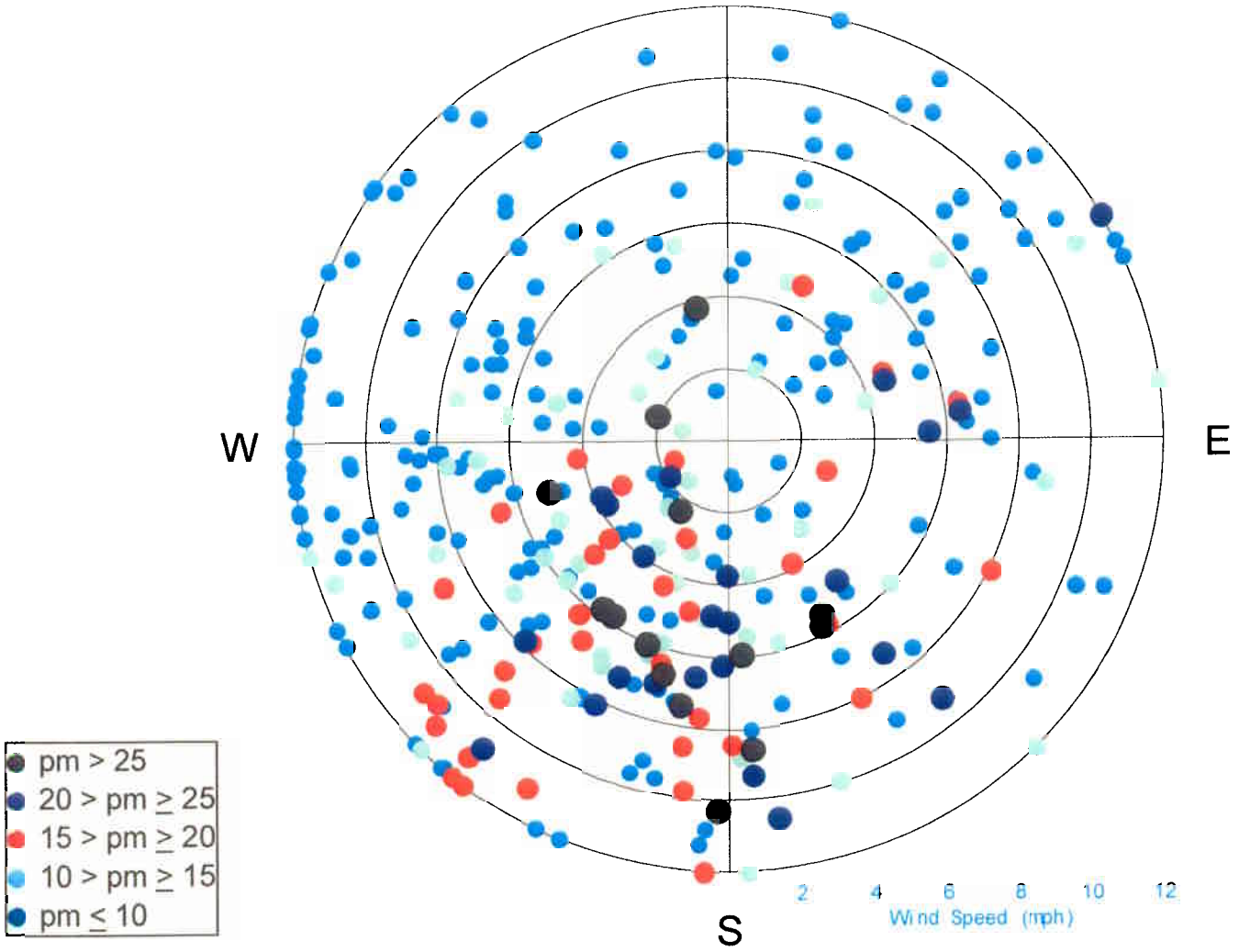
'02-'04 Sector Pollution Rose for Other Michigan

Site 260170014 [Bay, MI DV=10.7 A]



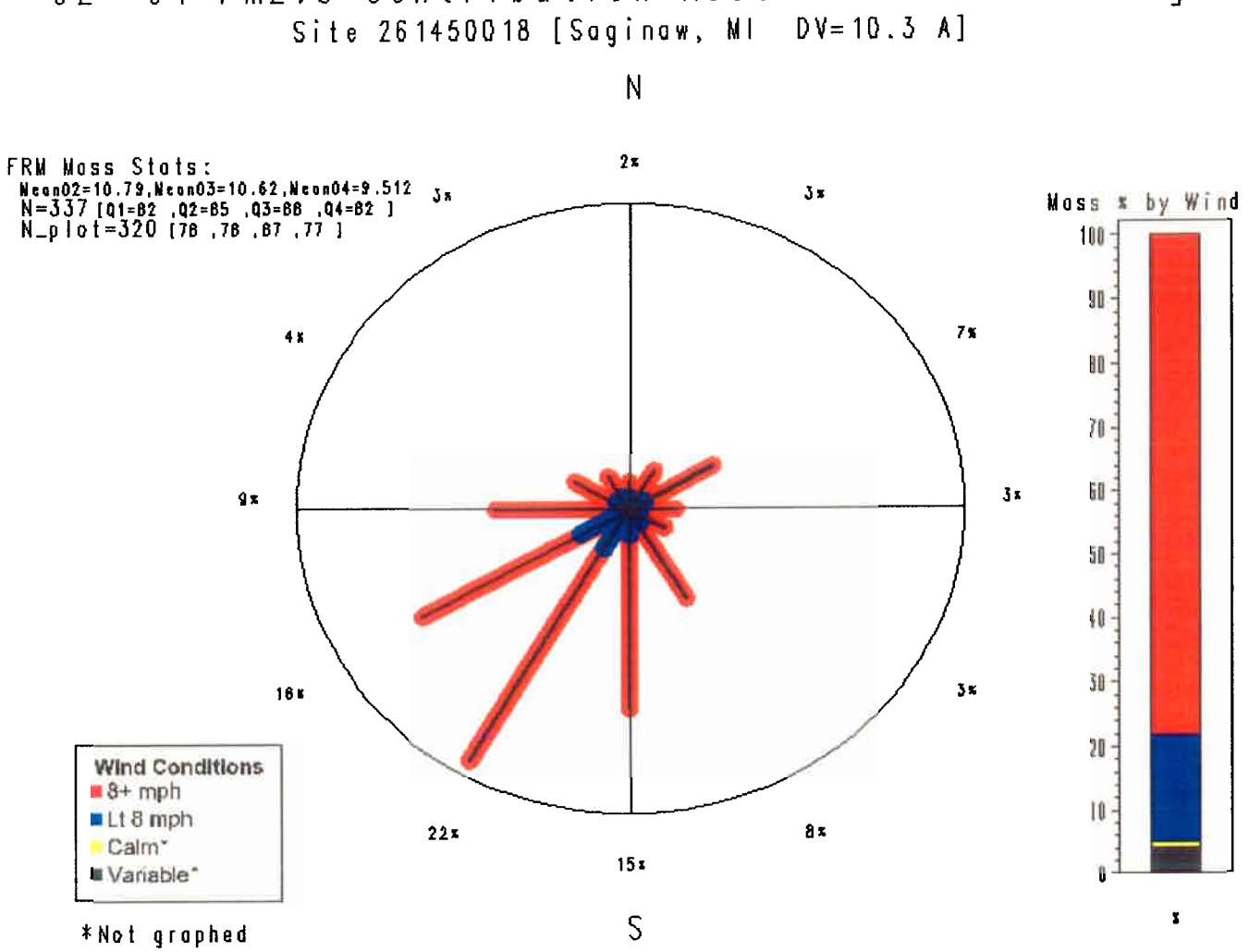
'02-'04 Bubble Pollution Roses

Area= Other Michigan; Site= 261450018



'02-'04 PM2.5 Contribution Rose for Other Michigan

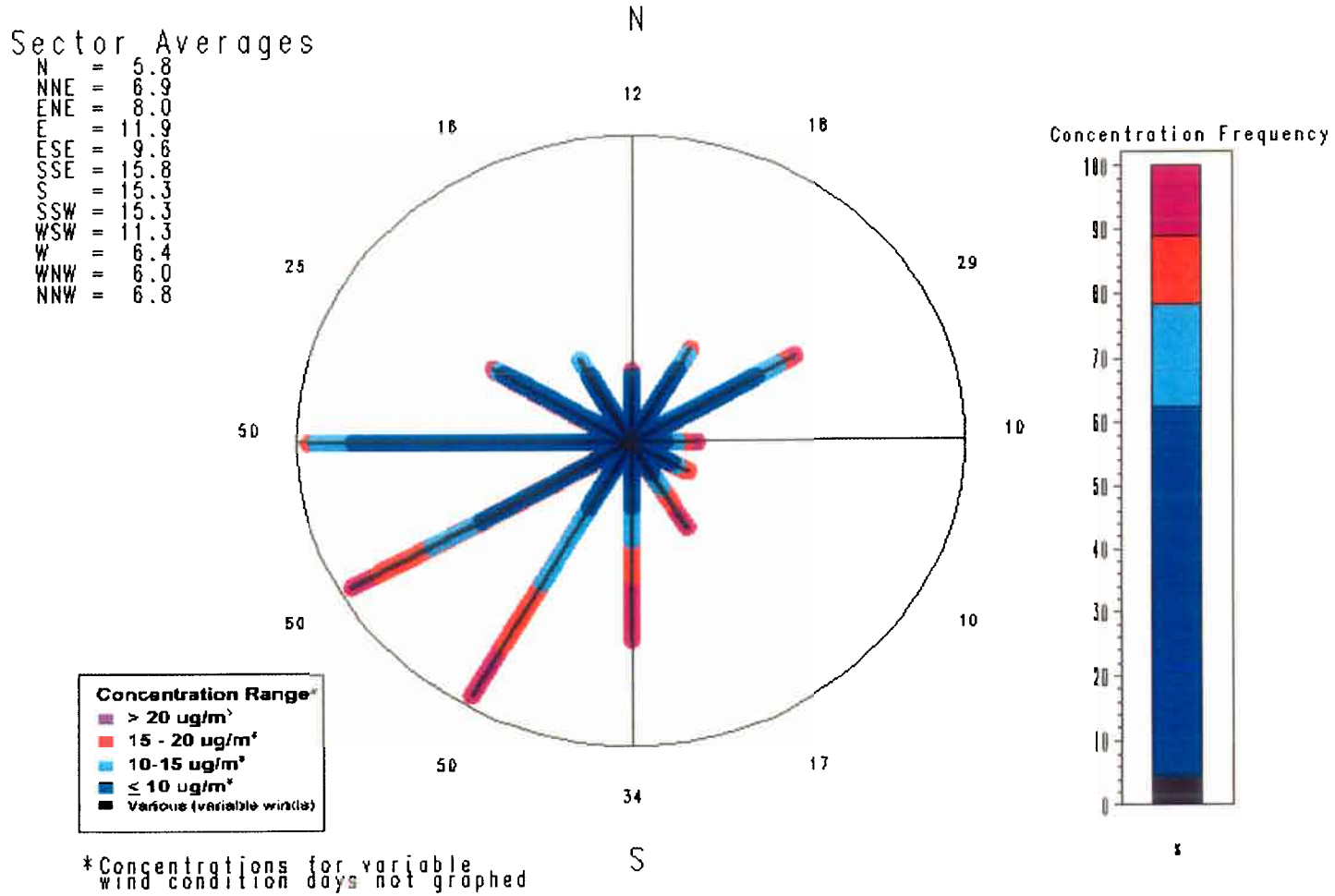
Site 261450018 [Saginaw, MI DV=10.3 A]



Met from 39miles (ID:14826)

'02-'04 Sector Pollution Rose for Other Michigan

Site 261450018 [Saginaw, MI DV=10.3 A]

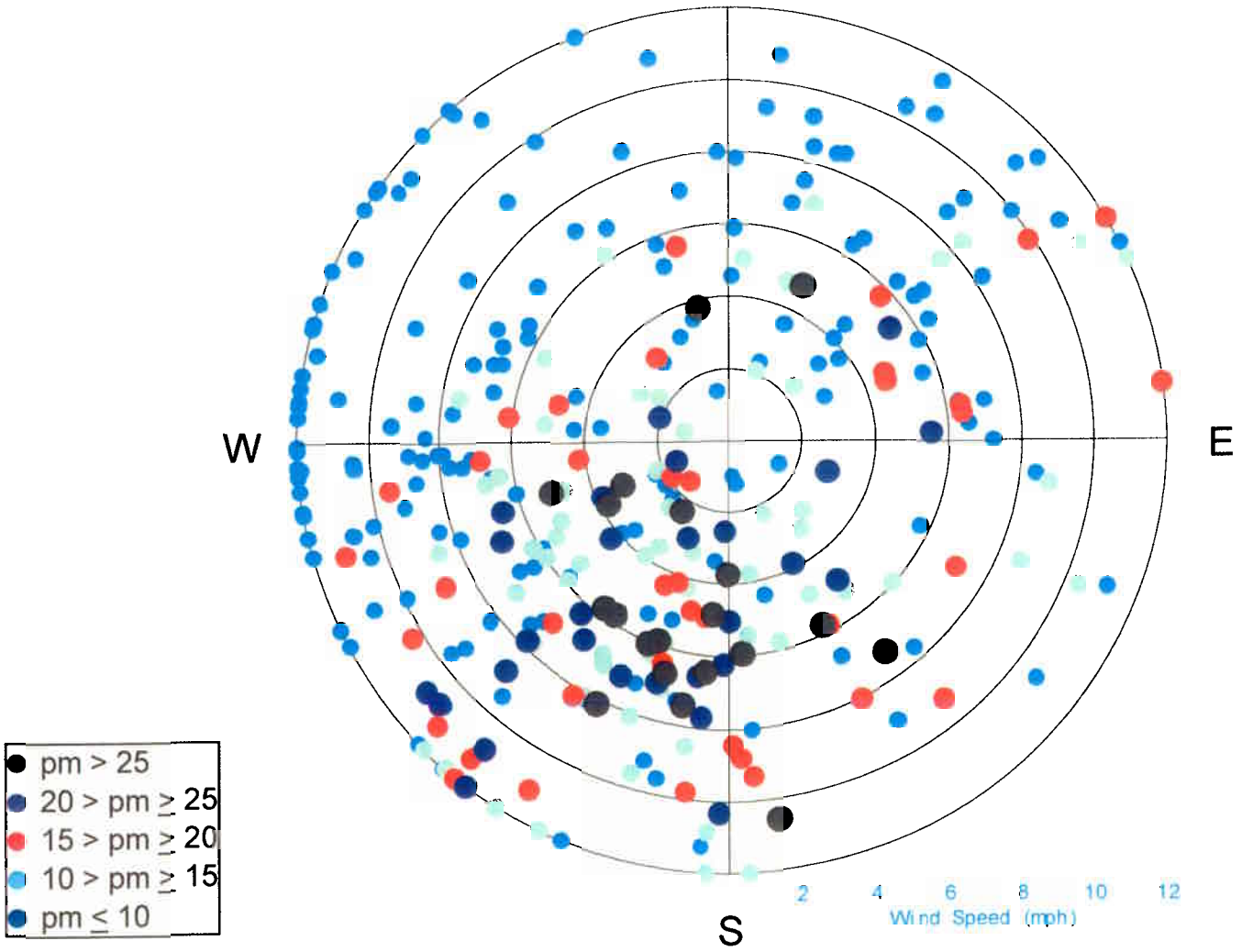


*Concentrations for variable wind condition days not graphed

Met from 39miles (ID:14826)

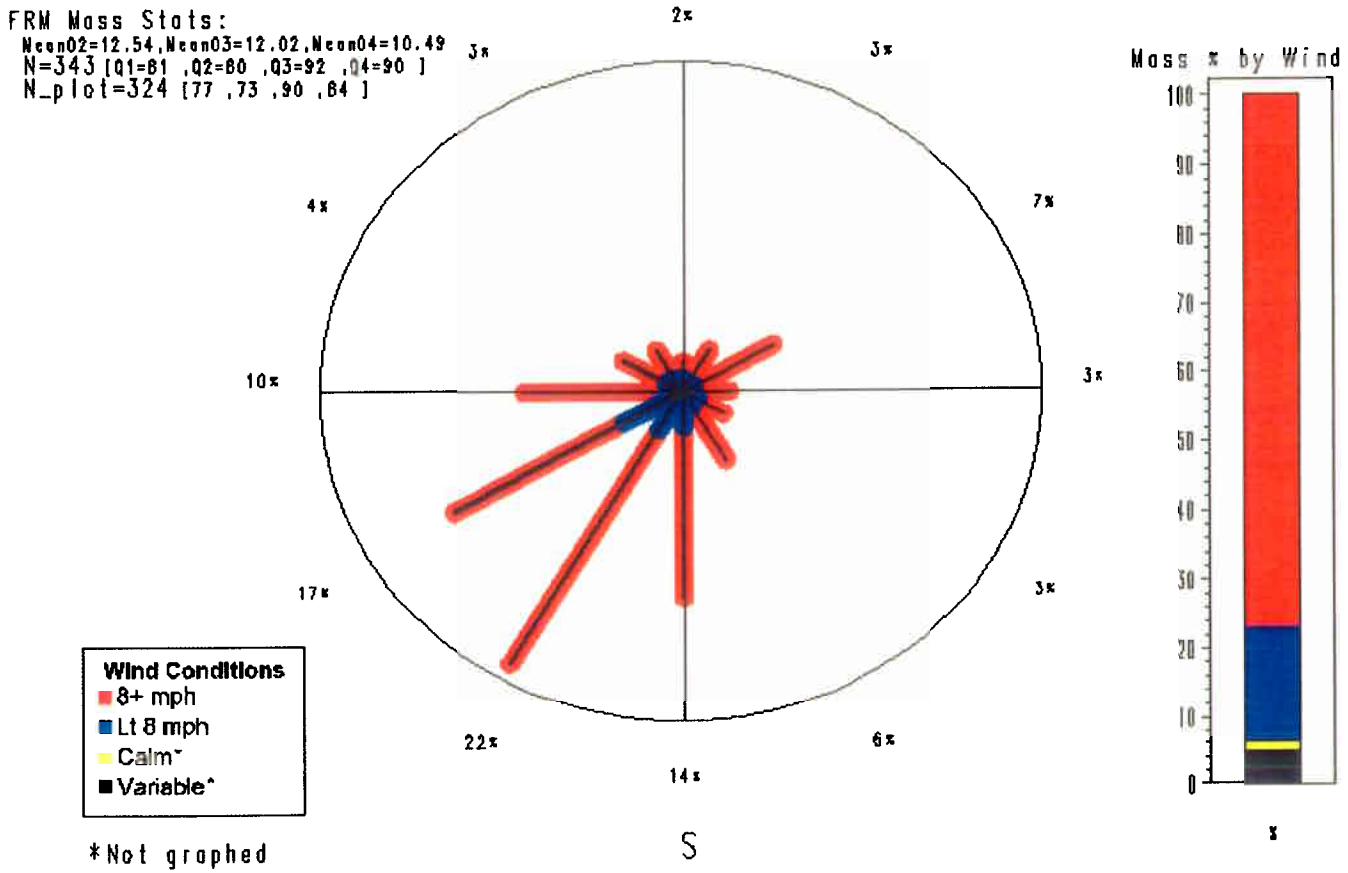
'02-'04 Bubble Pollution Roses

Area= Other Michigan; Site= 260490021



'02-'04 PM2.5 Contribution Rose for Other Michigan

Site 260490021 [Genesee, MI DV=11.7 A]

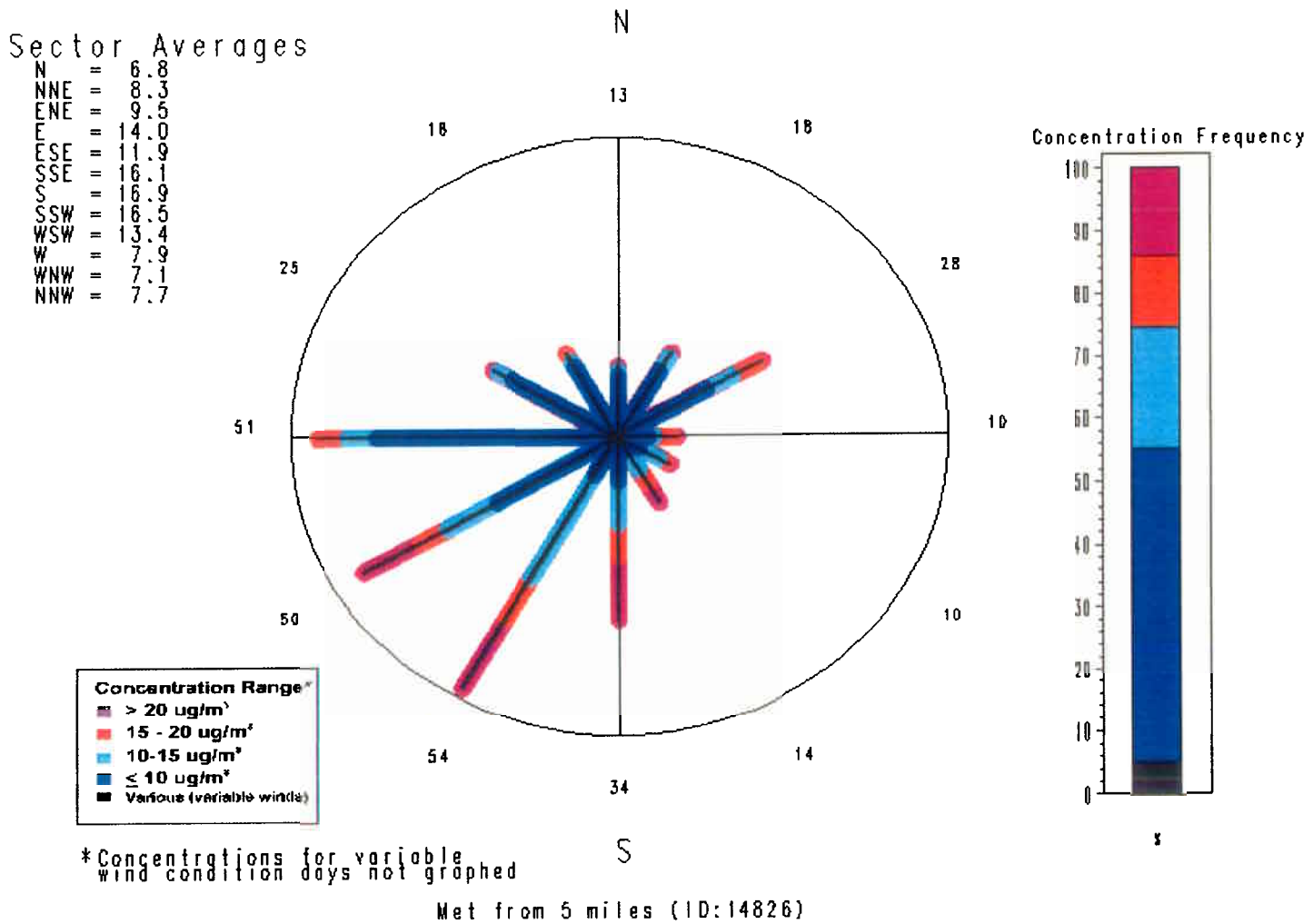


Met from 5 miles (ID:14826)

A-023
02-04 CR Flint

'02-'04 Sector Pollution Rose for Other Michigan

Site 260490021 [Genesee, MI DV=11.7 A]

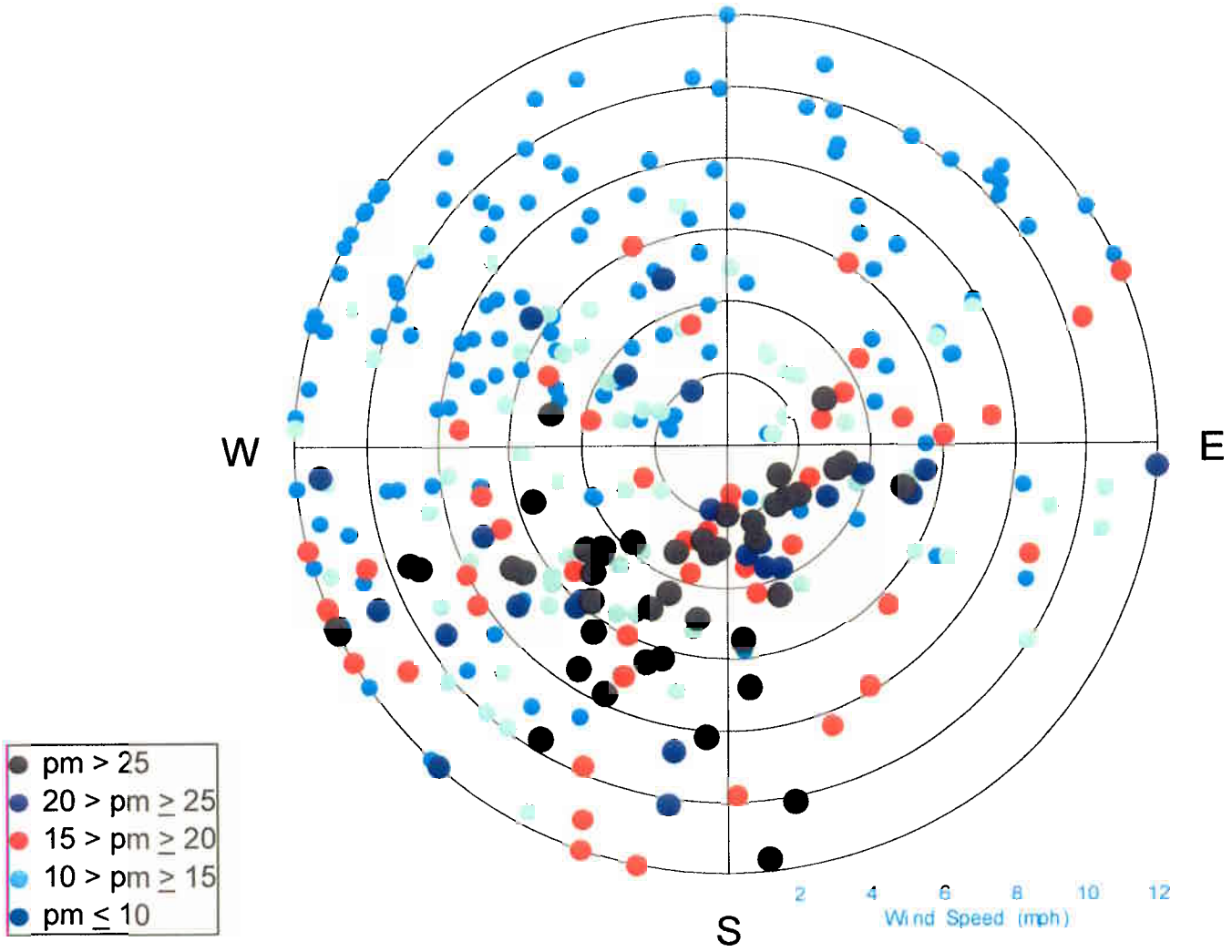


*Concentrations for variable wind condition days not graphed

Met from 5 miles (ID:14826)

'02-'04 Bubble Pollution Roses

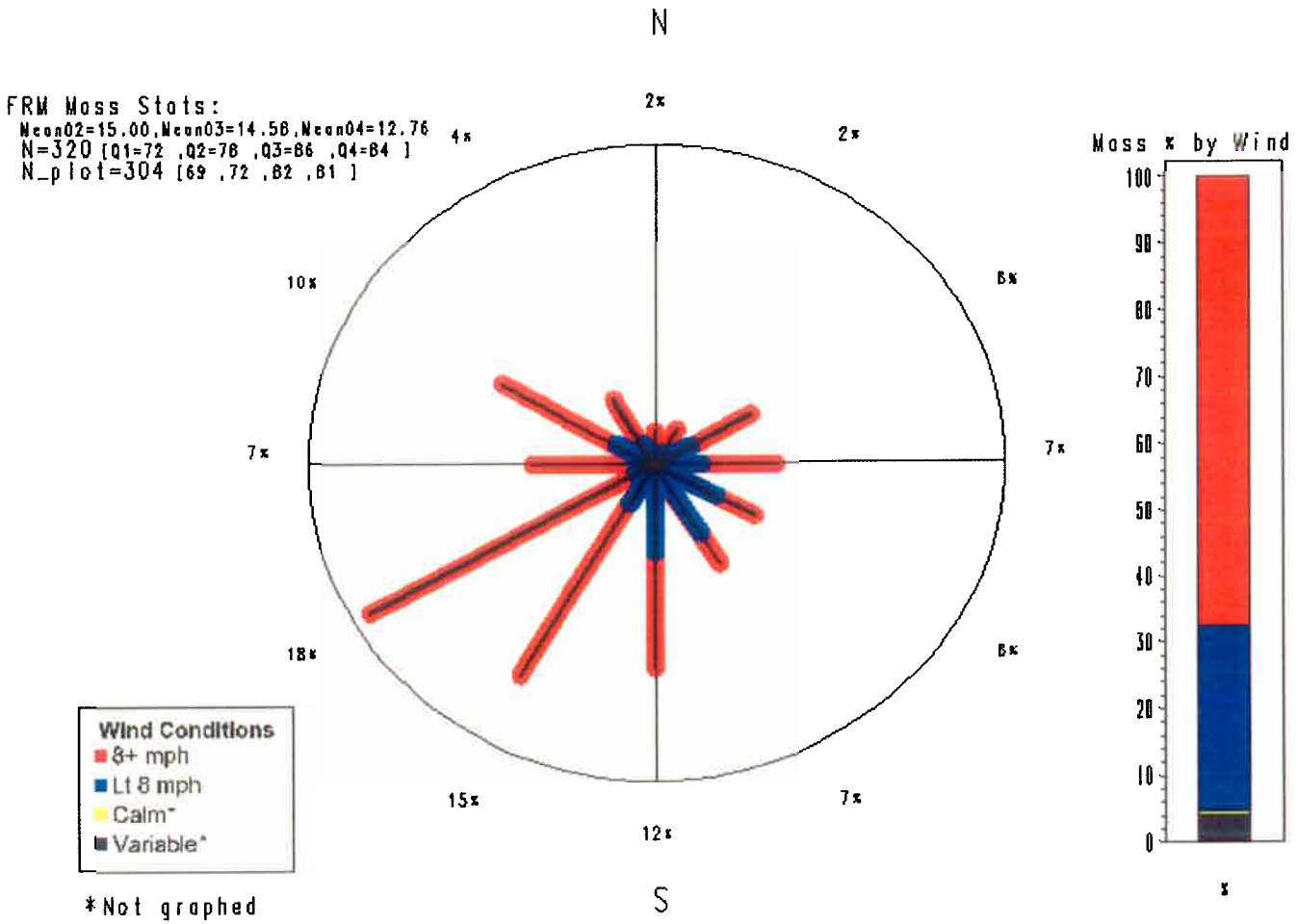
Area= Detroit-Ann Arbor, MI; Site= 261250001



A-025
02-04 BPR Oak Park

'02-'04 PM2.5 Contribution Rose for Detroit-Ann Arbor, MI

Site 261250001 [Oakland, MI DV=14.1 a]

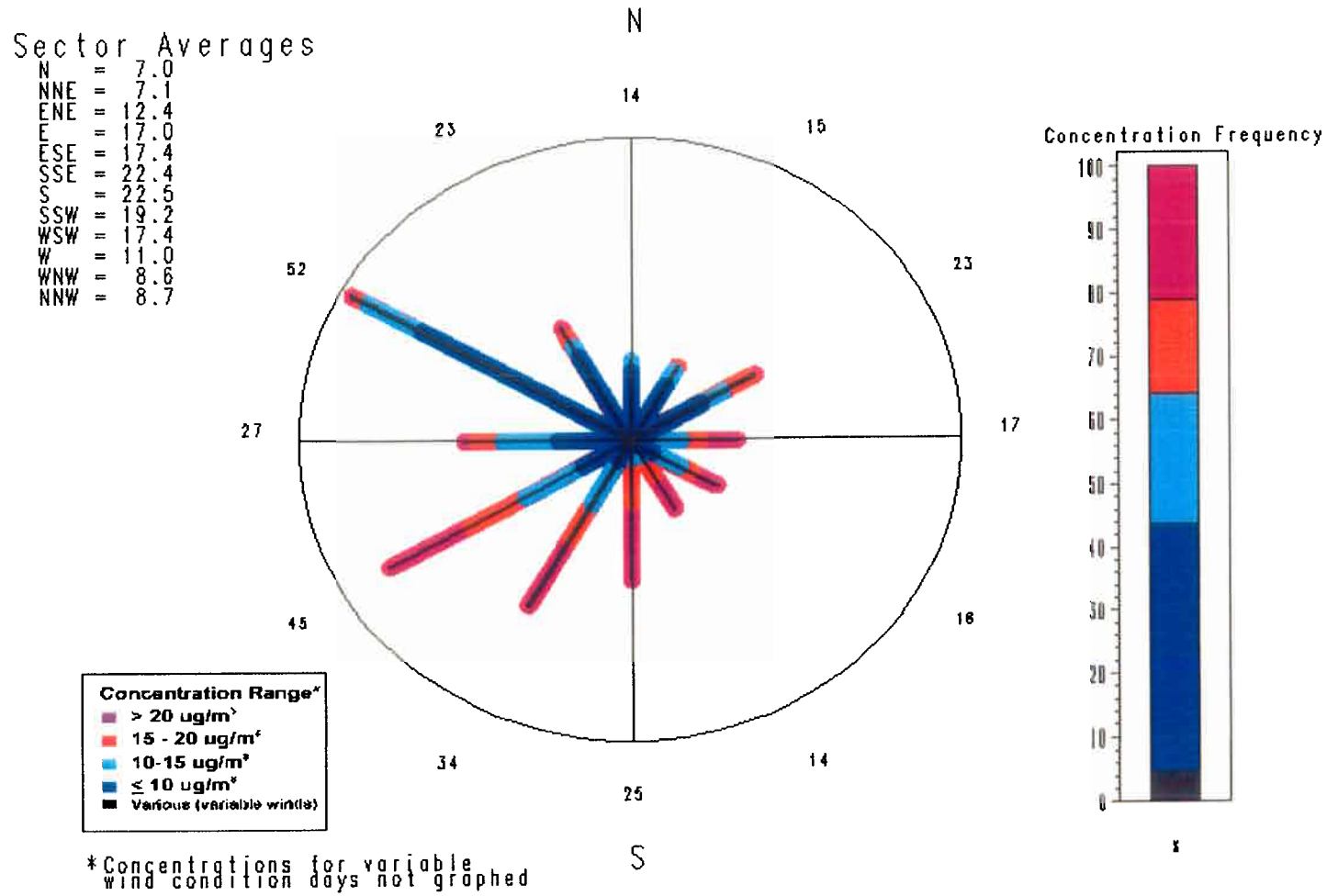


Met from 9 miles (ID:14822)

A-026
02-04 CR Oak Park

'02-'04 Sector Pollution Rose for Detroit-Ann Arbor, MI

Site 261250001 [Oakland, MI DV=14.1 a]

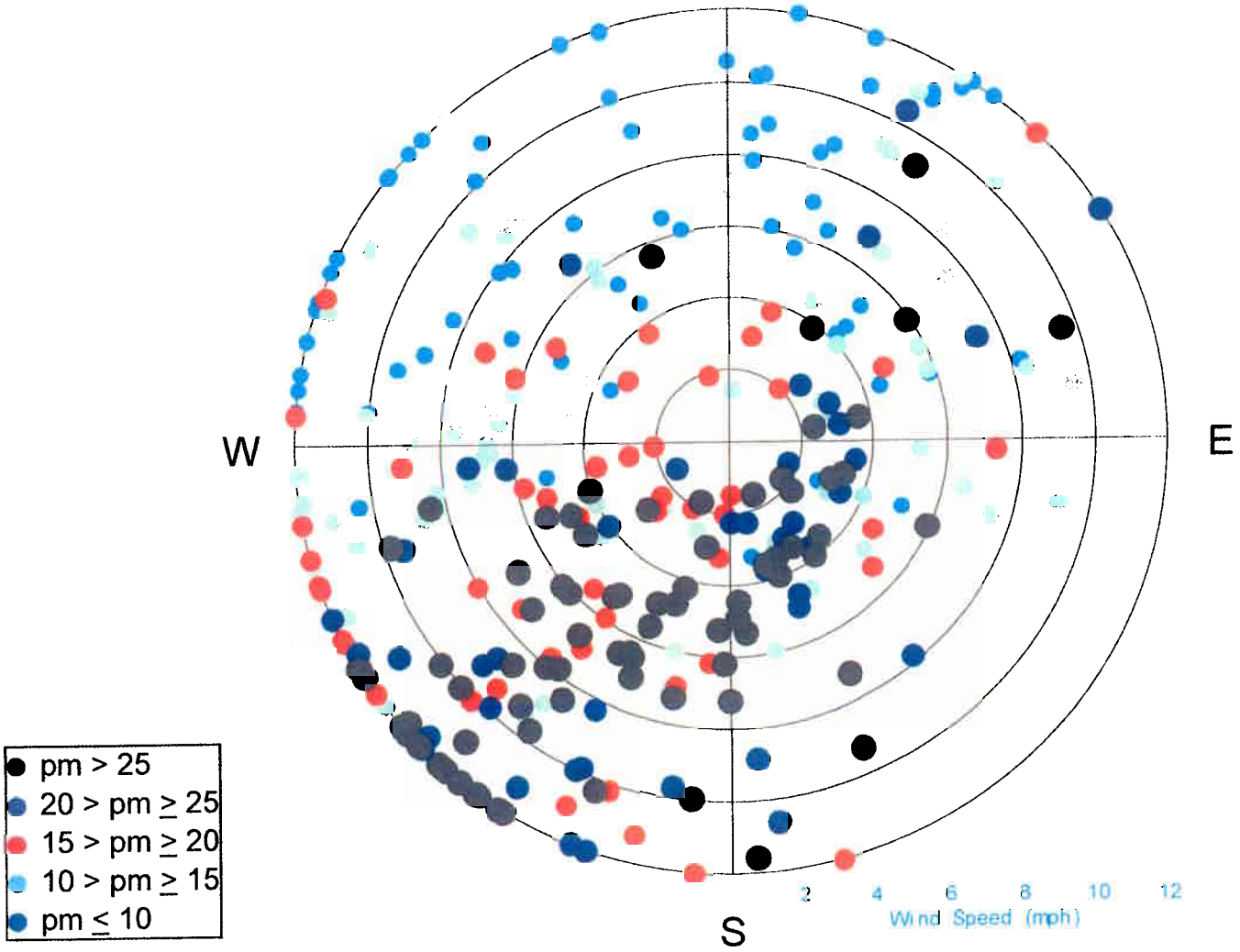


*Concentrations for variable wind condition days not graphed

Met from 9 miles (ID:14822)

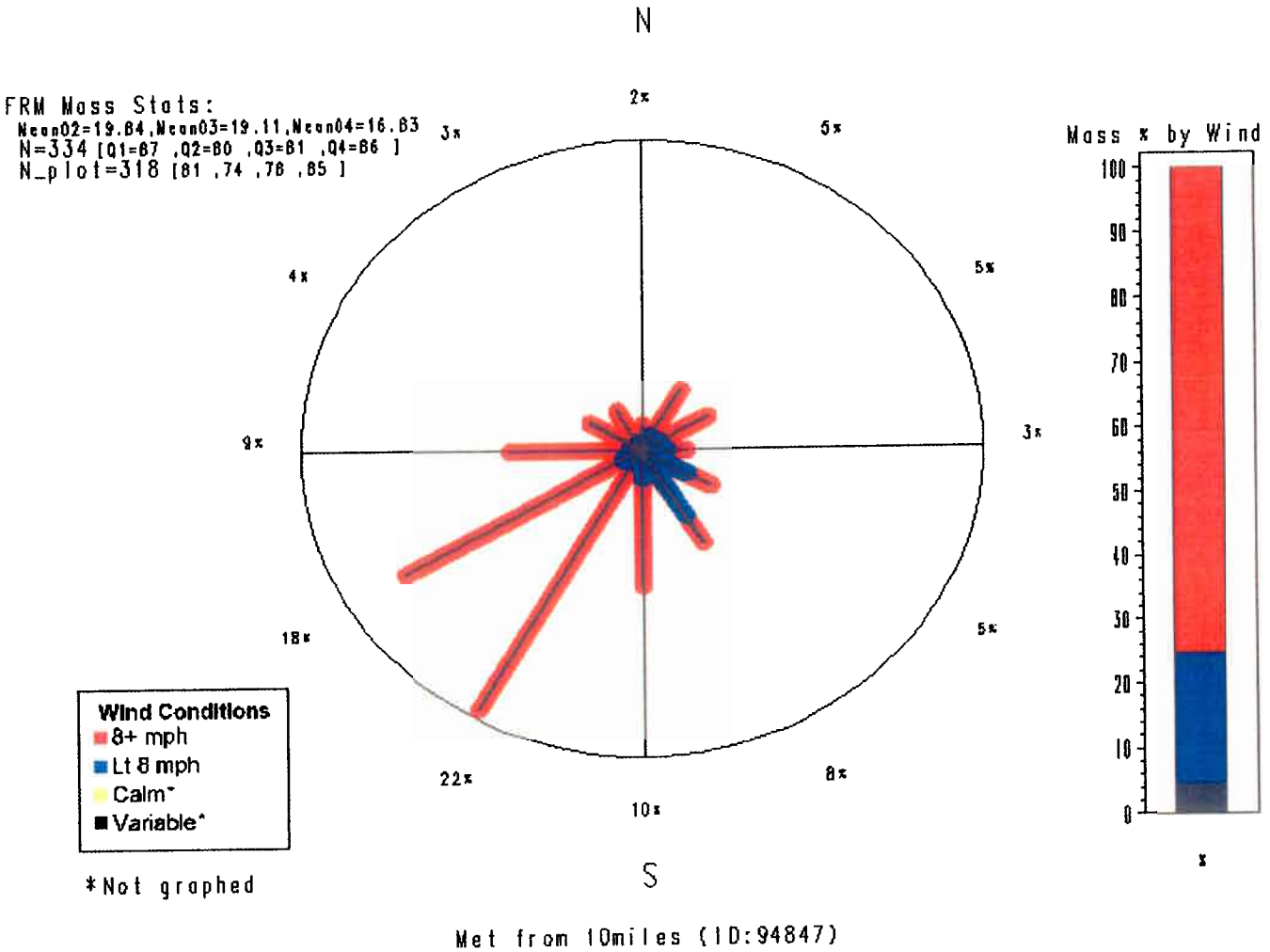
'02-'04 Bubble Pollution Roses

Area= Detroit-Ann Arbor, MI; Site= 261630033



'02-'04 PM2.5 Contribution Rose for Detroit-Ann Arbor, MI

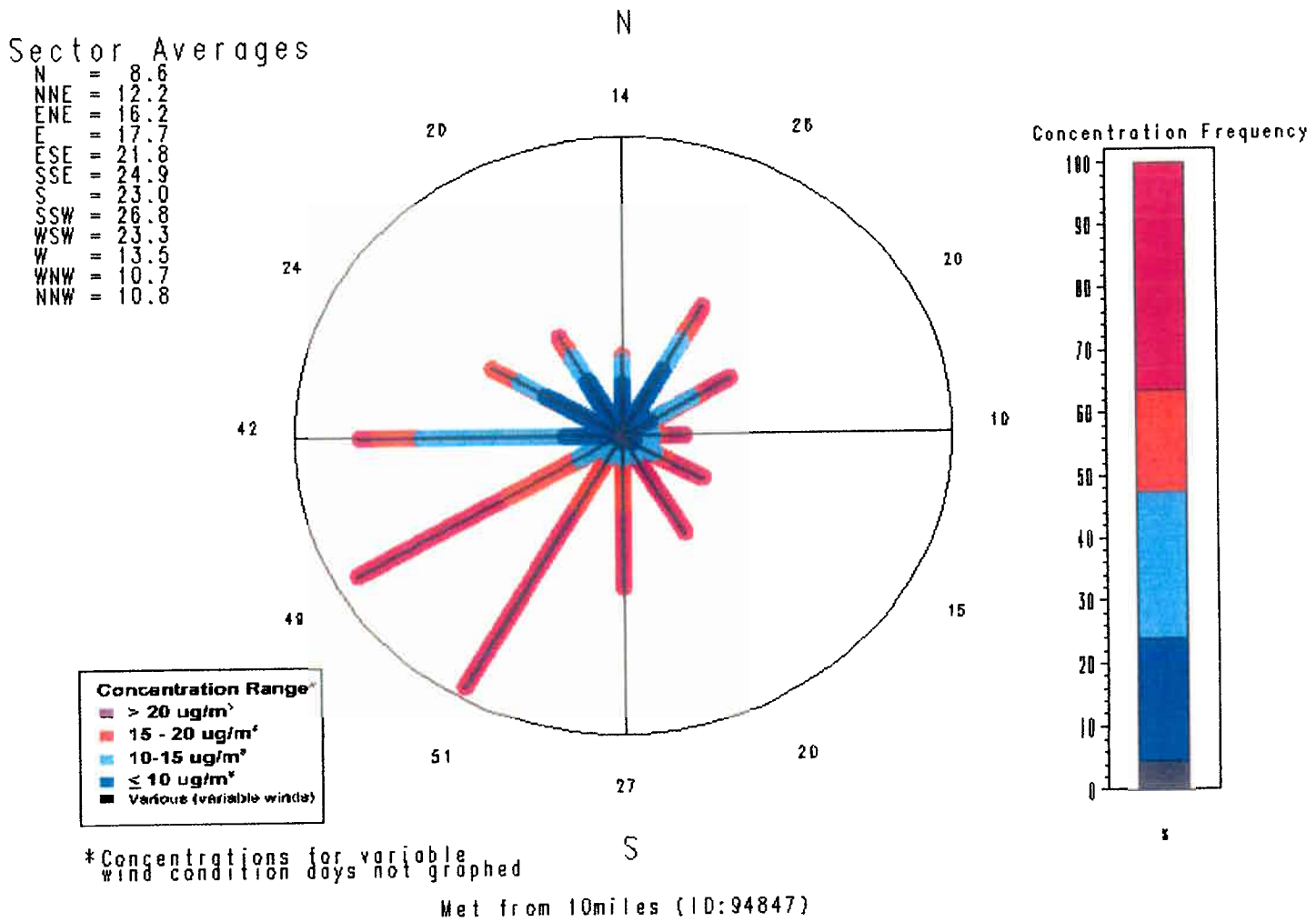
Site 261630033 [Wayne, MI DV=18.6 NA]



Met from 10miles (ID:94847)

'02-'04 Sector Pollution Rose for Detroit-Ann Arbor, MI

Site 261630033 [Wayne, MI DV=18.6 NA]



*Concentrations for variable wind condition days not graphed

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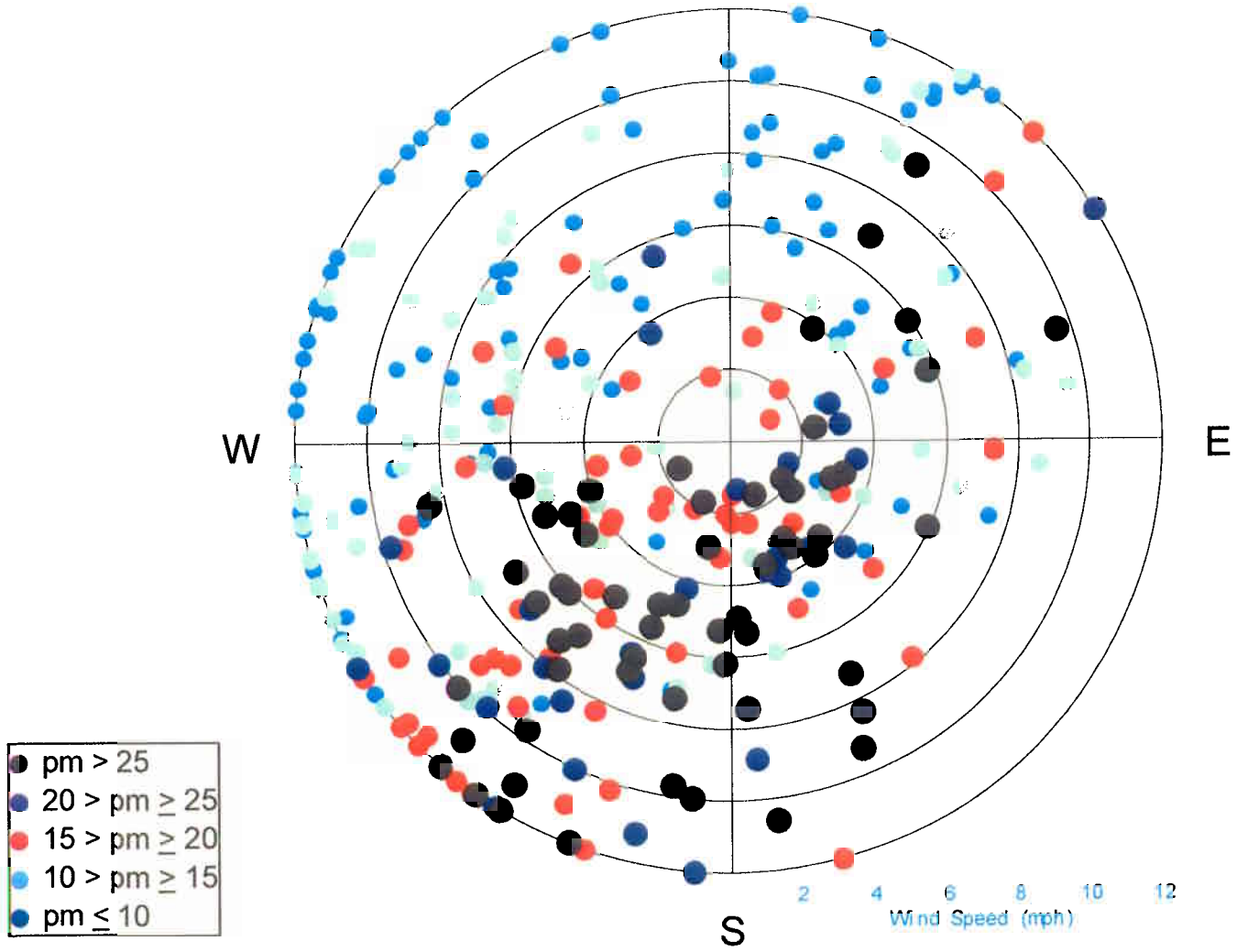
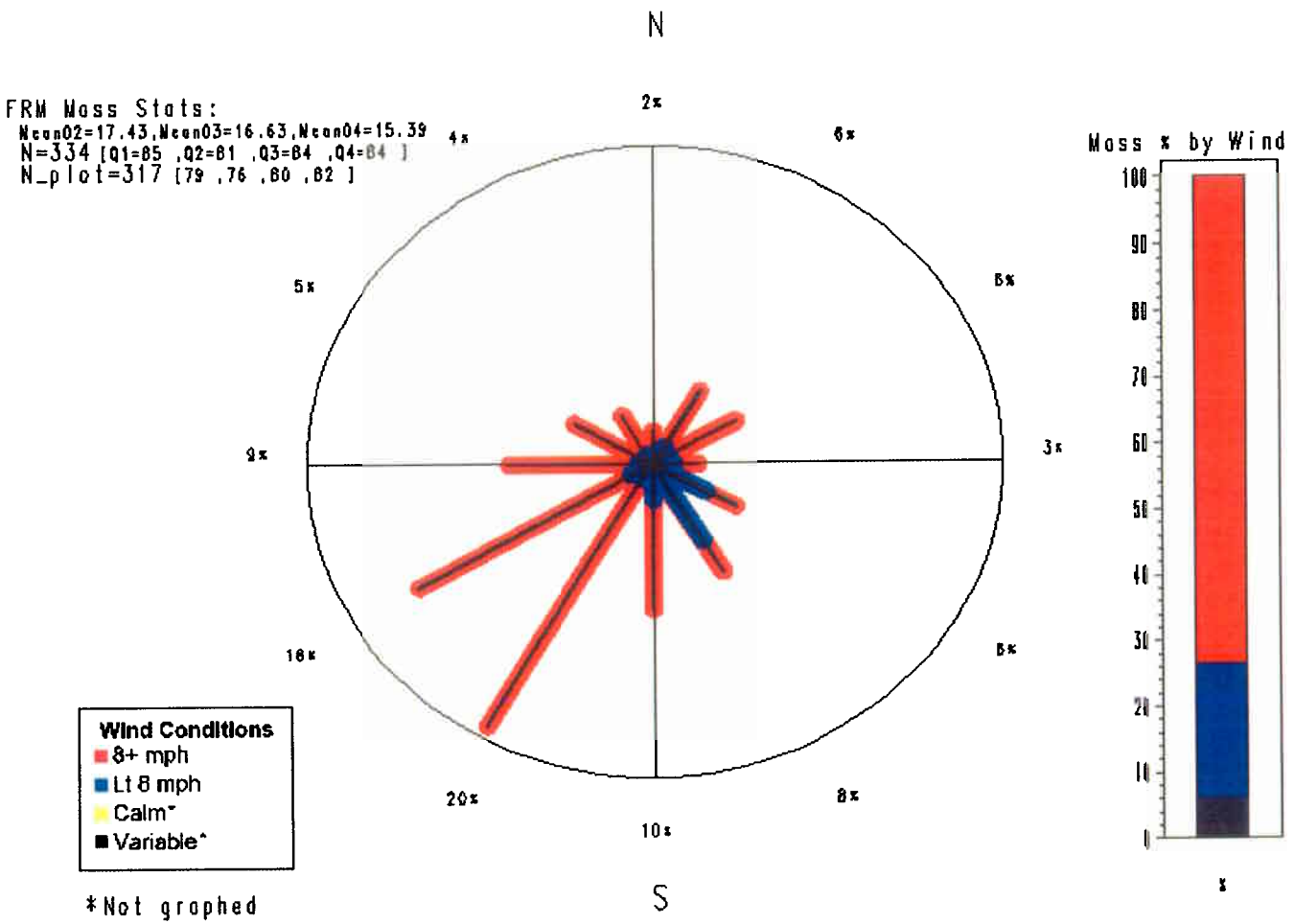
'02-'04 Bubble Pollution Roses

Area= Detroit-Ann Arbor, MI; Site= 261630015



'02-'04 PM2.5 Contribution Rose for Detroit-Ann Arbor, MI

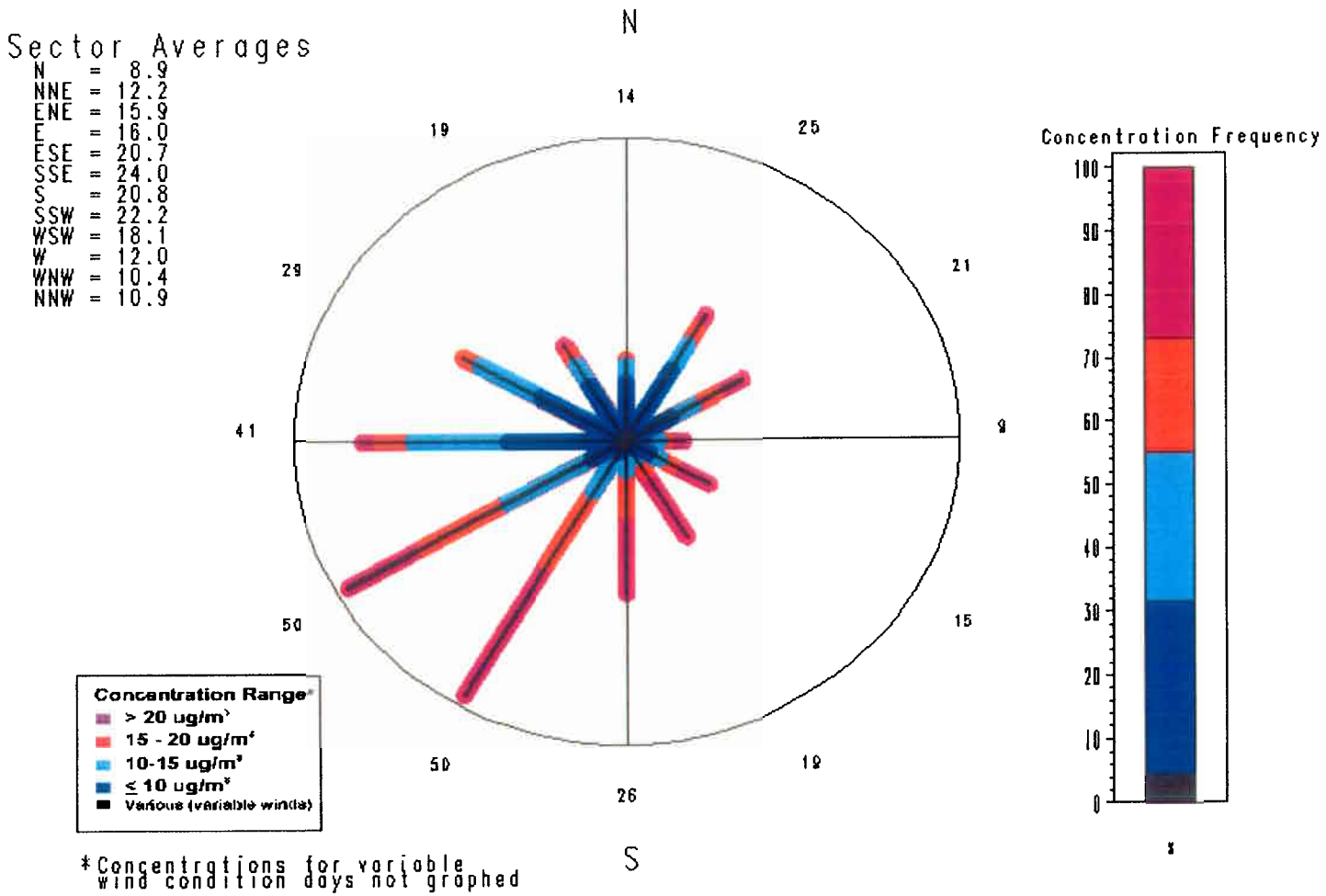
Site 261630015 [Wayne, MI DV=16.5 NA]



Met from 9 miles (ID:94847)

'02-'04 Sector Pollution Rose for Detroit-Ann Arbor, MI

Site 261630015 [Wayne, MI DV=16.5 NA]

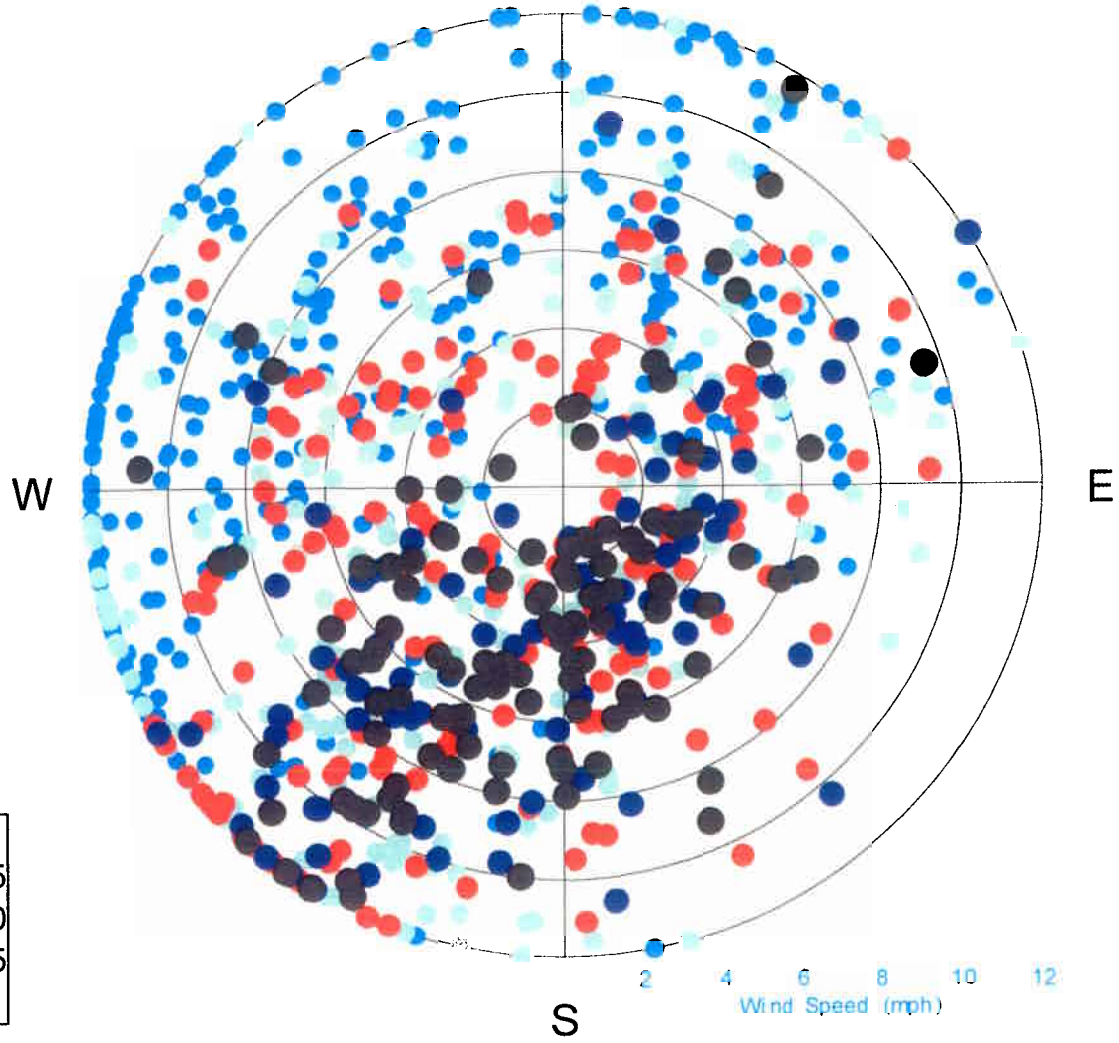


*Concentrations for variable wind condition days not graphed

Met from 9 miles (ID:94847)

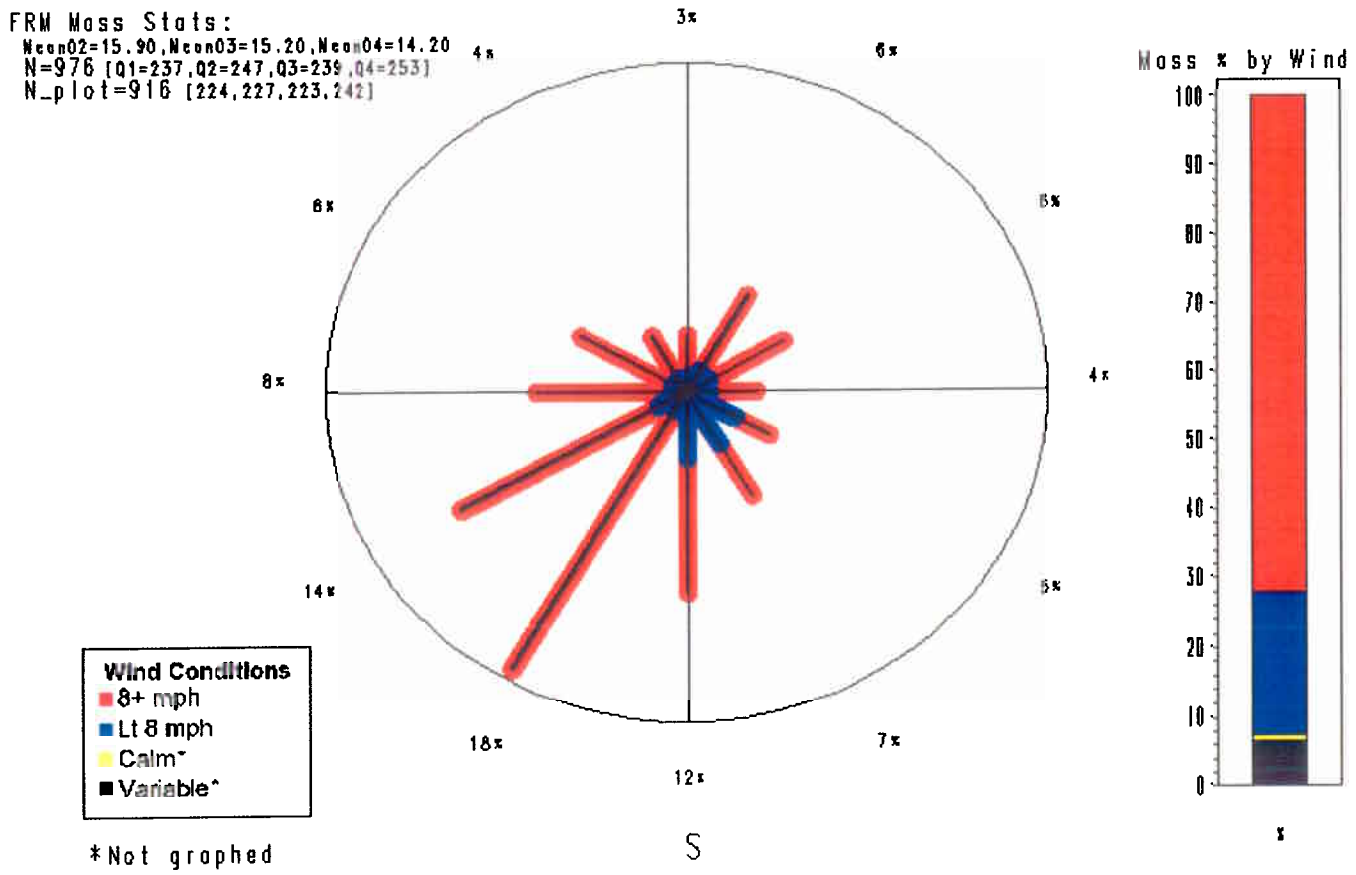
'02-'04 Bubble Pollution Roses

Area= Detroit-Ann Arbor, MI; Site= 261630001



'02-'04 PM2.5 Contribution Rose for Detroit-Ann Arbor, MI

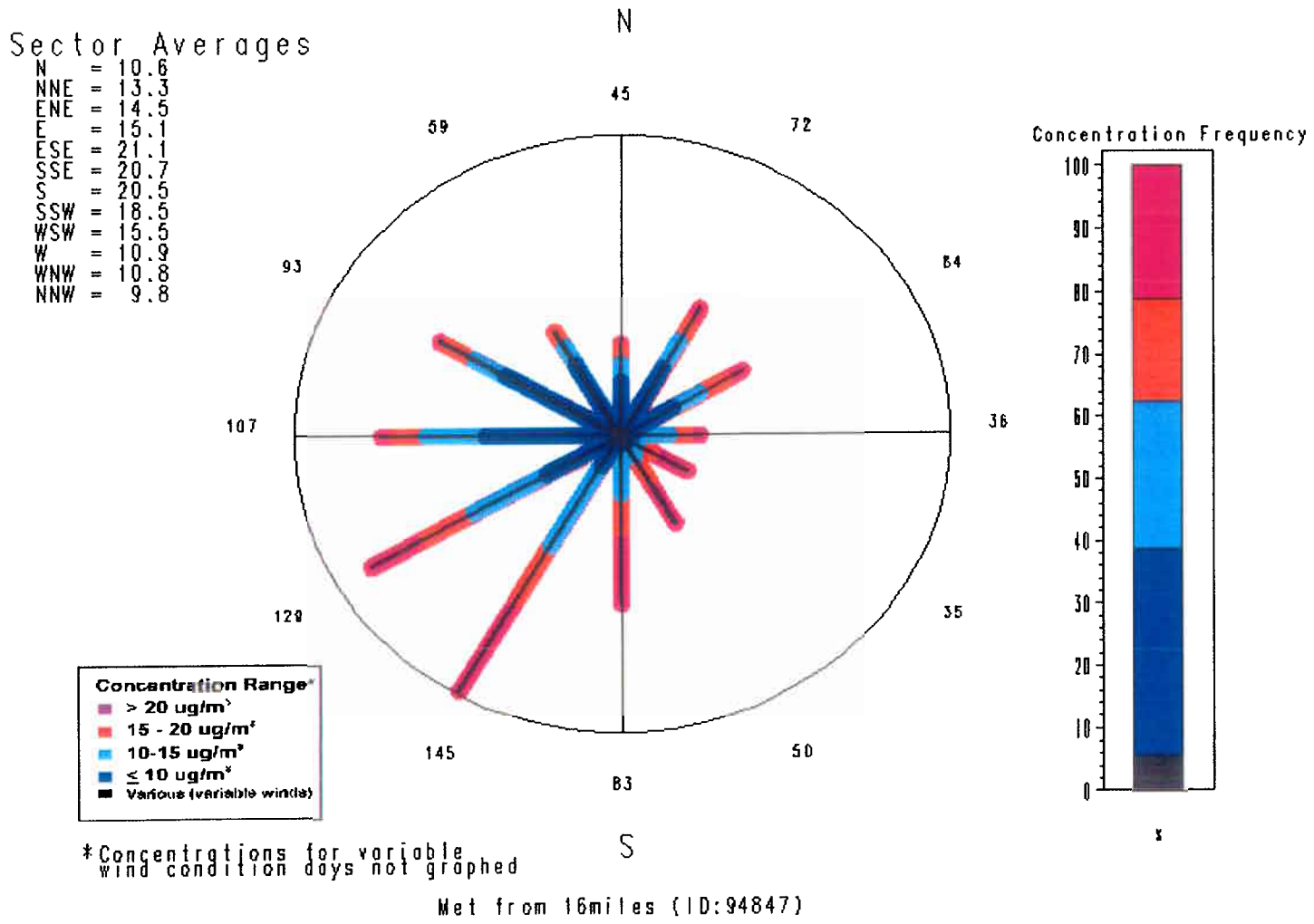
Site 261630001 [Wayne, MI DV=15.1 NA]



Met from 16miles (ID:94847)

'02-'04 Sector Pollution Rose for Detroit-Ann Arbor, MI

Site 261630001 [Wayne, MI DV=15.1 NA]

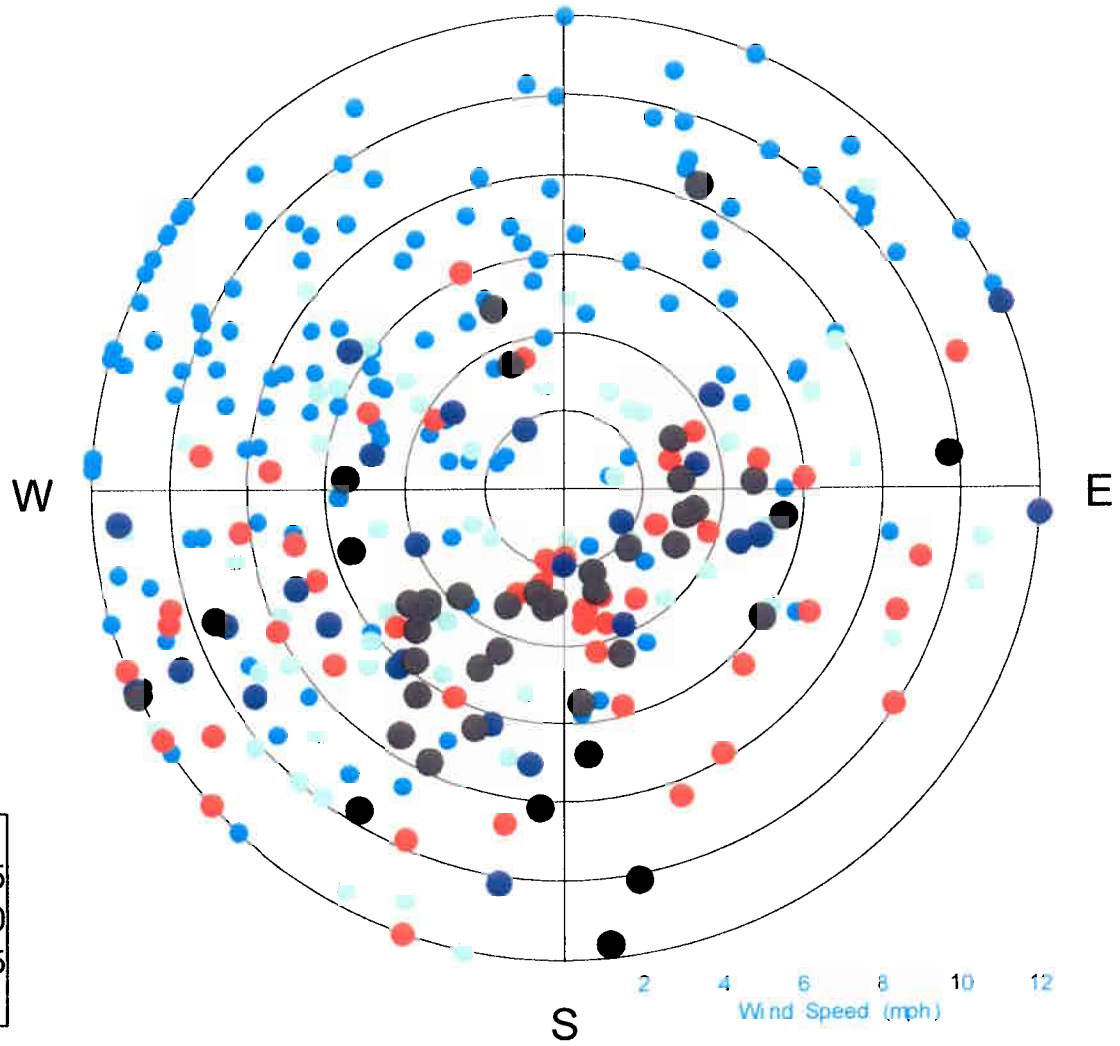


*Concentrations for variable wind condition days not graphed

Met from 16miles (ID:94847)

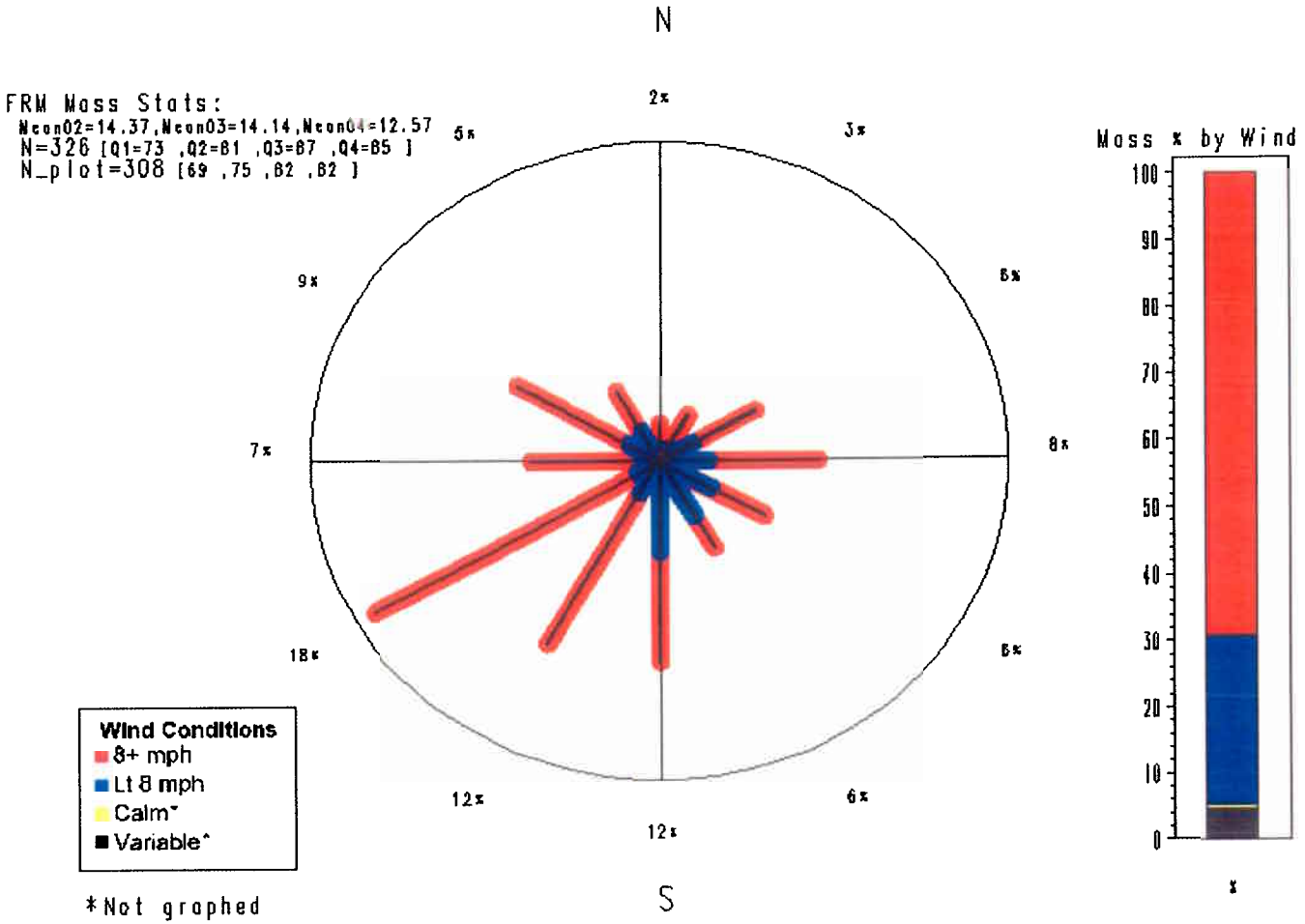
'02-'04 Bubble Pollution Roses

Area= Detroit-Ann Arbor, MI; Site= 261630025



'02-'04 PM2.5 Contribution Rose for Detroit-Ann Arbor, MI

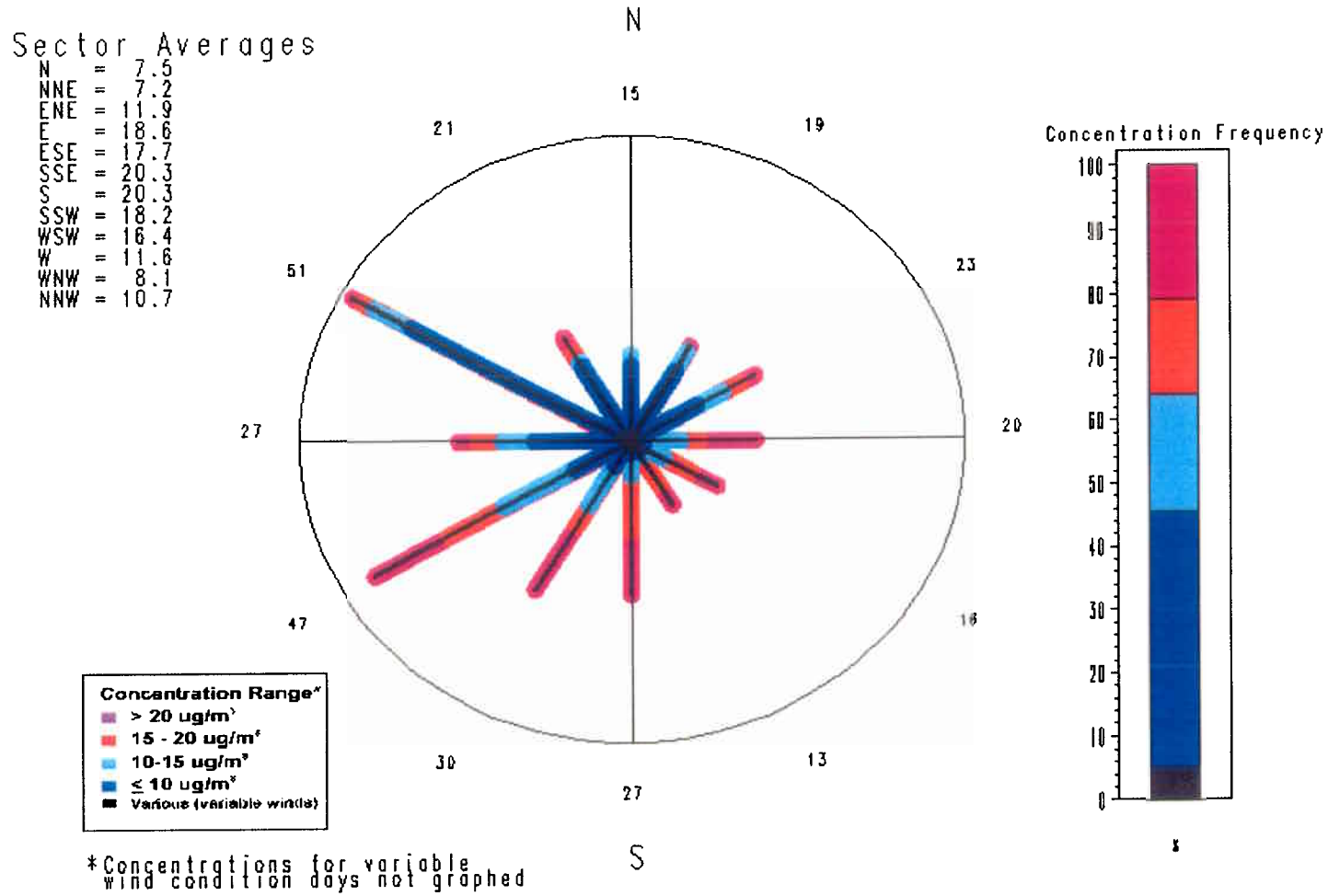
Site 261630025 [Wayne, MI DV=13.7 A]



Met from 21miles (ID:14822)

'02-'04 Sector Pollution Rose for Detroit-Ann Arbor, MI

Site 261630025 [Wayne, MI DV=13.7 A]

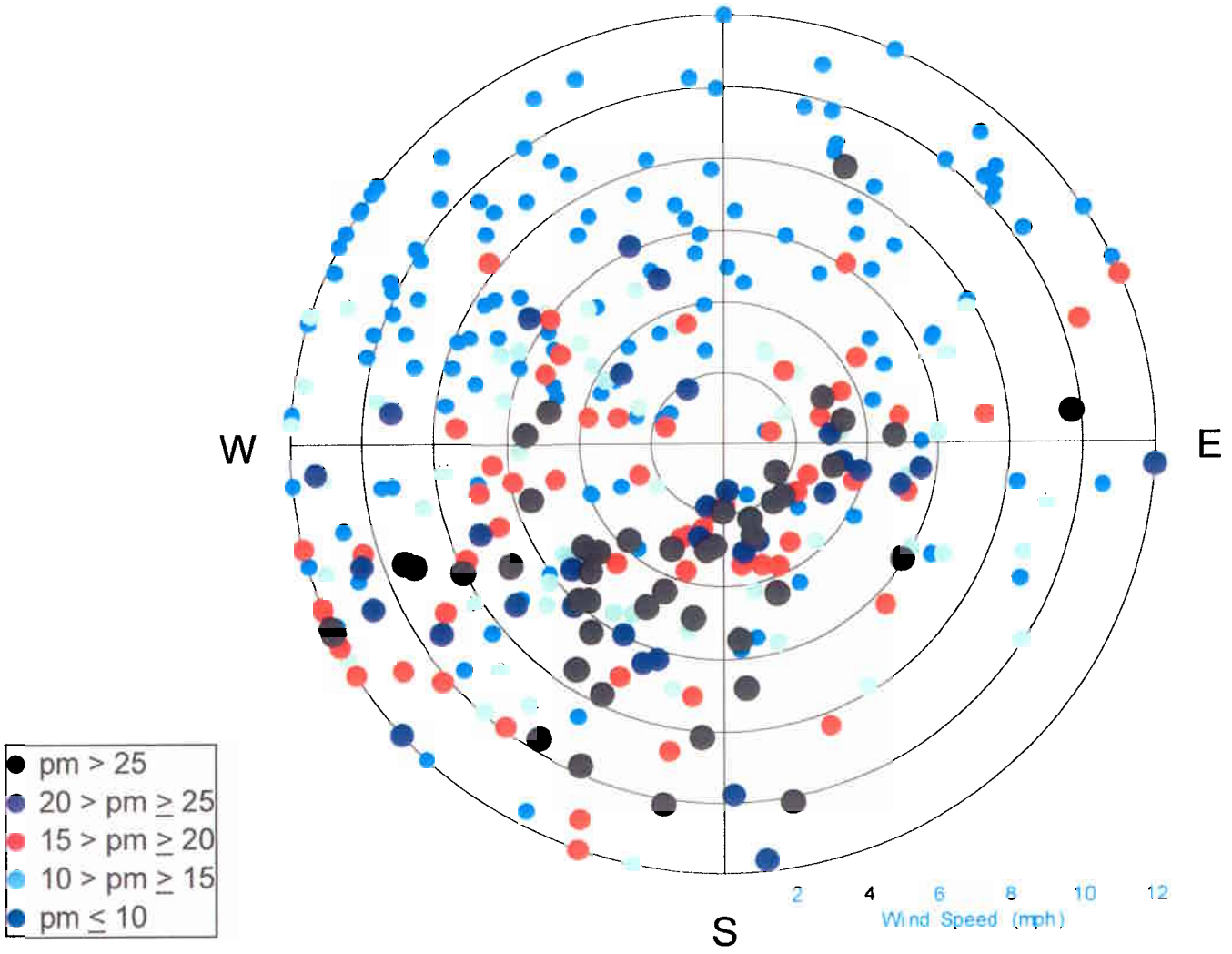


*Concentrations for variable wind condition days not graphed

Met from 21miles (ID:14822)

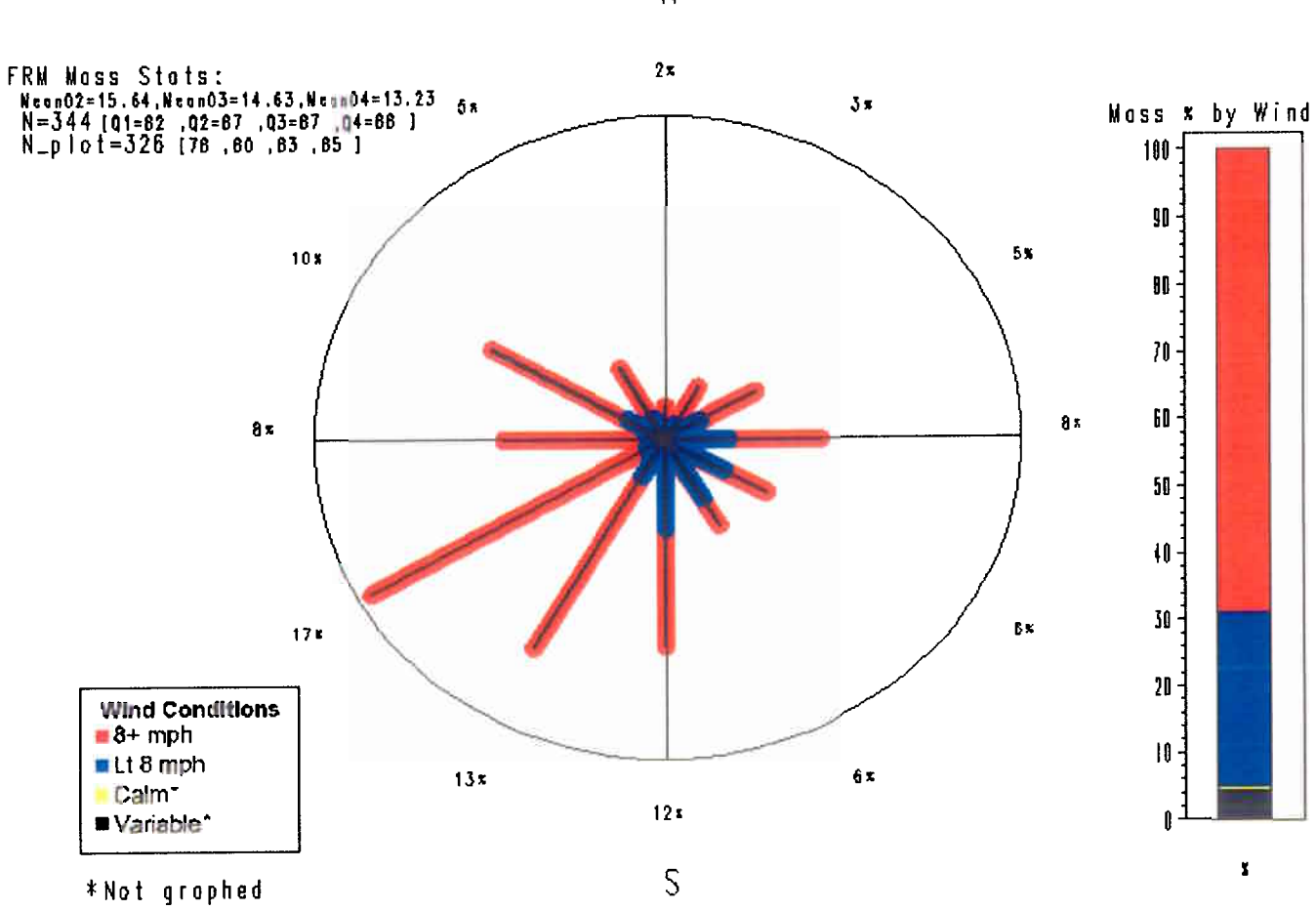
'02-'04 Bubble Pollution Roses

Area= Detroit-Ann Arbor, MI; Site= 261630019



'02-'04 PM2.5 Contribution Rose for Detroit-Ann Arbor, MI

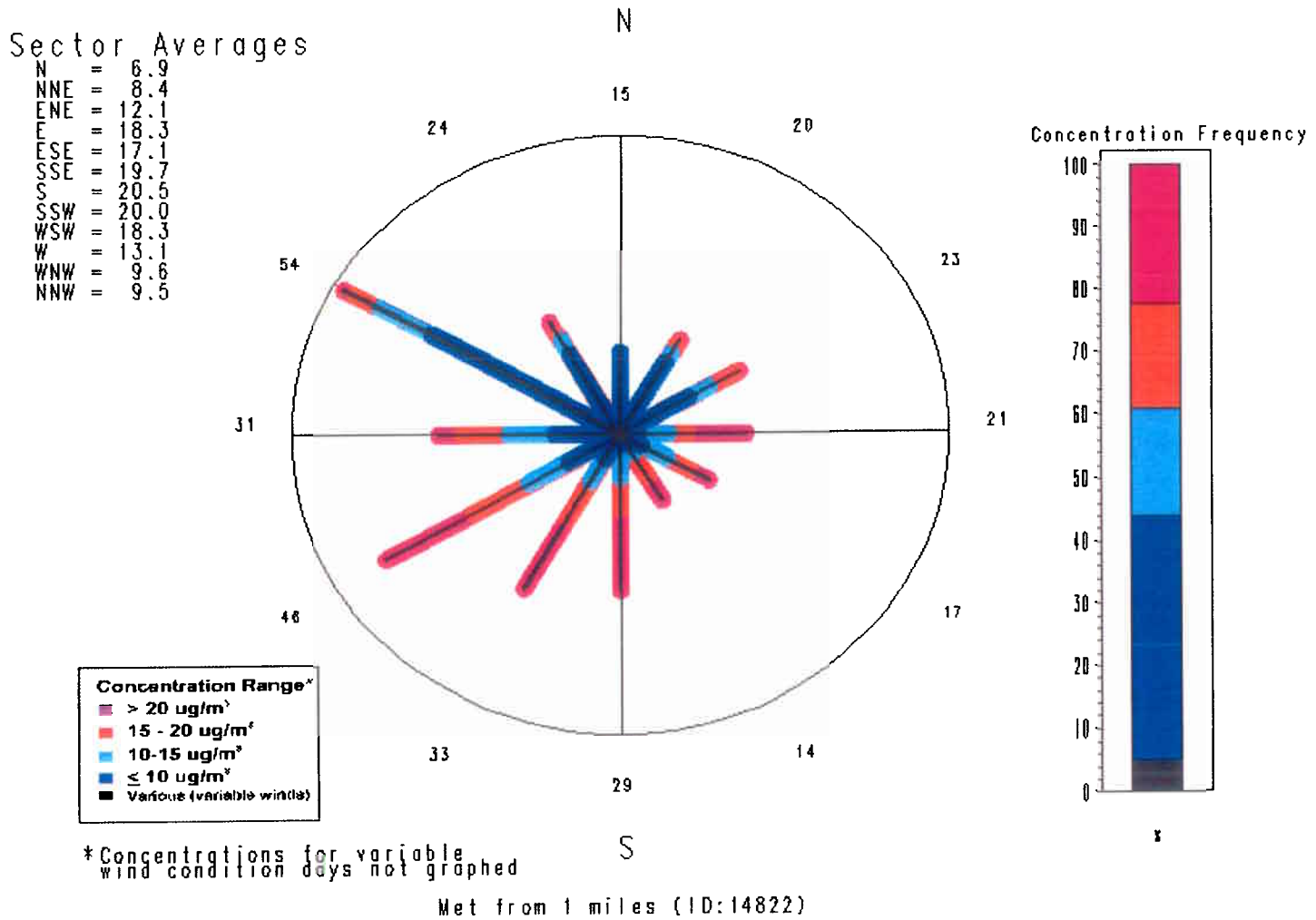
Site 261630019 [Wayne, MI DV=14.5 A]



Met from 1 miles (ID:14822)

'02-'04 Sector Pollution Rose for Detroit-Ann Arbor, MI

Site 261630019 [Wayne, MI DV=14.5 A]

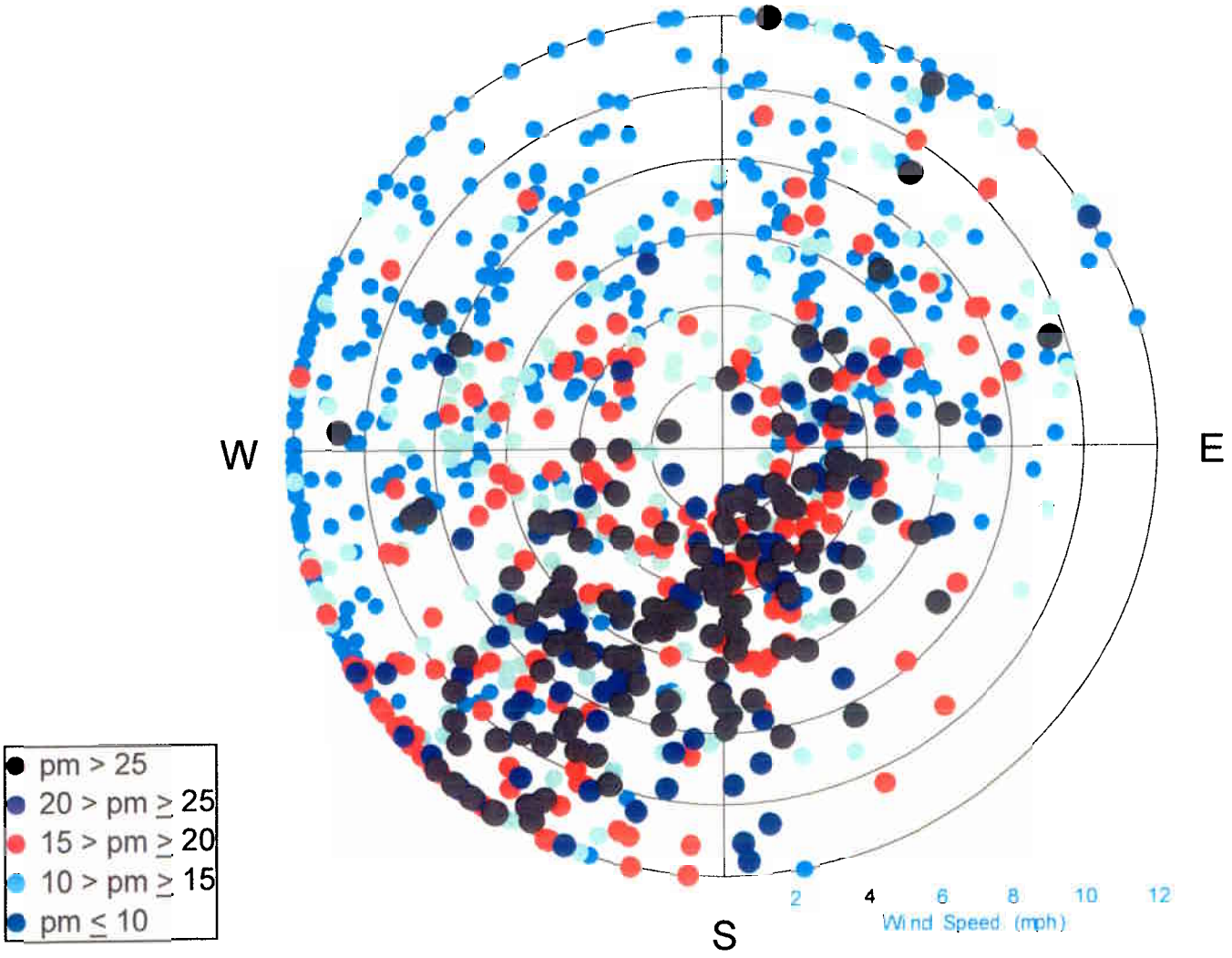


*Concentrations for variable wind condition days not graphed

Met from 1 miles (ID:14822)

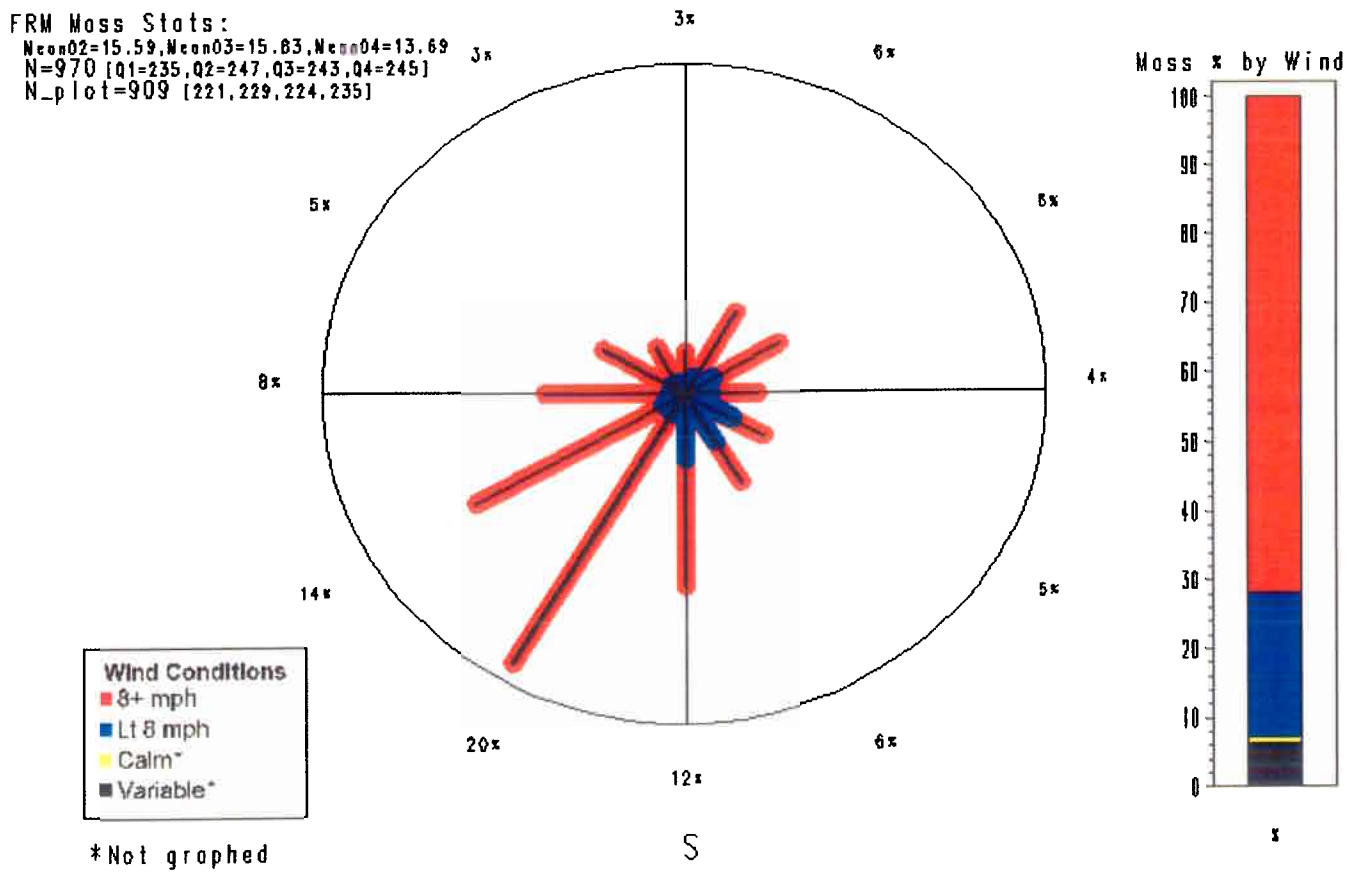
'02-'04 Bubble Pollution Roses

Area= Detroit-Ann Arbor, MI; Site= 261630016



'02-'04 PM2.5 Contribution Rose for Detroit-Ann Arbor, MI

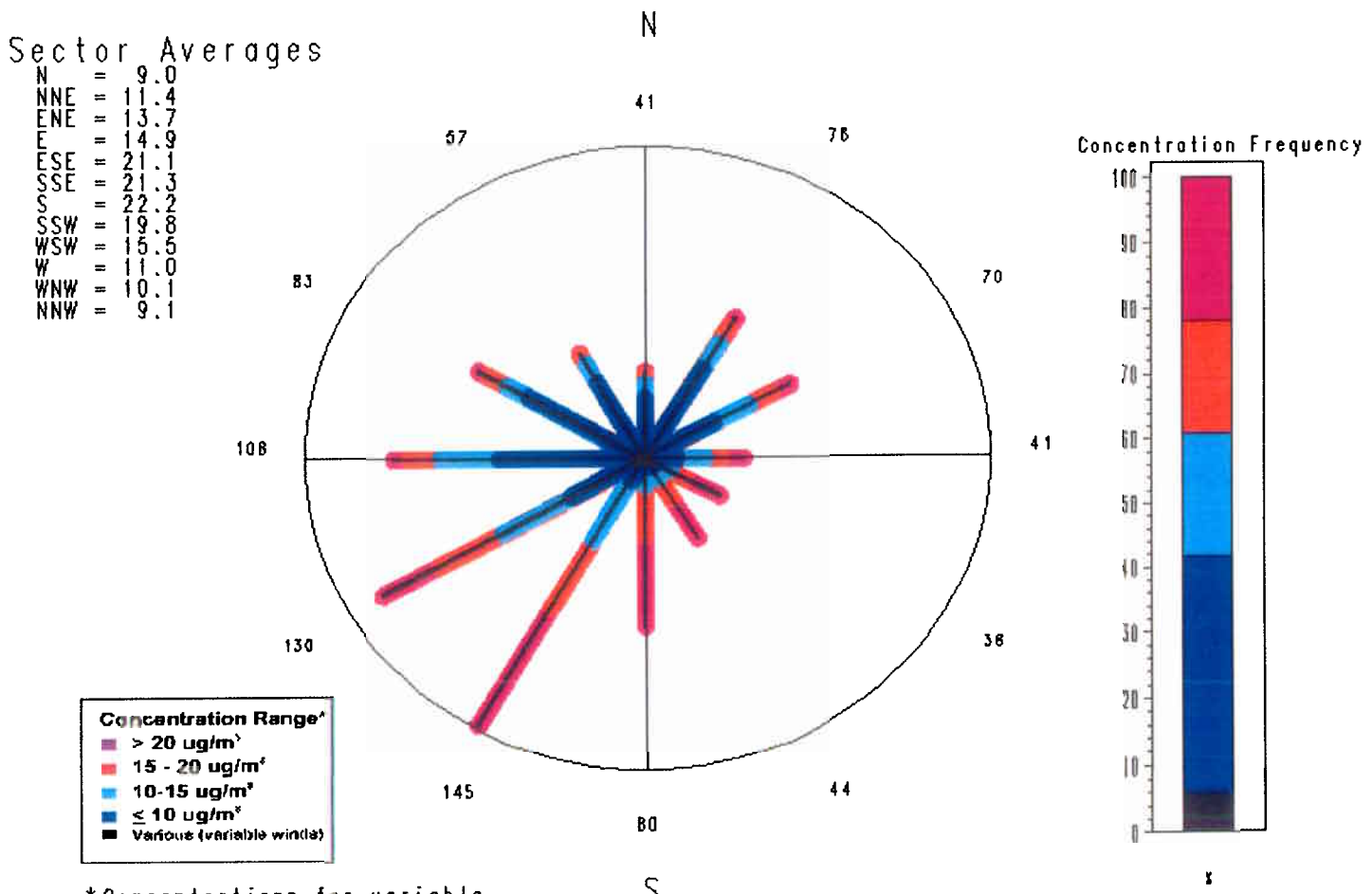
Site 261630016 [Wayne, MI DV=15 A]



Met from 6 miles (ID:94847)

'02-'04 Sector Pollution Rose for Detroit-Ann Arbor, MI

Site 261630016 [Wayne, MI DV=15 A]

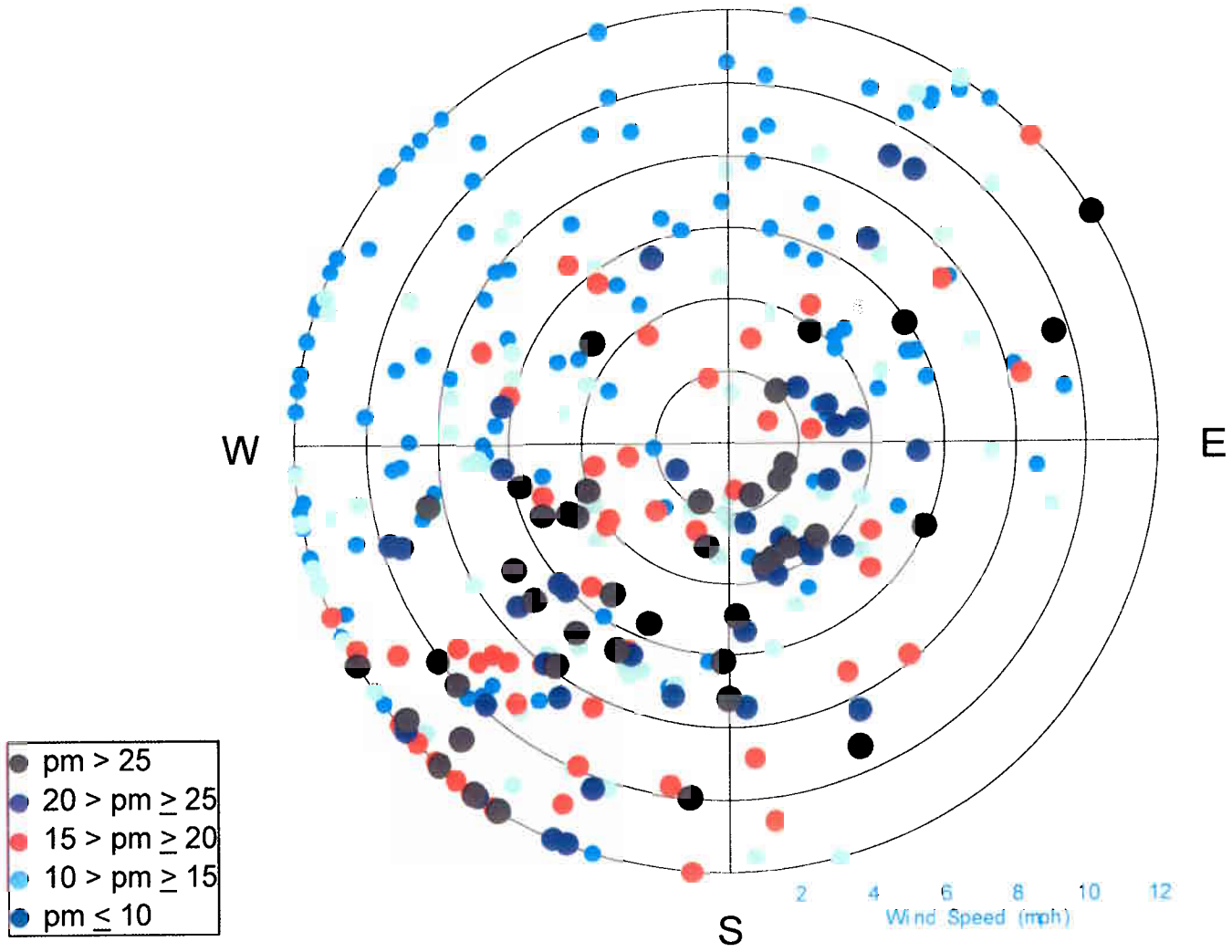


*Concentrations for variable wind condition days not graphed

Met from 6 miles (ID:94847)

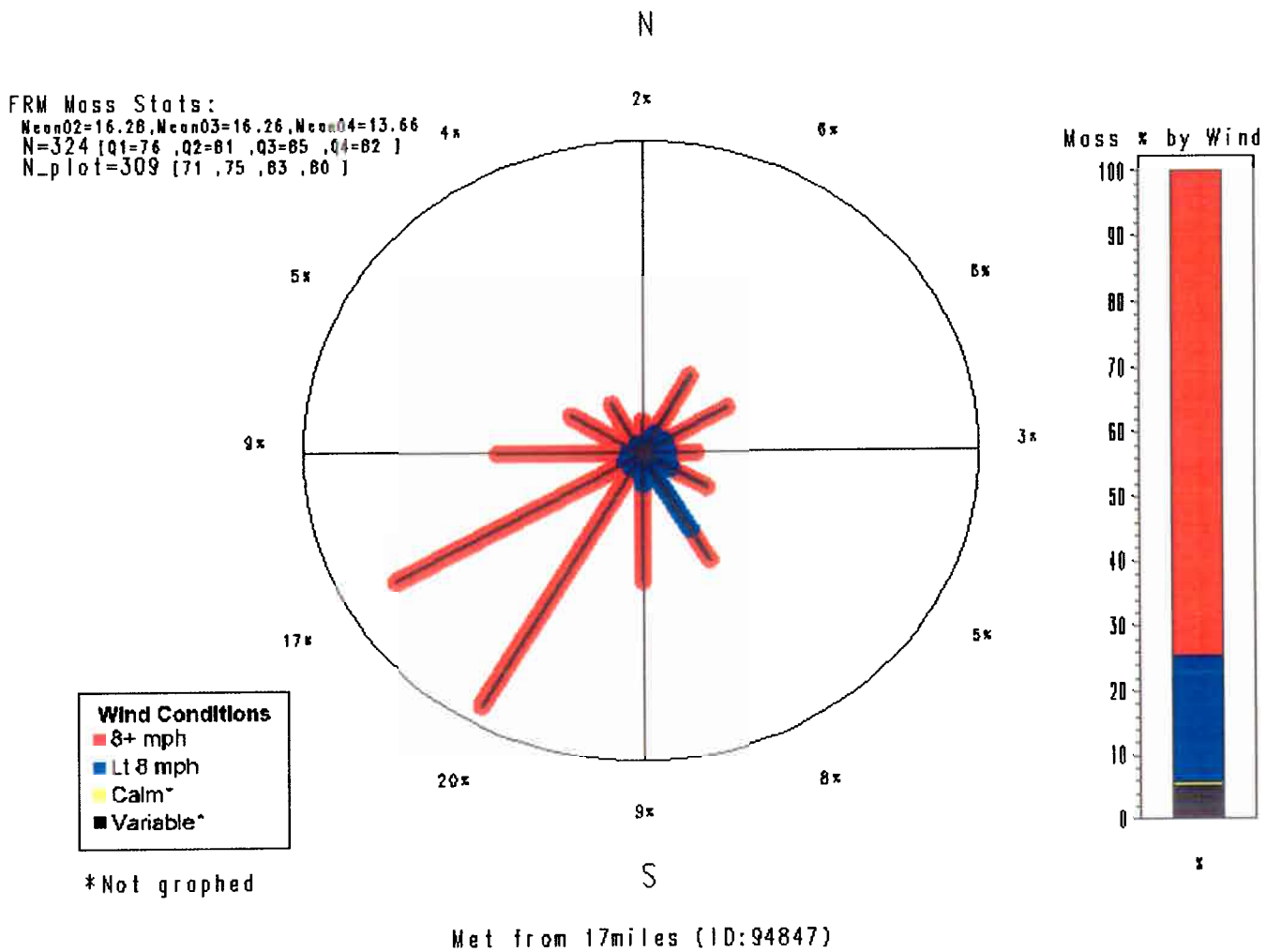
'02-'04 Bubble Pollution Roses

Area= Detroit-Ann Arbor, MI; Site= 261630036



'02-'04 PM2.5 Contribution Rose for Detroit-Ann Arbor, MI

Site 261630036 [Wayne, MI DV=15.4 NA]

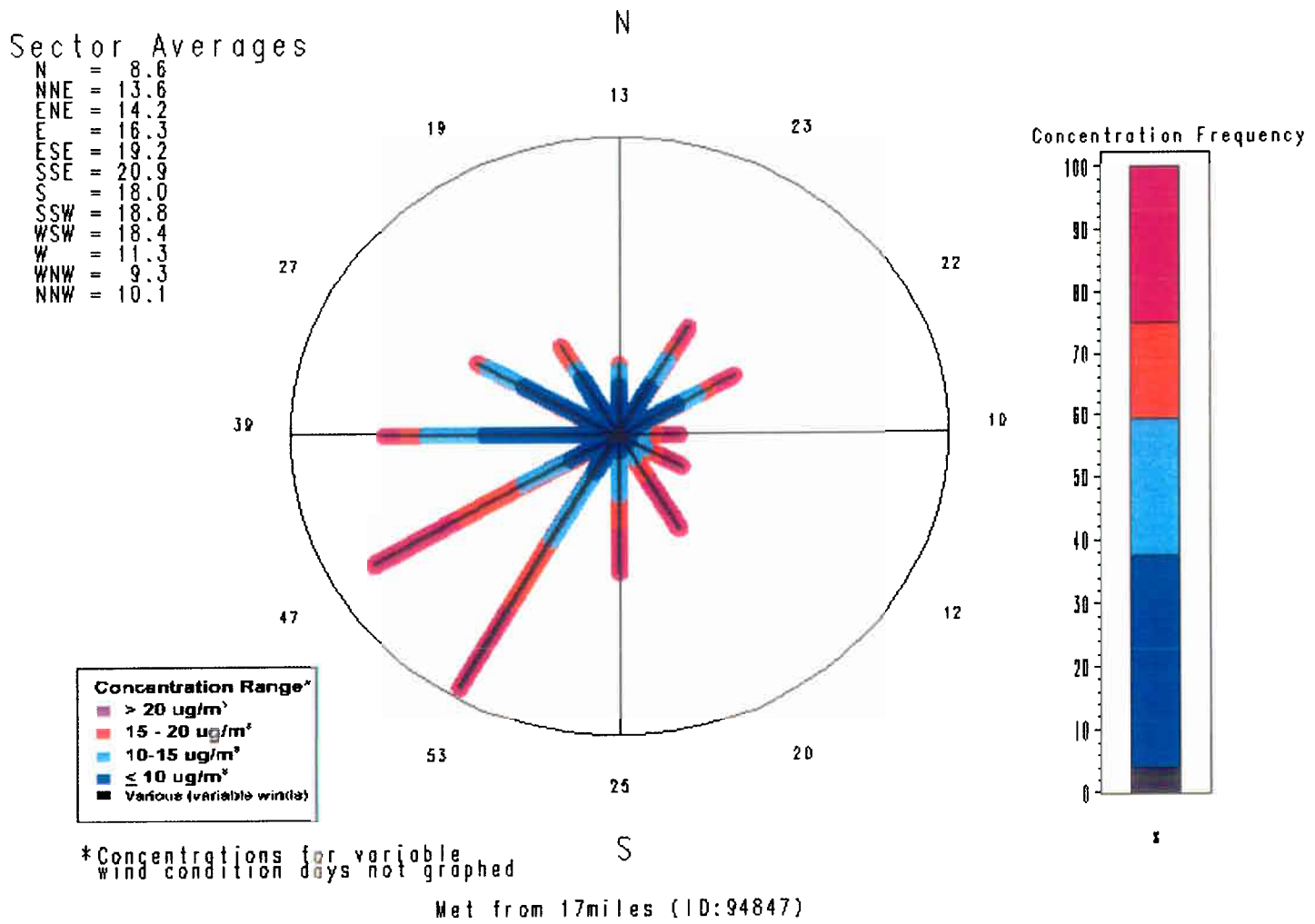


Met from 17miles (ID:94847)

A-047
02-04 CR Wyandotte

'02-'04 Sector Pollution Rose for Detroit-Ann Arbor, MI

Site 261630036 [Wayne, MI DV=15.4 NA]

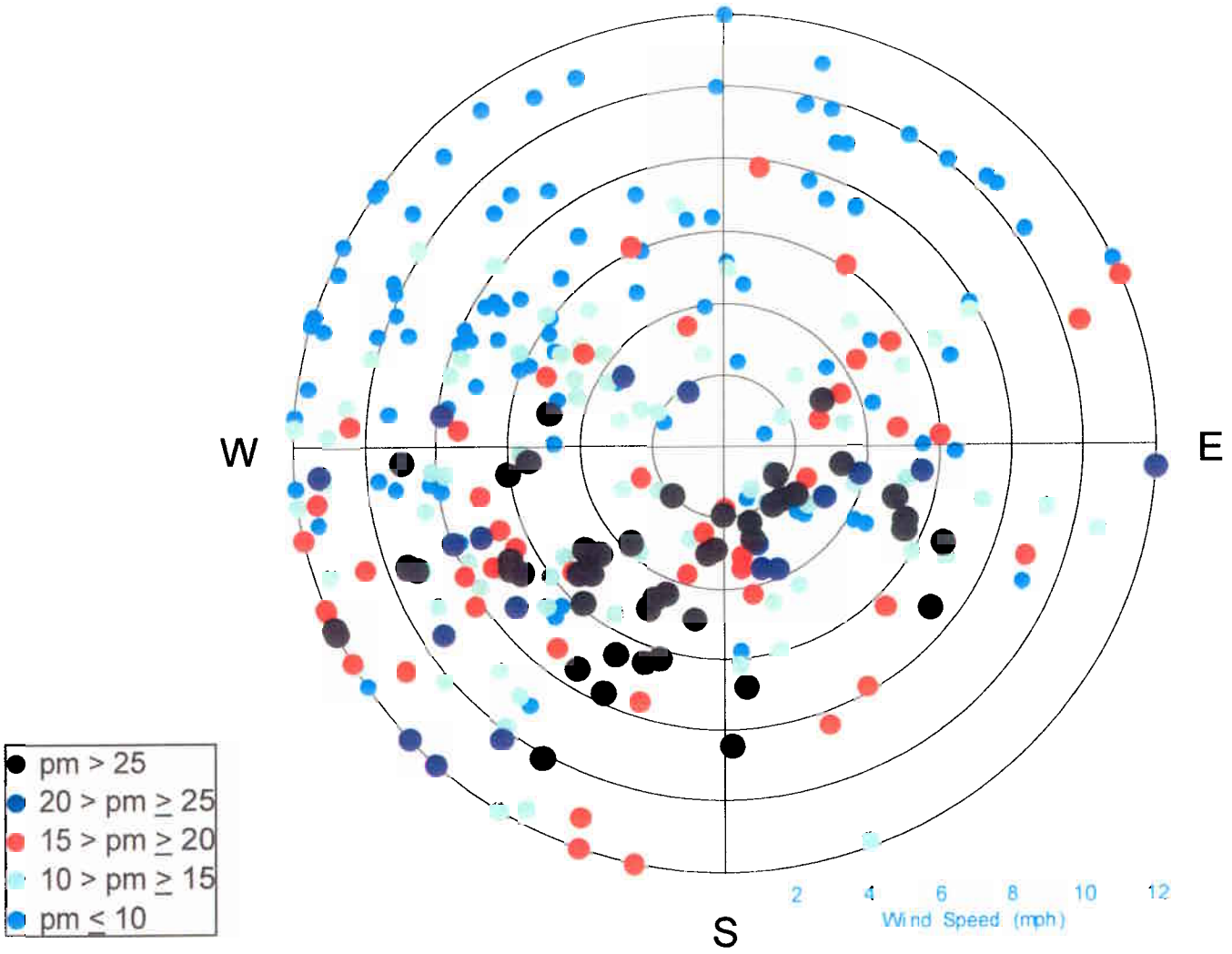


*Concentrations for variable wind condition days not graphed

Met from 17miles (ID:94847)

'01-'03 Bubble Pollution Roses

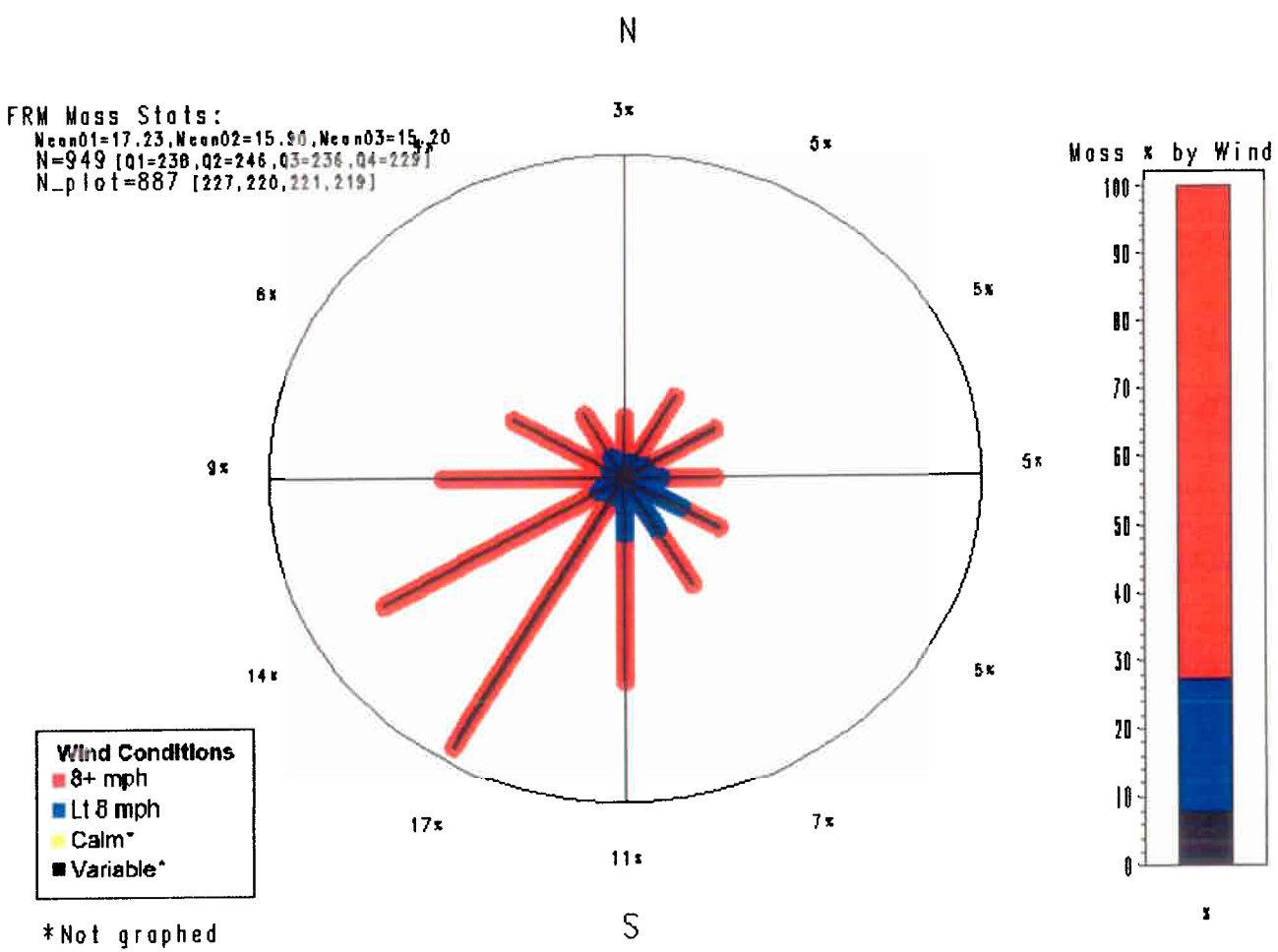
Area= Detroit, MI; Site= 261250001



A-049
01-03 BPR Oak Park

'01-'03 PM2.5 Contribution Rose for Detroit, MI

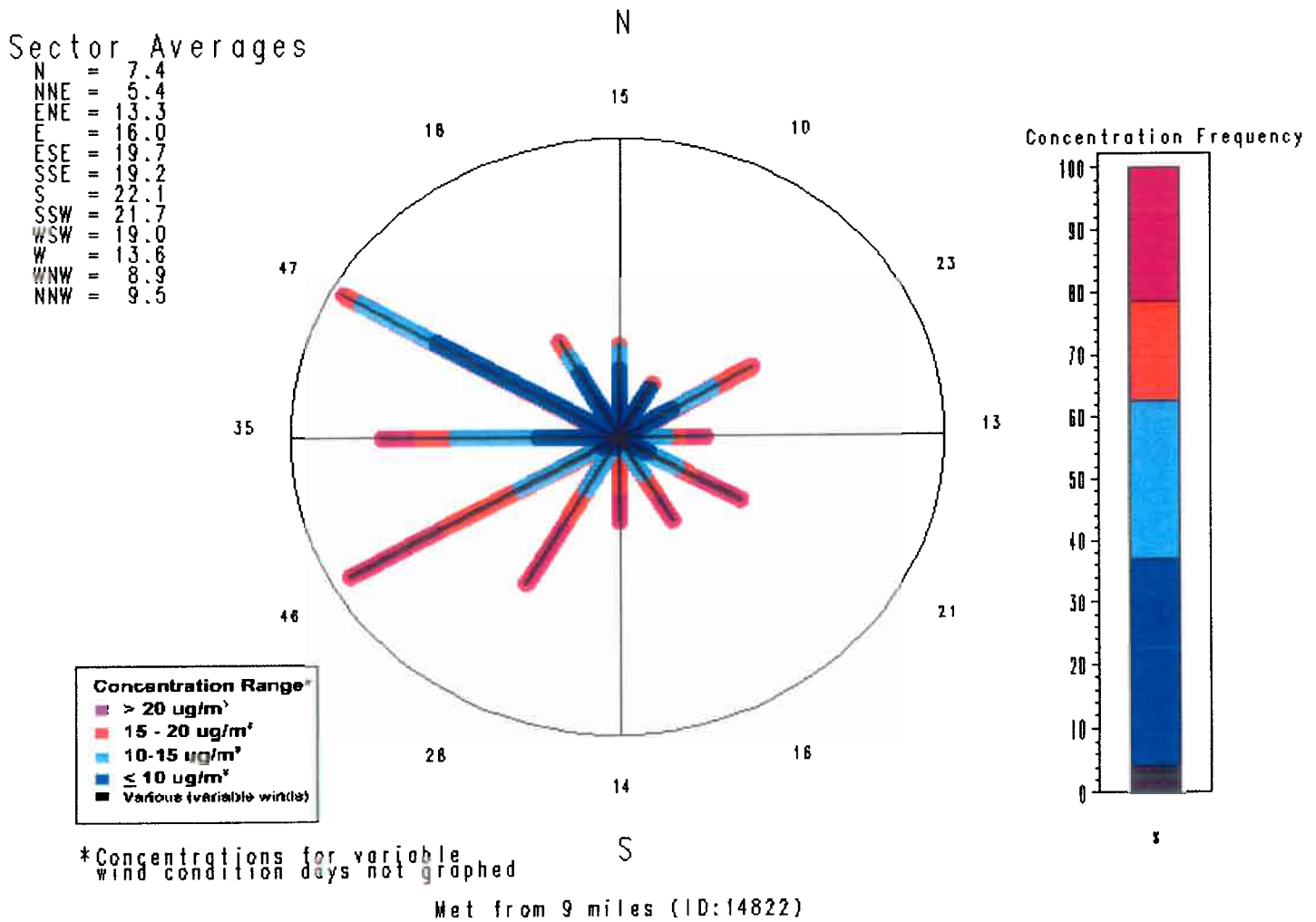
Site 261630001 [Wayne, MI DV=16.1 NA]



Met from 16miles (ID:94847)

'01-'03 Simple Pollution Rose for Detroit, MI

Site 261250001 [Oakland, MI DV=14.8 a]

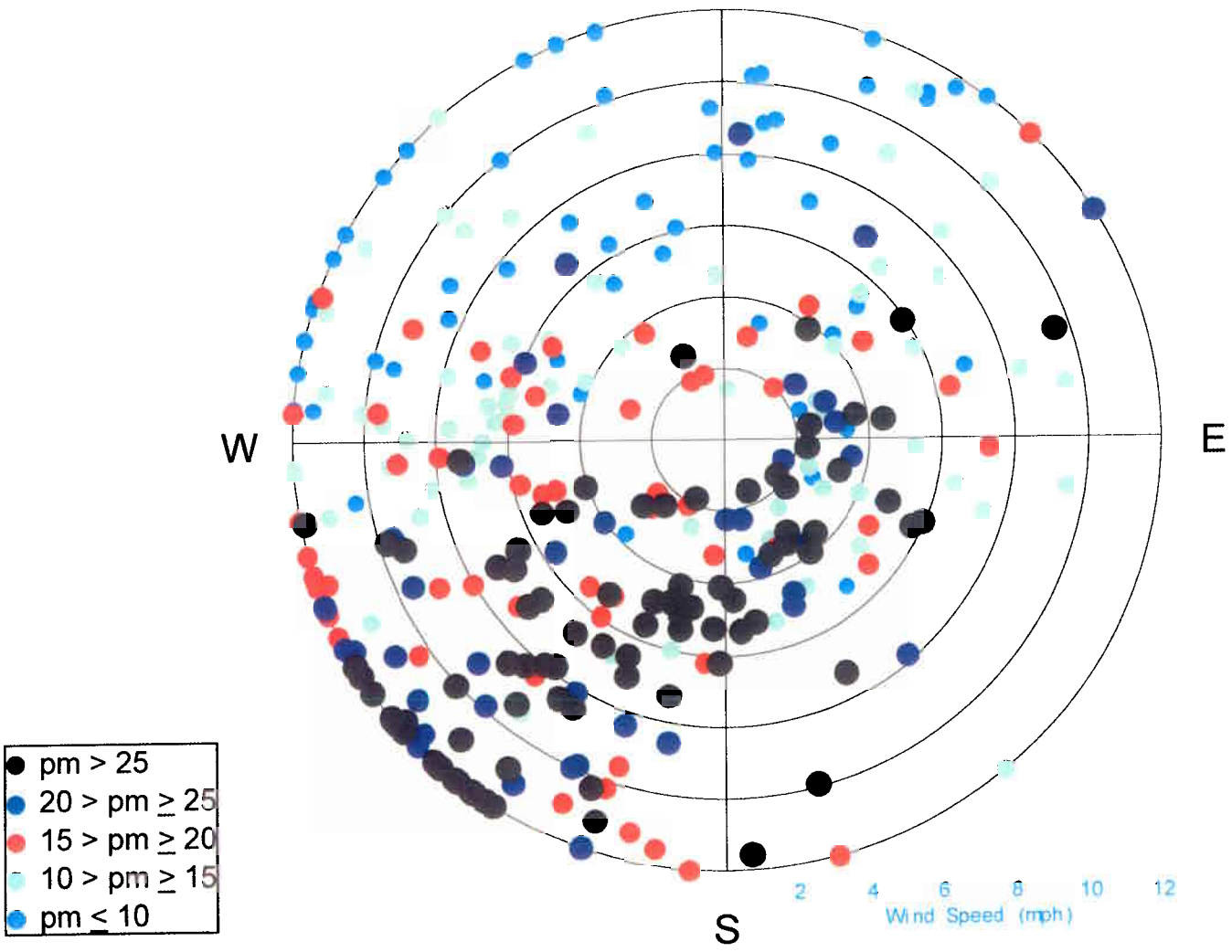


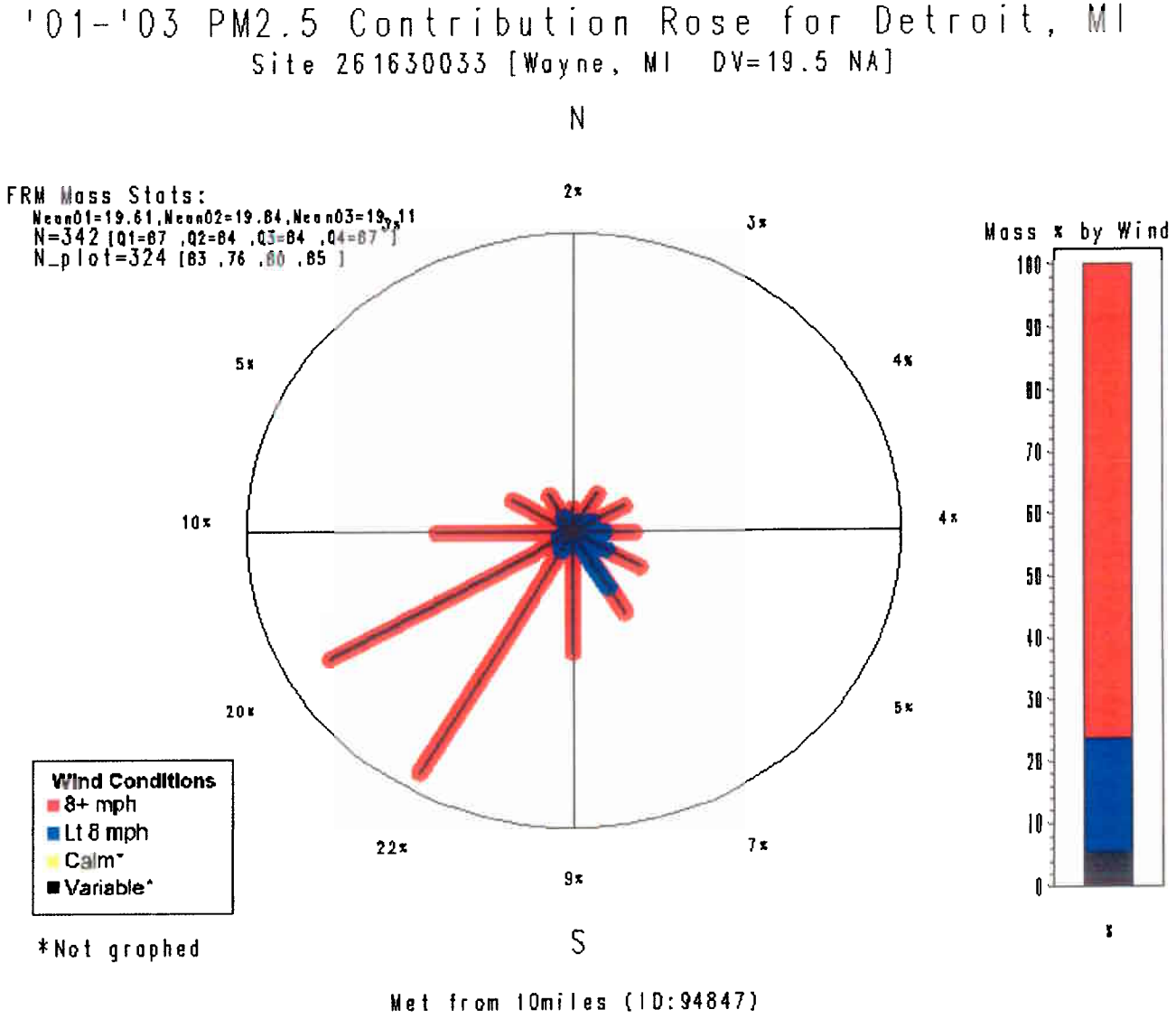
*Concentrations for variable wind condition days not graphed

Met from 9 miles (ID:14822)

'01-'03 Bubble Pollution Roses

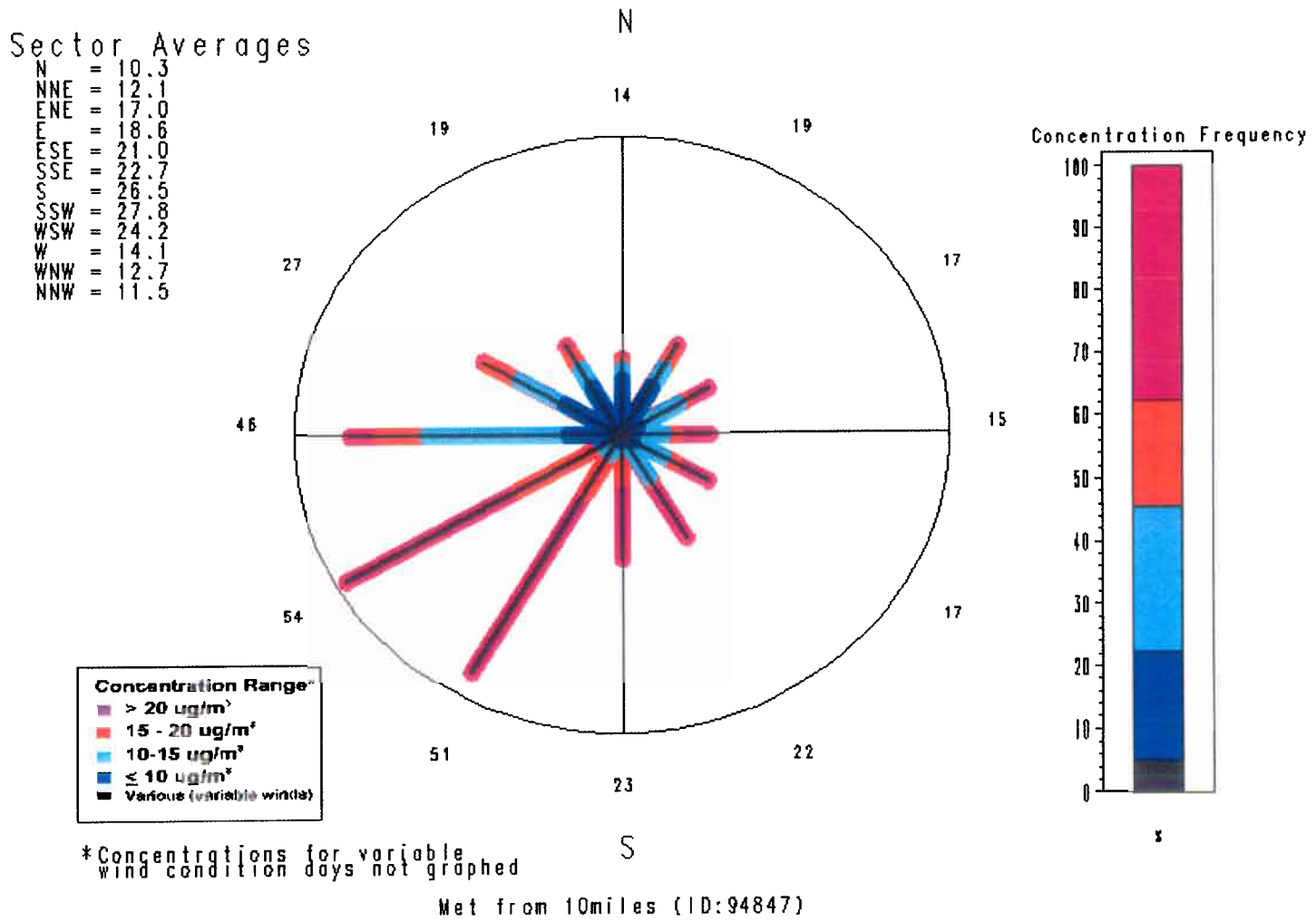
Area= Detroit, MI; Site= 261630033




'01-'03 PM2.5 Contribution Rose for Detroit, MI
Site 261630033 [Wayne, MI DV=19.5 NA]
N
FRM Mass Stats:
Mean01=19.61,Mean02=19.84,Mean03=19.11
N=342 [Q1=87 ,Q2=84 ,Q3=84 ,Q4=87]
N_plot=324 [83 ,76 ,80 ,85]
2%
3%
4%
4%
5%
7%
9%
22%
20%
10%
5%
Wind Conditions
8+ mph
Lt 8 mph
Calm*
Variable*
*Not graphed
S
Mass % by Wind
100
90
80
70
60
50
40
30
20
10
0
%
Met from 10miles (ID:94847)

'01-'03 Simple Pollution Rose for Detroit, MI

Site 261630033 [Wayne, MI DV=19.5 NA]

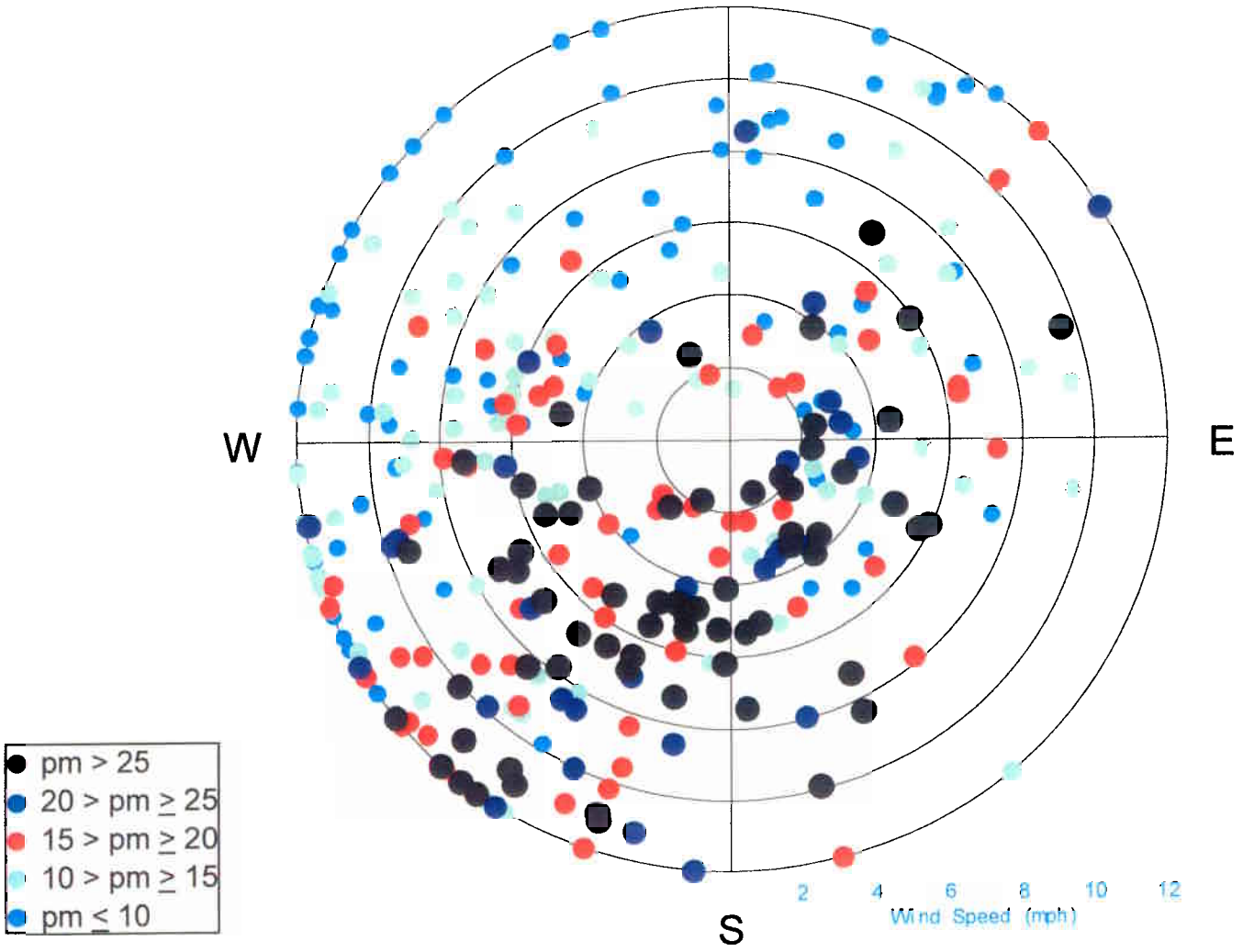


*Concentrations for variable wind condition days not graphed

Met from 10miles (ID:94847)

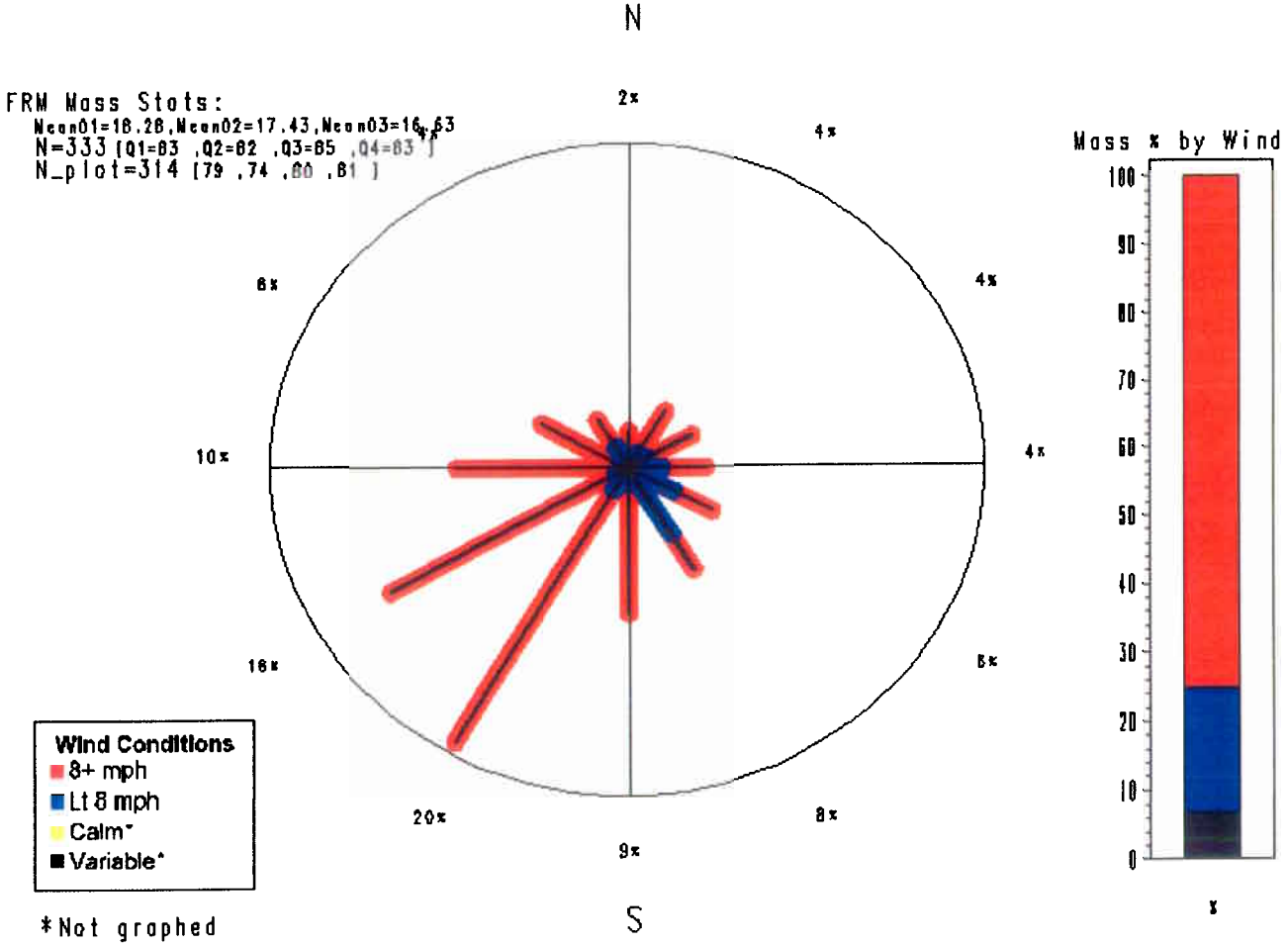
'01-'03 Bubble Pollution Roses

Area= Detroit, MI; Site= 261630015



'01-'03 PM2.5 Contribution Rose for Detroit, MI

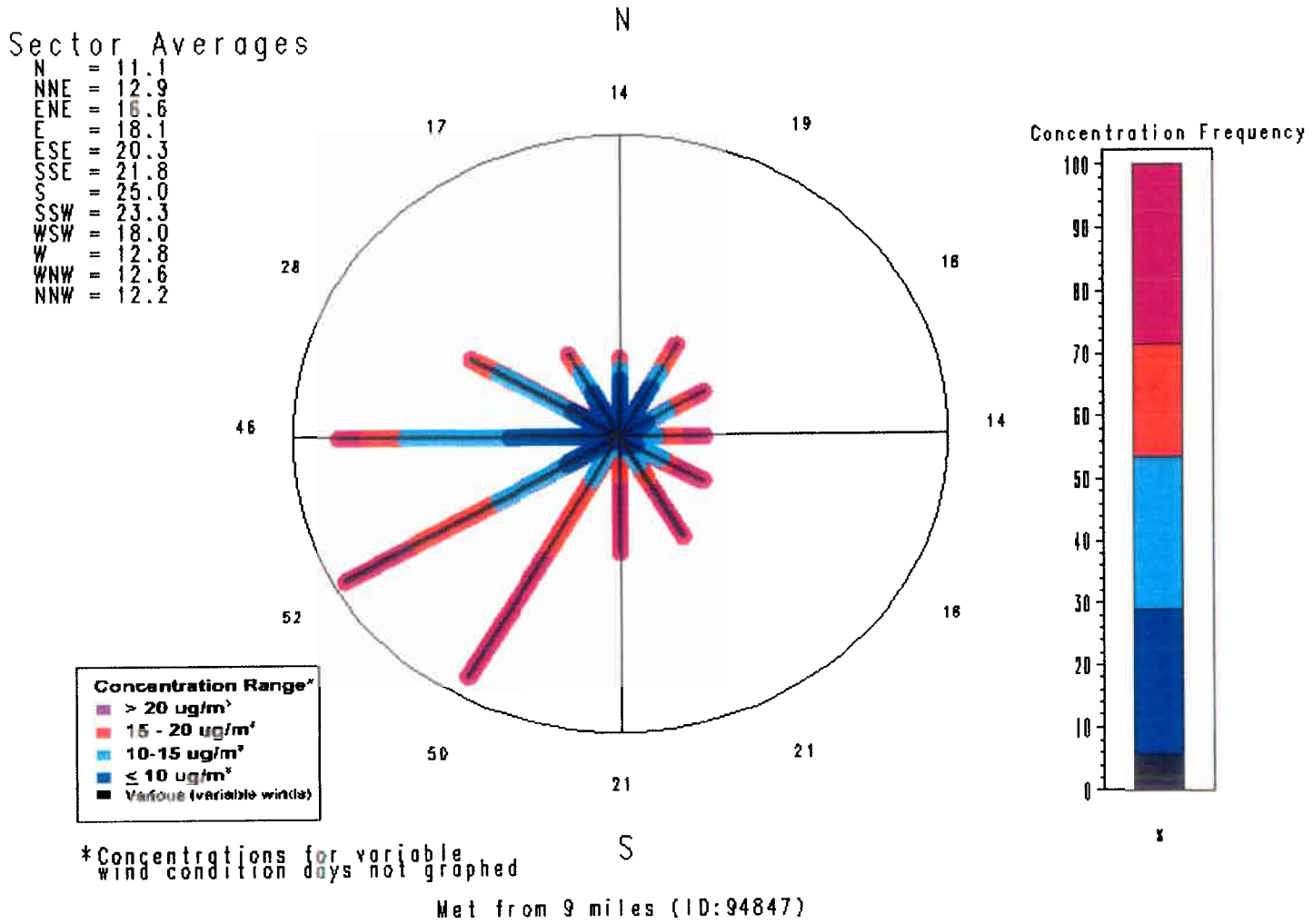
Site 261630015 [Wayne, MI DV=17.4 NA]



Met from 9 miles (ID:94847)

'01-'03 Simple Pollution Rose for Detroit, MI

Site 261630015 [Wayne, MI DV=17.4 NA]

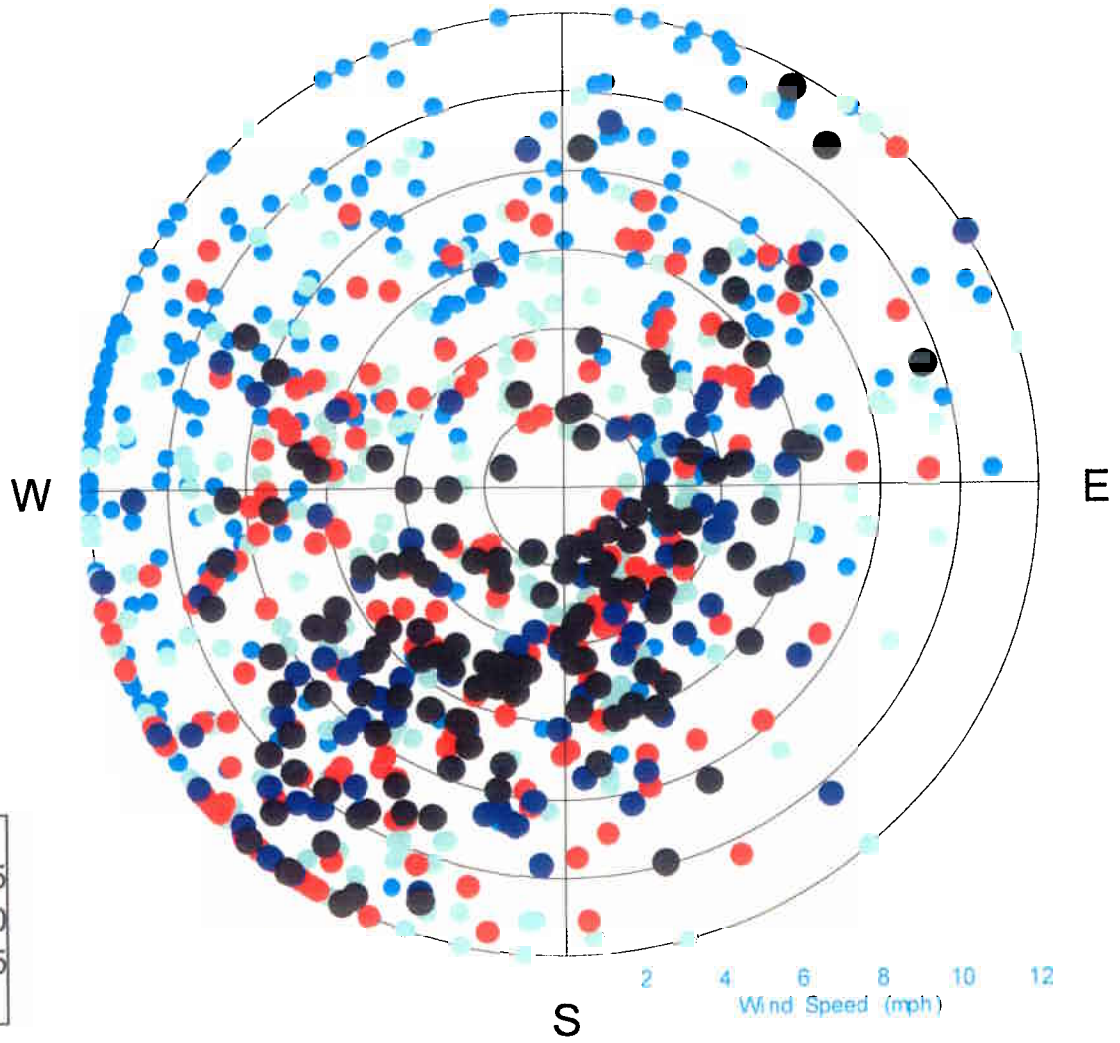


*Concentrations for variable wind condition days not graphed

Met from 9 miles (ID:94847)

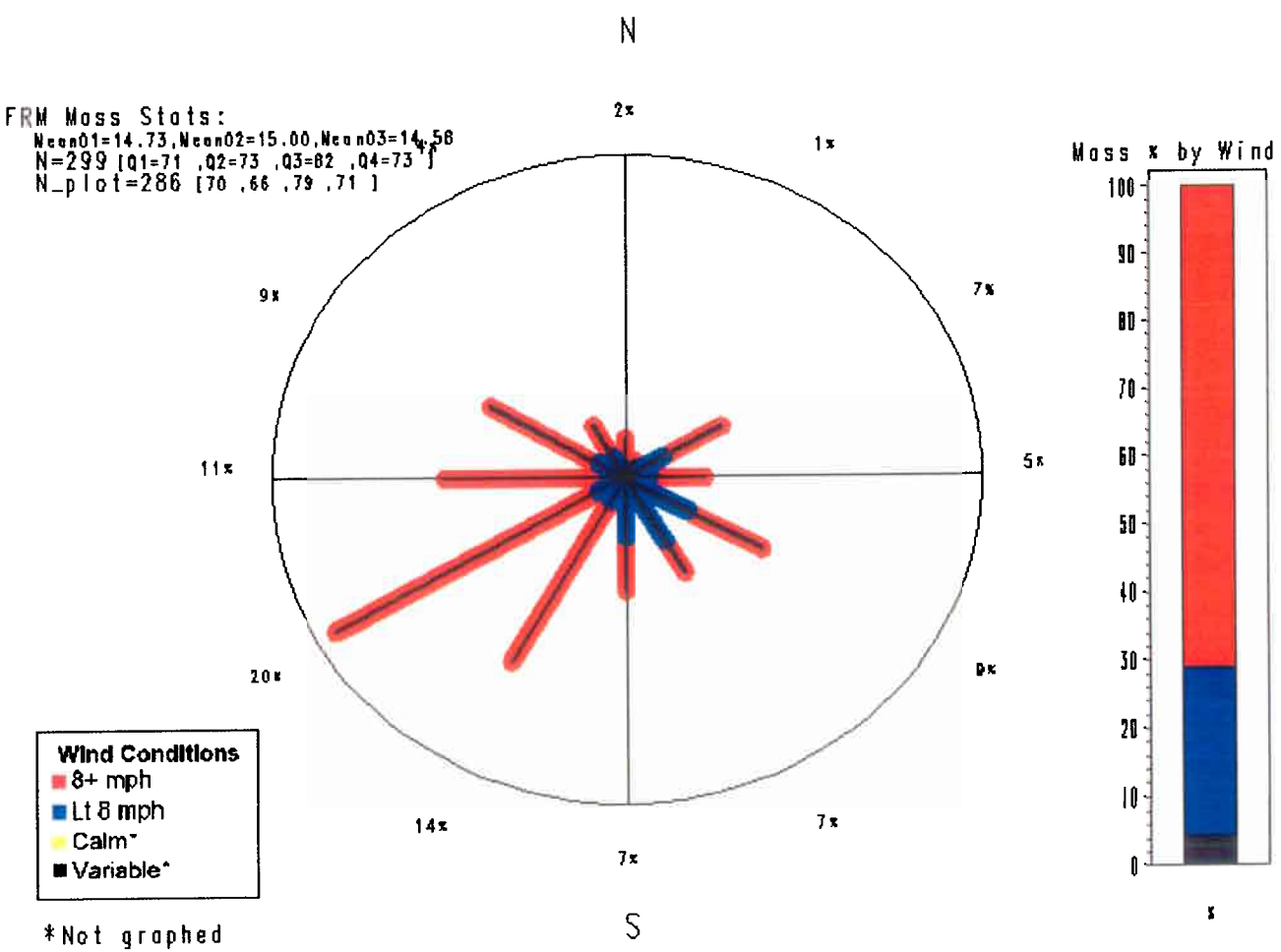
'01-'03 Bubble Pollution Roses

Area= Detroit, MI; Site= 261630001



'01-'03 PM2.5 Contribution Rose for Detroit, MI

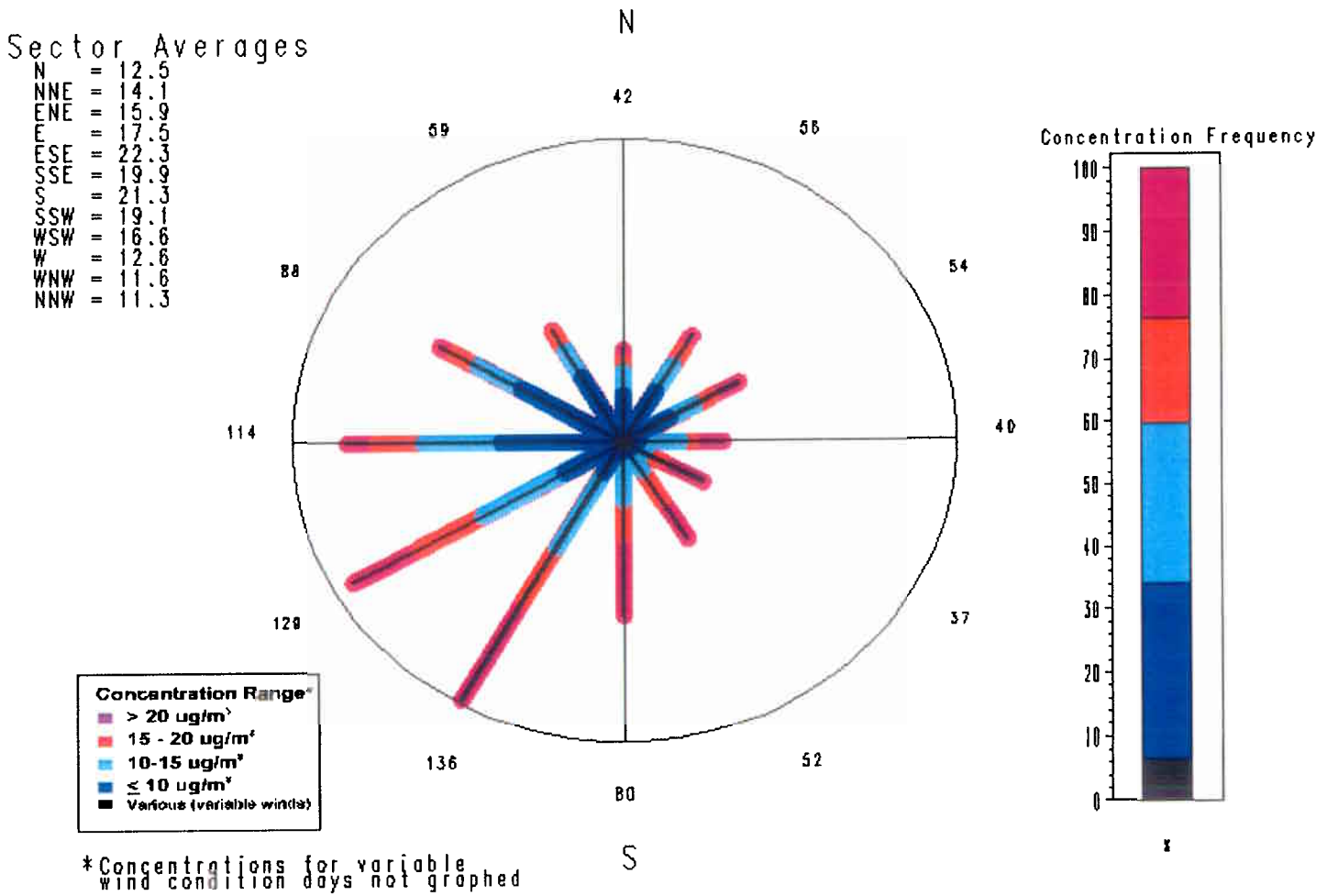
Site 261250001 [Oakland, MI DV=14.8 a]



Met from 9 miles (ID:14822)

'01-'03 Simple Pollution Rose for Detroit, MI

Site 261630001 [Wayne, MI DV=16.1 NA]

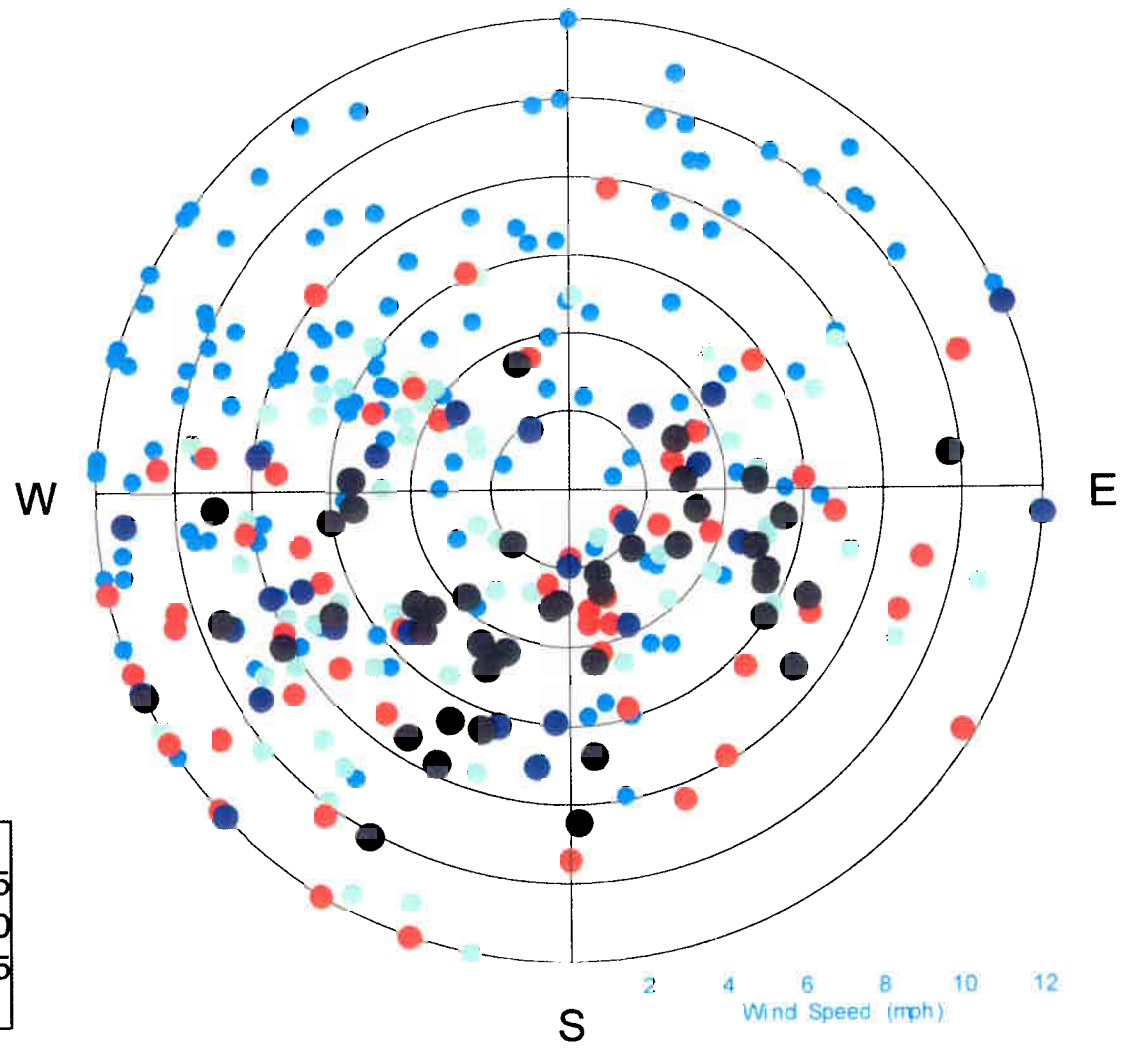


*Concentrations for variable wind condition days not graphed

Met from 16miles (ID:94847)

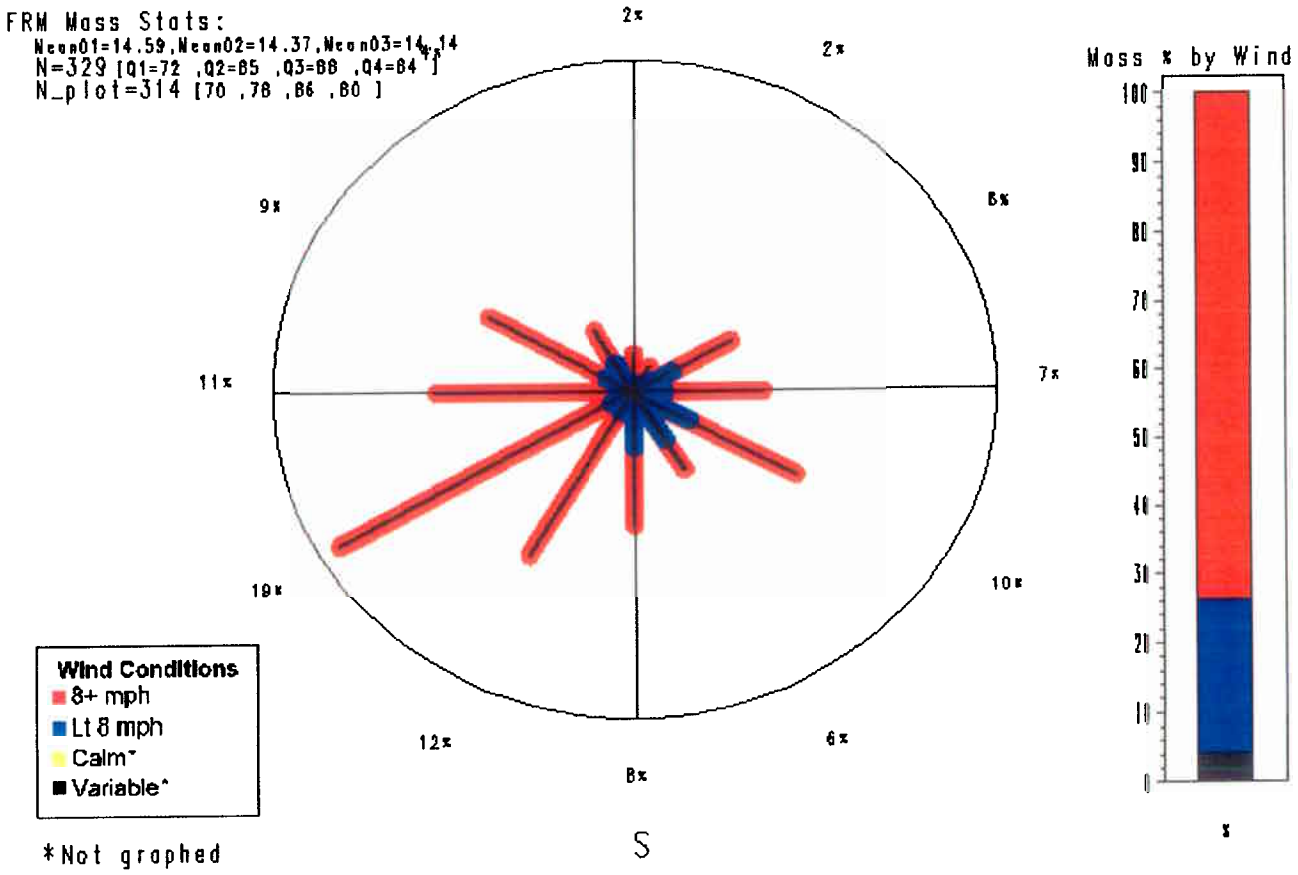
'01-'03 Bubble Pollution Roses

Area= Detroit, MI; Site= 261630025



'01-'03 PM2.5 Contribution Rose for Detroit, MI

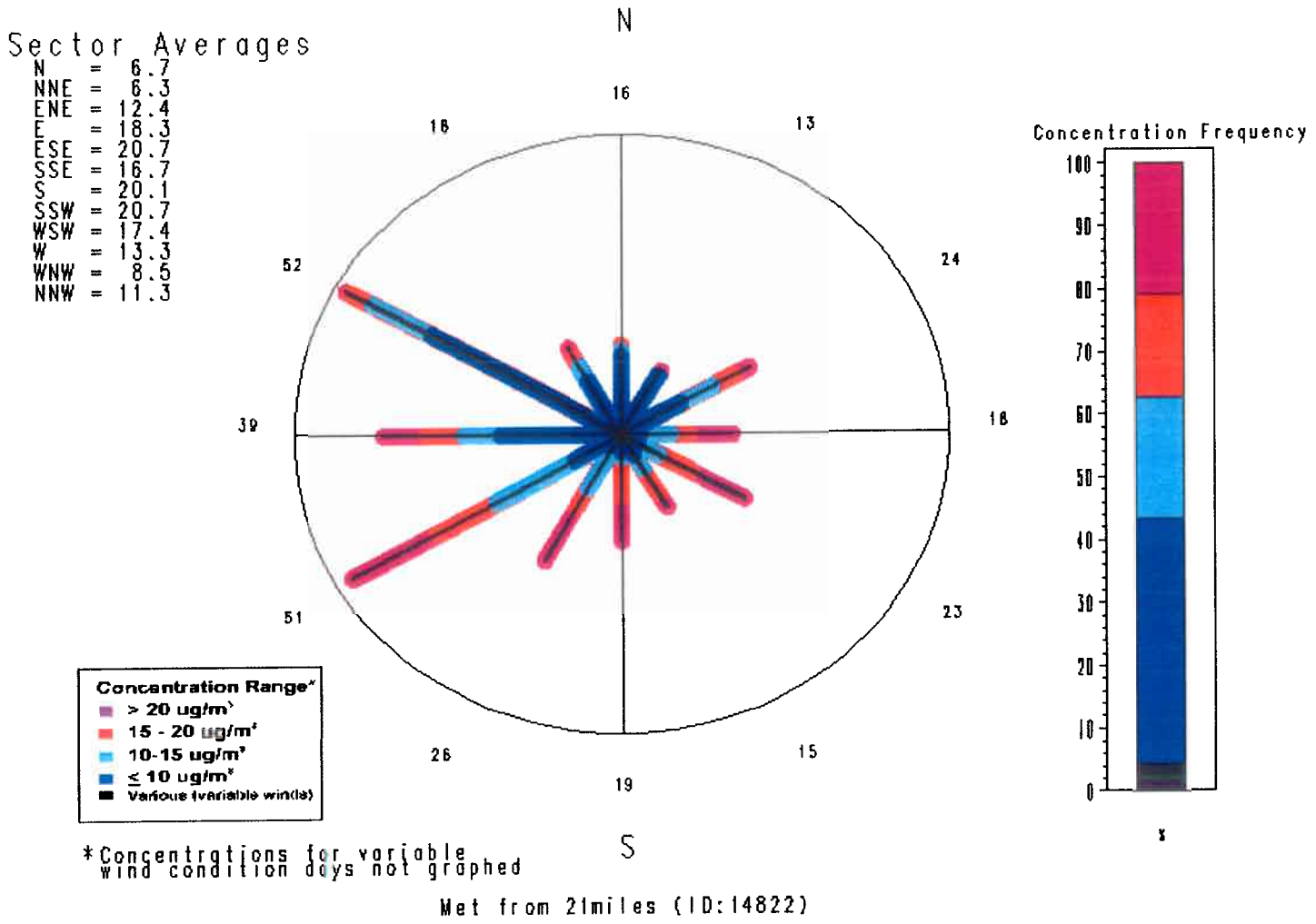
Site 261630025 [Wayne, MI DV=14.4 a]



Met from 21miles (ID:14822)

'01-'03 Simple Pollution Rose for Detroit, MI

Site 261630025 [Wayne, MI DV=14.4 a]

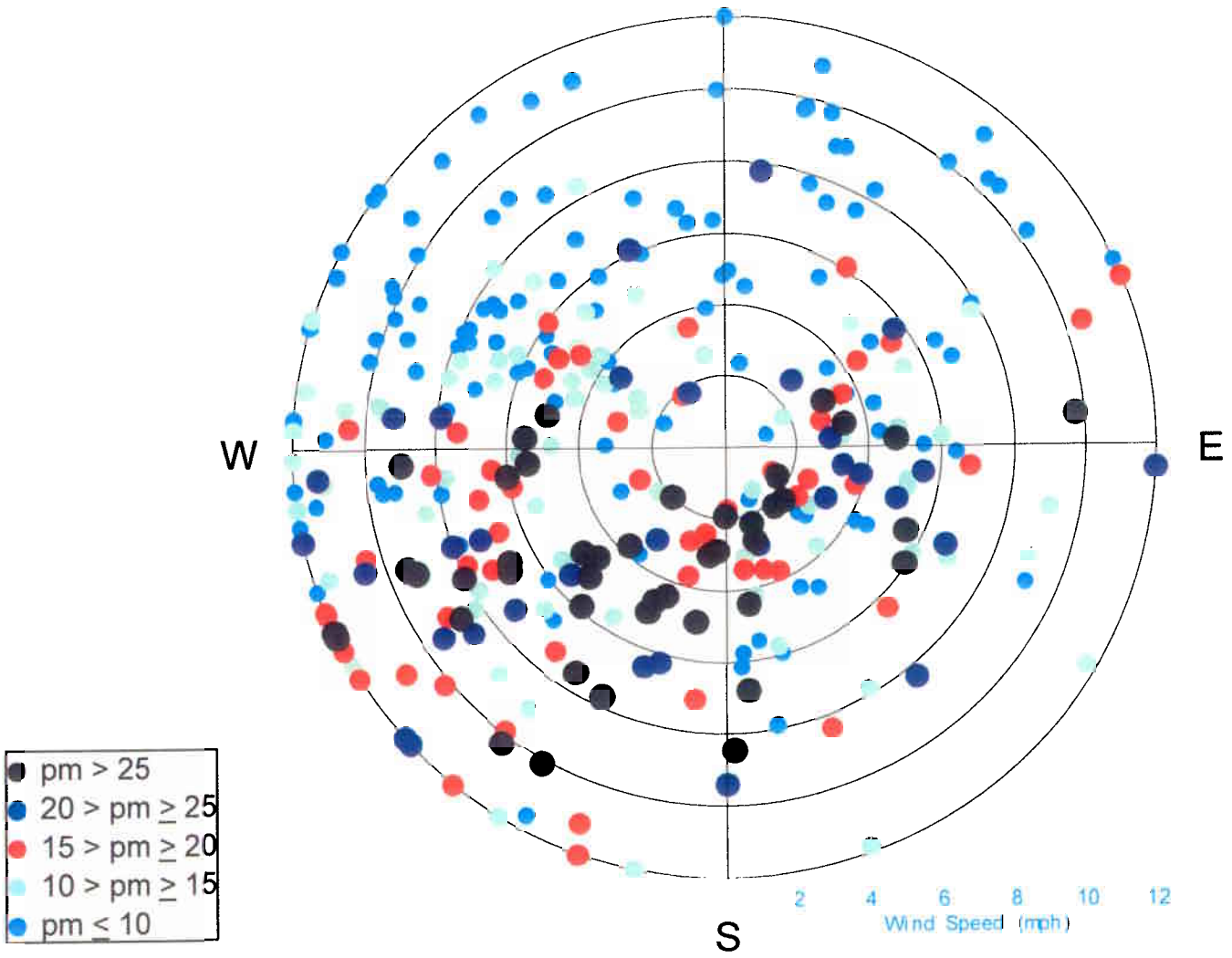


*Concentrations for variable wind condition days not graphed

Met from 21miles (ID:14822)

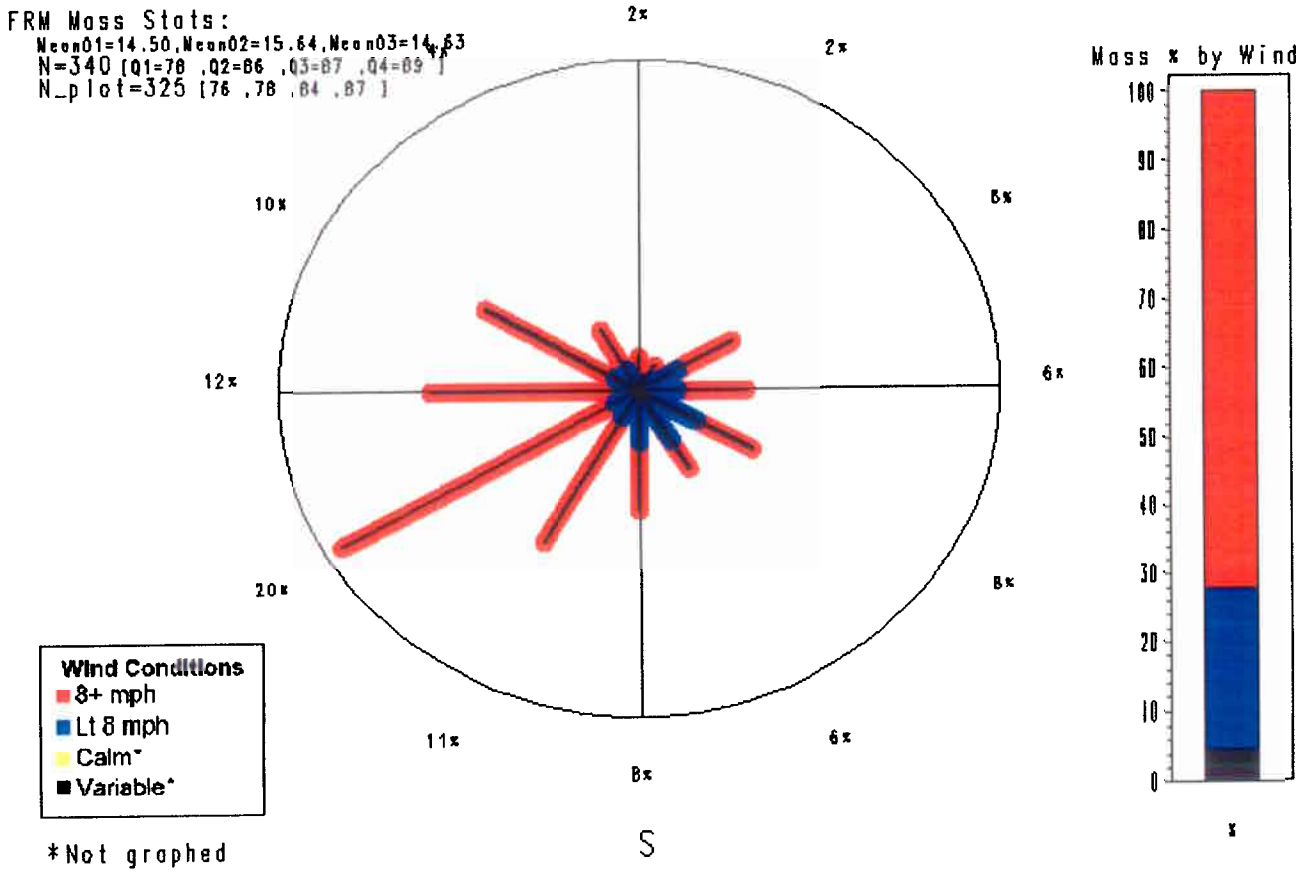
'01-'03 Bubble Pollution Roses

Area= Detroit, MI; Site= 261630019



'01-'03 PM2.5 Contribution Rose for Detroit, MI

Site 261630019 [Wayne, MI DV=14.9 A]

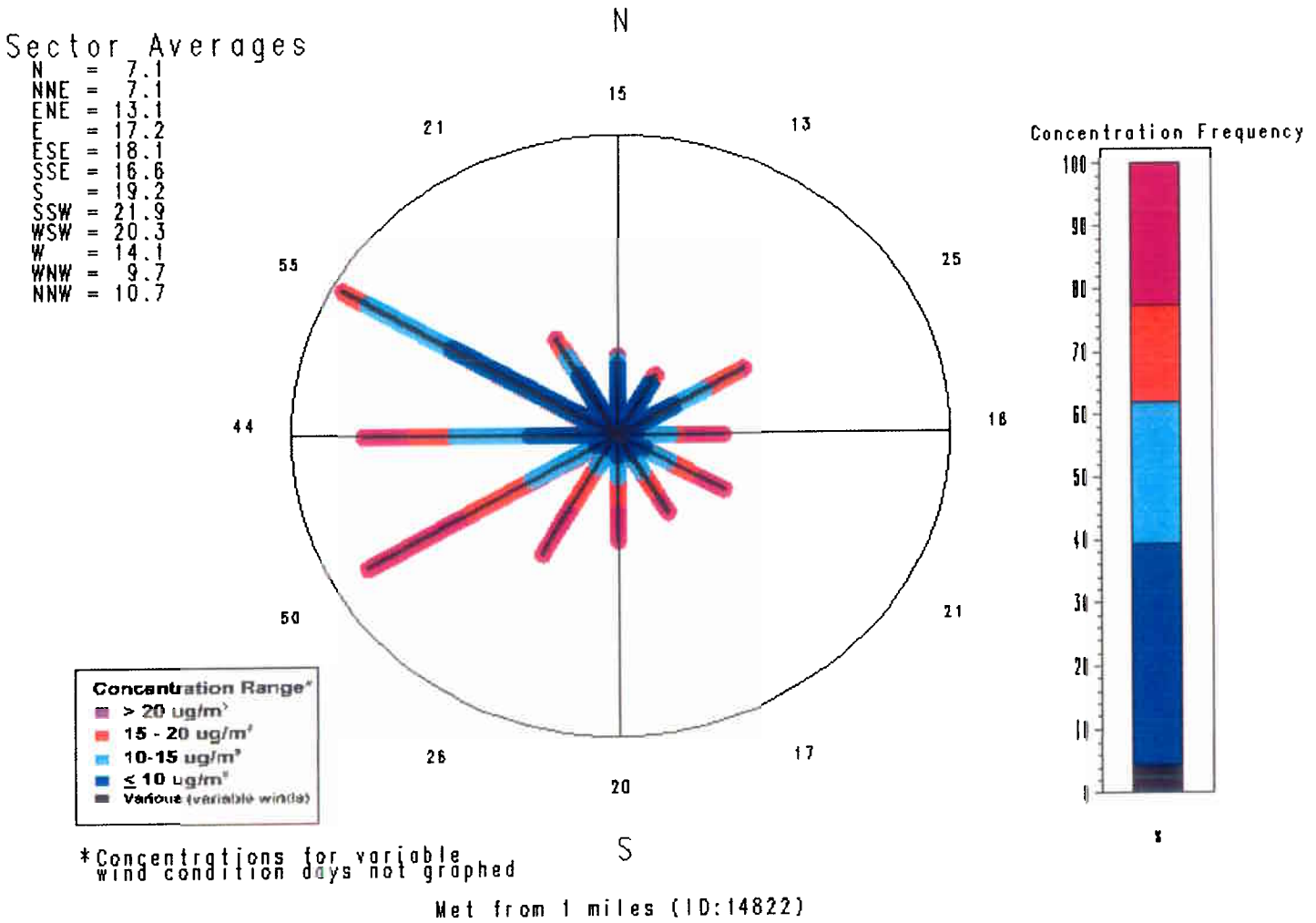


Met from 1 miles (ID:14822)

A-065
01-03 CR E 7 Mile

'01-'03 Simple Pollution Rose for Detroit, MI

Site 261630019 [Wayne, MI DV=14.9 A]

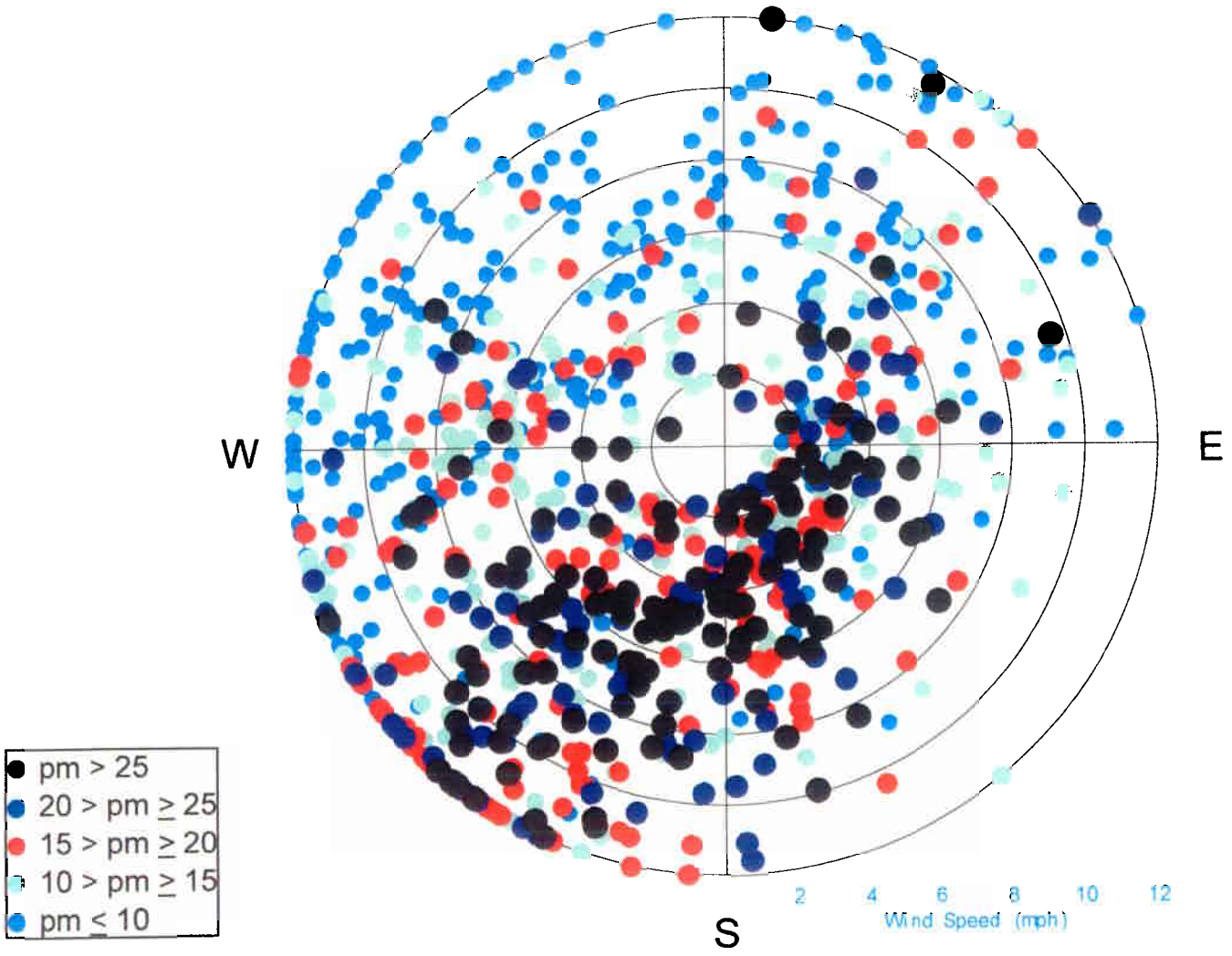


*Concentrations for variable wind condition days not graphed

Met from 1 miles (ID:14822)

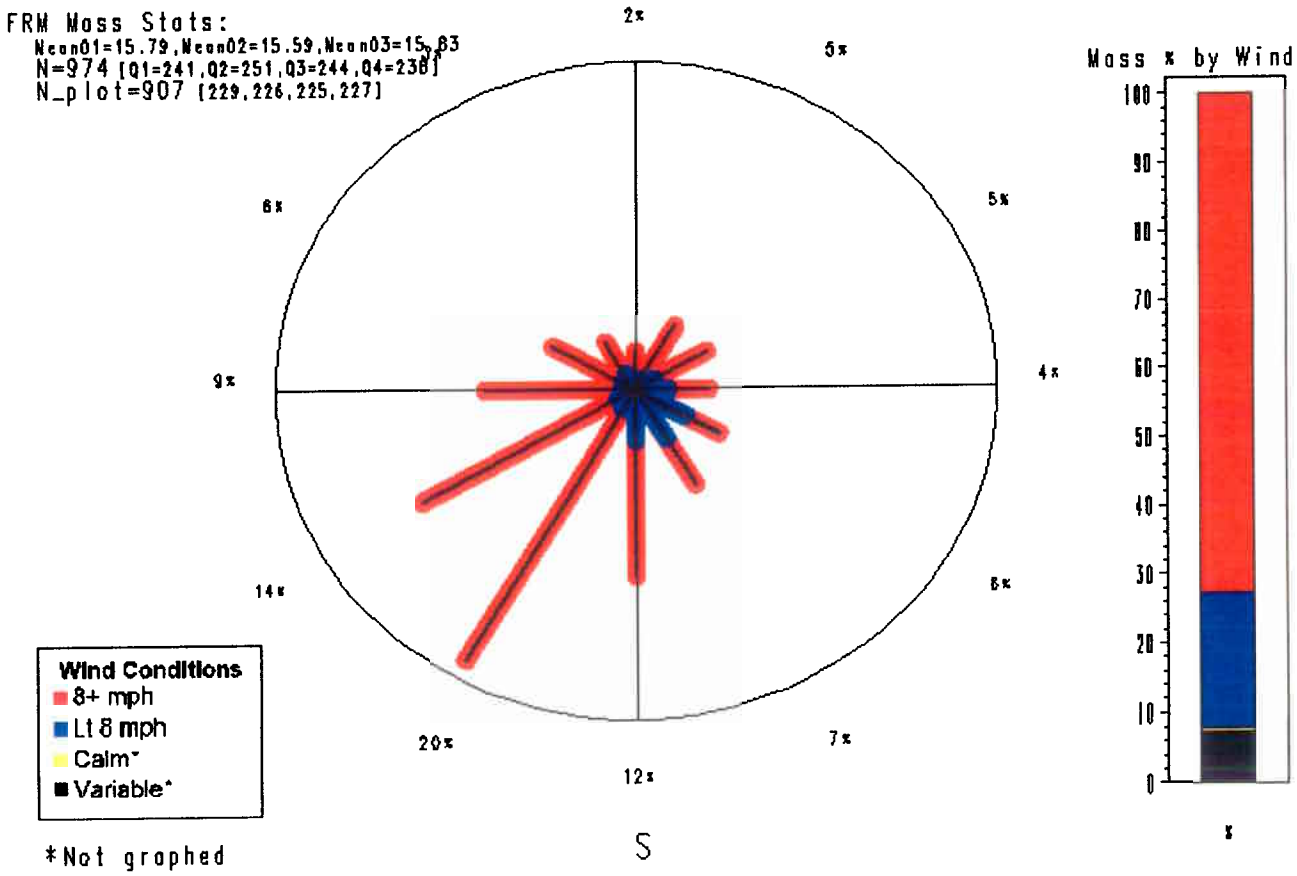
'01-'03 Bubble Pollution Roses

Area= Detroit, MI; Site= 261630016



'01-'03 PM2.5 Contribution Rose for Detroit, MI

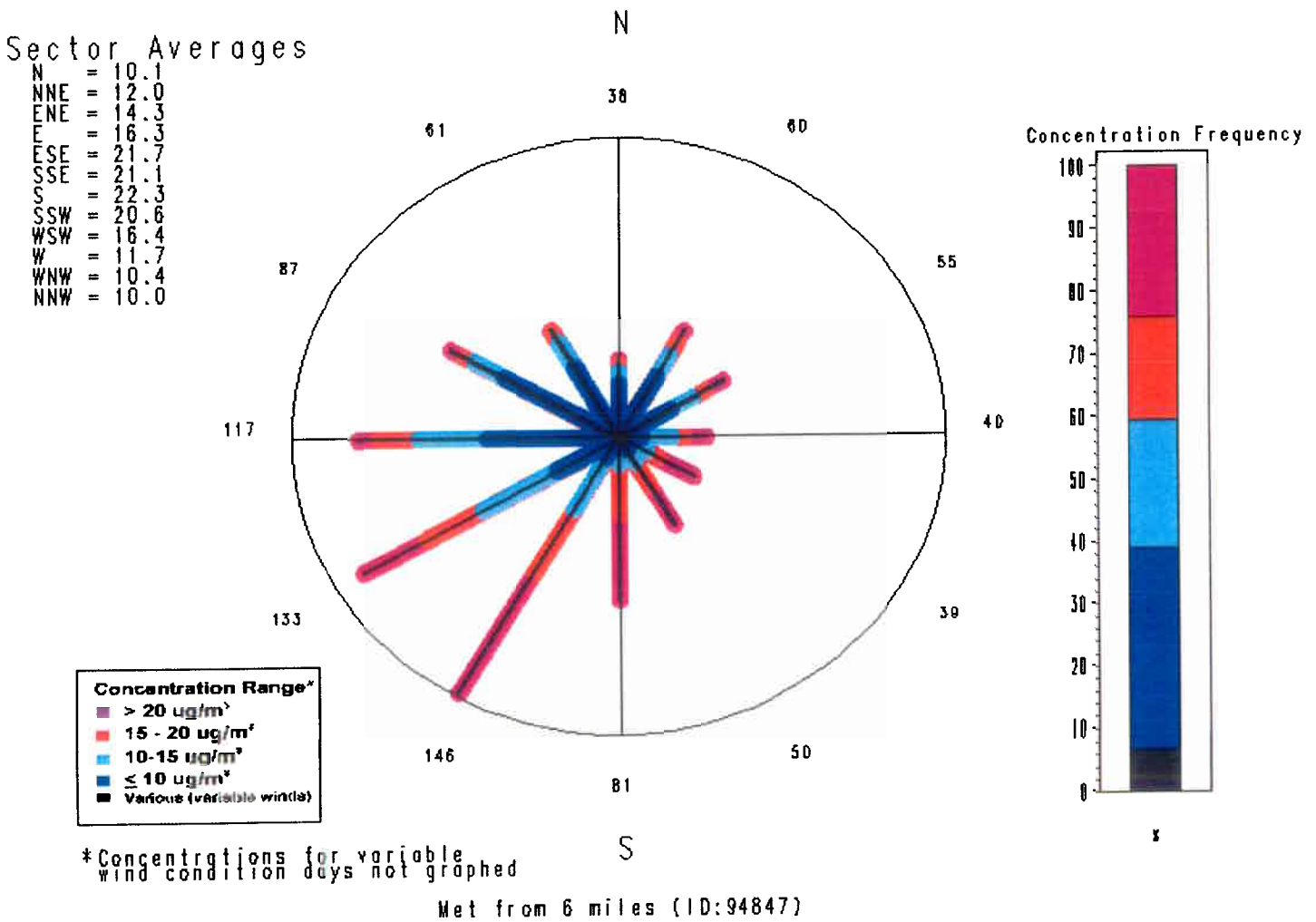
Site 261630016 [Wayne, MI DV=15.7 NA]



Met from 6 miles (ID:94847)

'01-'03 Simple Pollution Rose for Detroit, MI

Site 261630016 [Wayne, MI DV=15.7 NA]

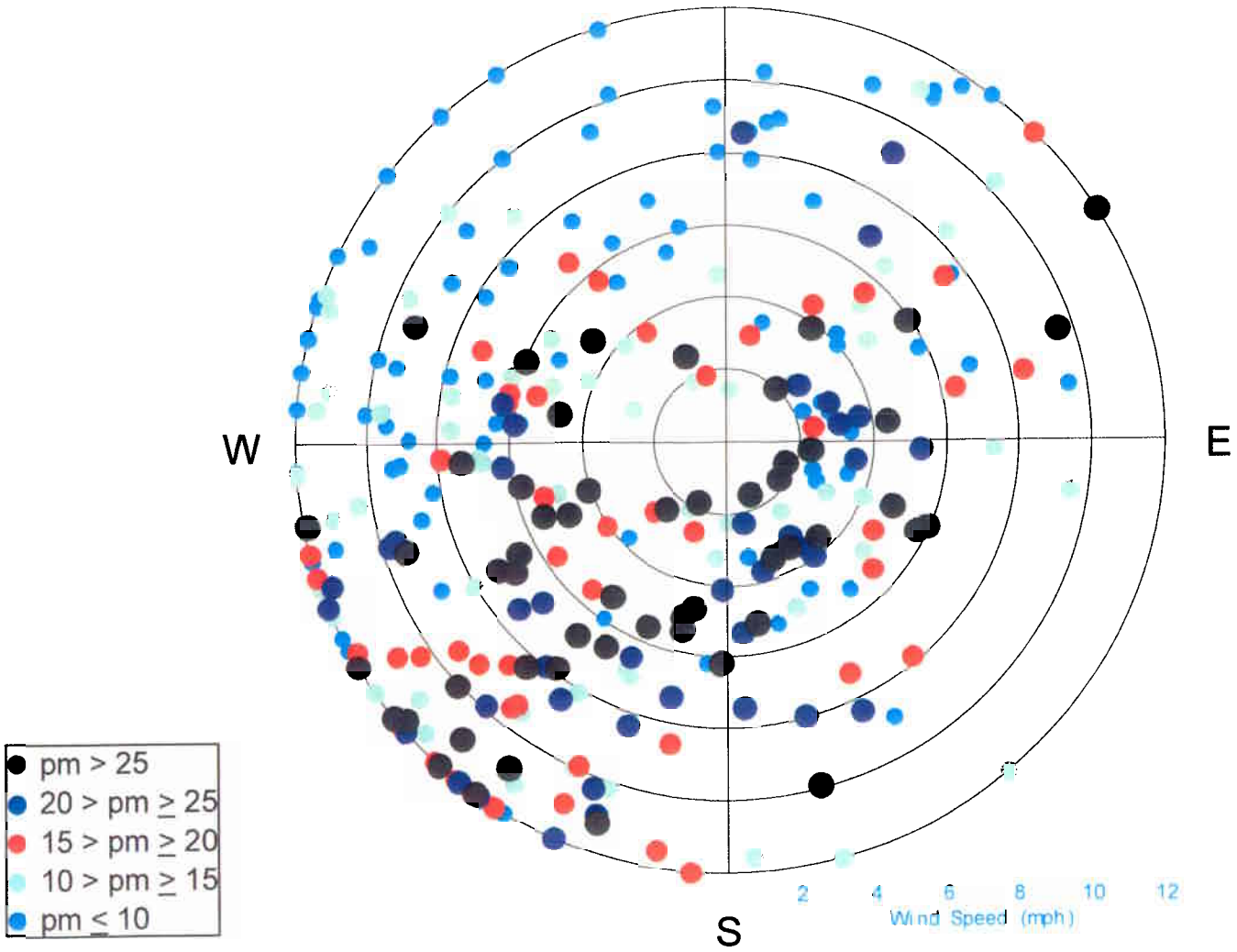


*Concentrations for variable wind condition days not graphed

Met from 6 miles (ID:94847)

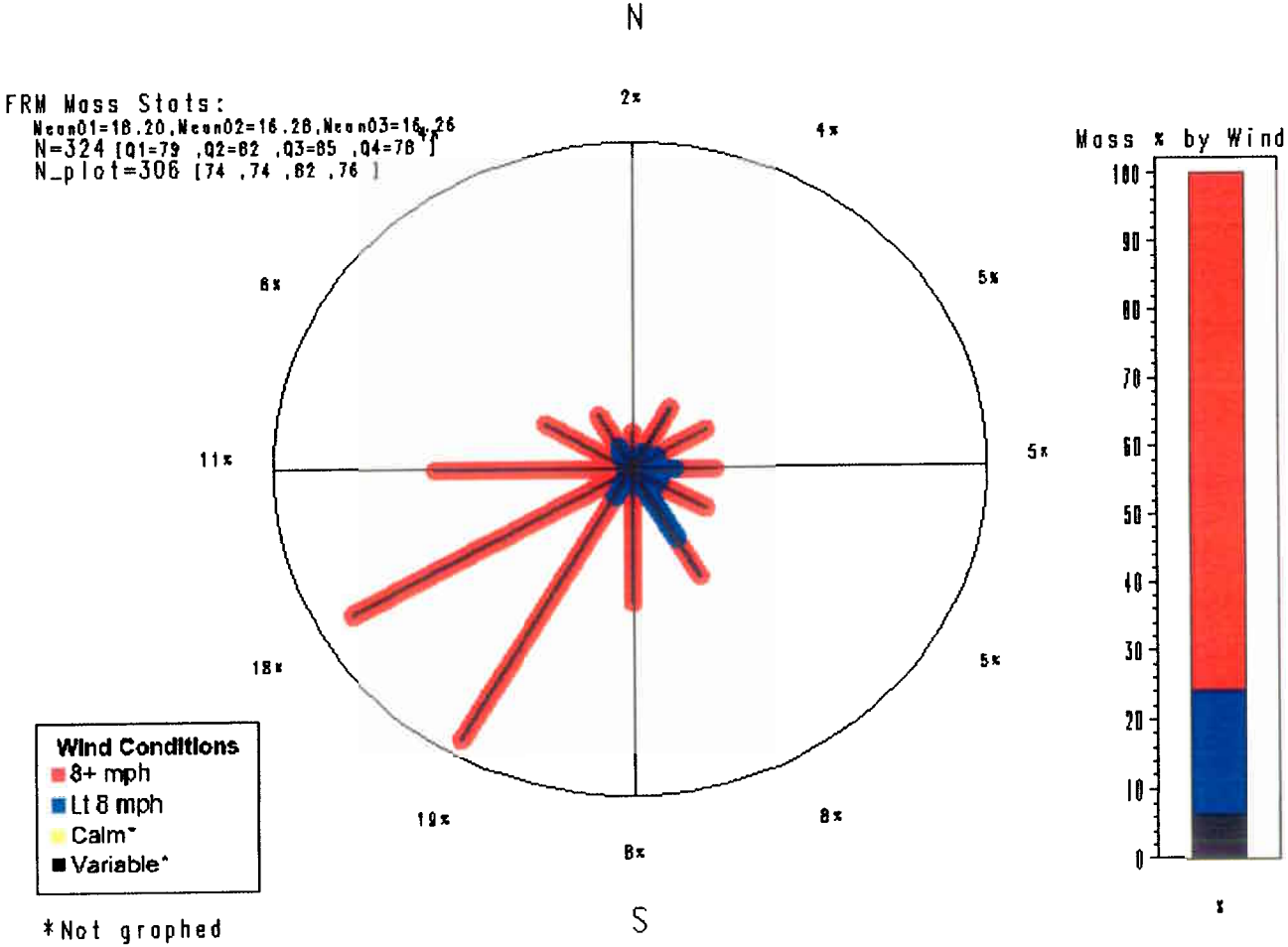
'01-'03 Bubble Pollution Roses

Area= Detroit, MI; Site= 261630036



'01-'03 PM2.5 Contribution Rose for Detroit, MI

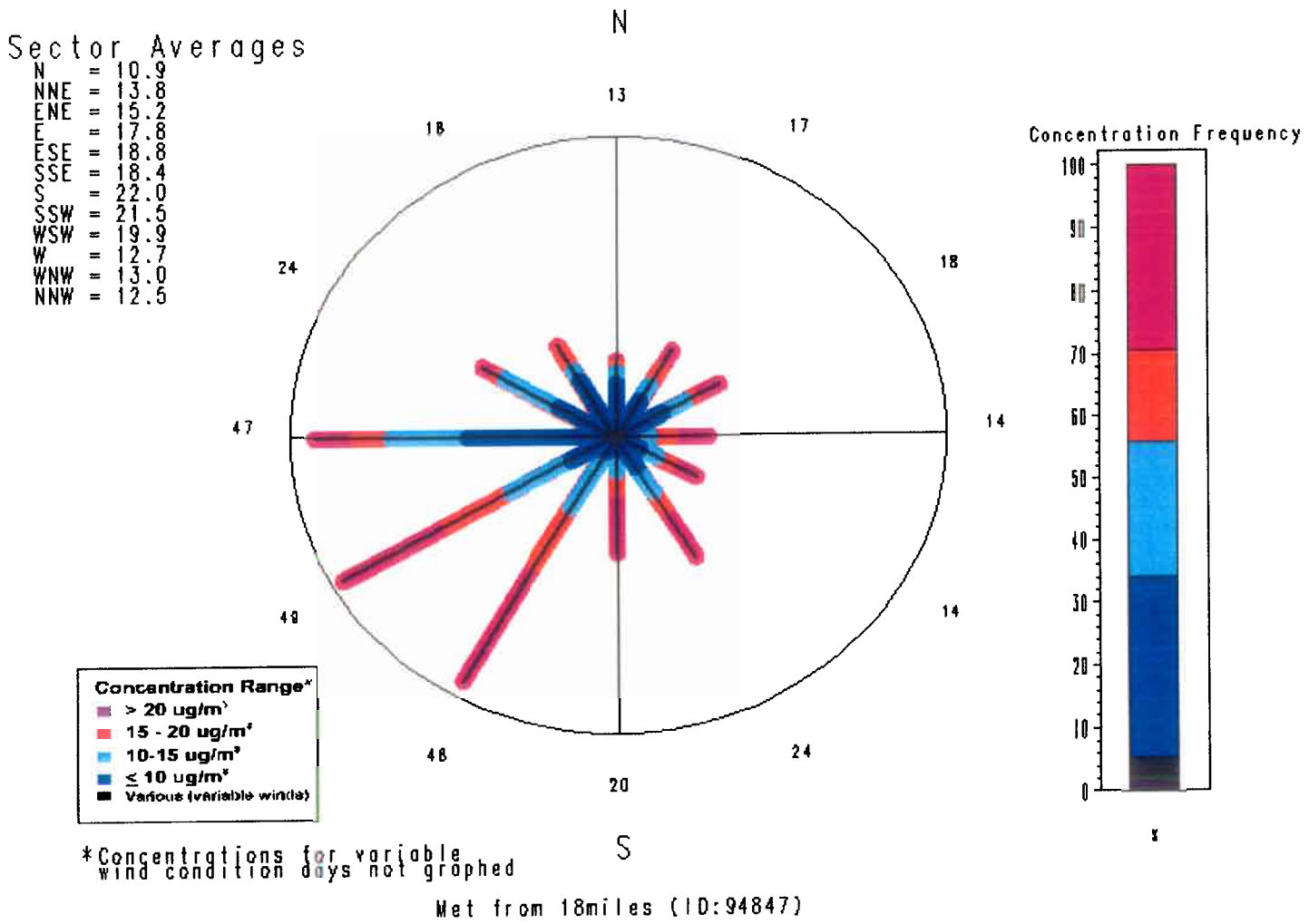
Site 261630036 [Wayne, MI DV=16.9 NA]



Met from 18miles (ID:94847)

'01-'03 Simple Pollution Rose for Detroit, MI

Site 261630036 [Wayne, MI DV=16.9 NA]



*Concentrations for variable wind condition days not graphed

Met from 18miles (ID:94847)