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Environmental Monitoring Series

DIURNAL VARIATIONS IN CARBON MONOXIDE CONCENTRATIONS, TRAFFIC COUNTS AND METEOROLOGY

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by

Gerard A. DeMarrais
Meteorology and Assessment Division
Environmental Sciences Research Laboratory
Research Triangle Park, N.C. 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, N.C. 27711

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AUTHOR'S AFFILIATION

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ABSTRACT

Although pollutant emission patterns play important roles, they cannot adequately explain the diurnal variations in carbon monoxide concentrations found in urban areas. In this study, hourly data from a large network of carbon monoxide monitoring stations, with instrumentation corrected for moisture interference, are analyzed and compared with traffic flow and meteorological conditions at several locations in Maryland. The meteorological phenomena that appear to be important in explaining the diurnal variations involve the ventilation effects resulting from variable wind speeds and mixing heights.

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INTRODUCTION

State and local pollution control agencies in complying with federal regulations (1), gather air quality data at a tremendous rate. The two main purposes for collecting these data are to determine whether air quality standards are being exceeded and to provide baseline check points for assessing changes in air quality. Little use has been made of these data, which have been gathered for many years, as a resource for determining the effects of variations in meteorology on the observed air quality.

In this report of a study of data for January through November 1973, hourly carbon monoxide (CO) measurements from the air quality network operated in the State of Maryland are evaluated and compared with specific meteorological variables. The major sources of the CO emissions in the area are motor vehicles (2); traffic counts, therefore, are considered. Major emphasis is given to the diurnal variation of CO concentrations in each month, and in two cases, to the differences in CO concentrations between a relatively unpolluted workweek followed by a polluted workweek.

CONCLUSIONS AND RECOMMENDATIONS

1. The average diurnal variation of CO concentrations at the nine Maryland stations has a bimodal distribution with peaks in the morning and late afternoon.

2. The diurnal variation of CO concentrations at the nine stations is not well correlated with the local diurnal variation in traffic density. Further studies should be undertaken to determine whether this Maryland finding is typical of other locations.

3. The diurnal variations of wind speed, mixing height, and traffic density explain about 50 percent of the variance in CO concentrations. More detailed studies, with the traffic count and air quality stations in closer proximity should be undertaken to determine whether a greater amount of the variance can be explained by the traffic, wind speed and mixing height.

4. The diurnal variation of CO concentrations consistently shows marked peaks that persist for 4 hours or less. New studies should be made to determine whether averaging CO concentrations for 8 hour periods tends to minimize a CO problem.

5. A curbside station and one remote from traffic but in a metropolitan area showed very little difference in diurnal variations in CO concentrations. This indicates that CO is not a very localized problem but readily covers the nearby area.

DATA AND METHOD

CO INSTRUMENTATION AND DATA

Carbon monoxide concentrations are determined by the nondispersive infrared absorption method used in the Maryland air quality network. The instrumentation (3) includes an infrared source, sample and reference cells, detectors in each cell, a control unit and amplifier, and a recorder. Because water vapor also absorbs infrared radiation, a standard drying technique is used to eliminate potential interference. The reference and sample gas are brought to 60°F and 15 percent relative humidity before being brought into the cells.

The CO network in Maryland consisted of 19 stations in 1973. A few stations, however, did not have the drying mechanisms operating properly early in the year. The data analyzed here are from the file of the National Air Data Branch (NADB) for the U. S. Environmental Protection Agency, which maintains pollutant data from throughout the nation. (No December CO data were available.). The NADB hourly average values are listed at the starting time of each hour. An individual station record for either a month or work-week was not used unless each hourly period had at least 60 percent of the possible measurements; monthly data were not used unless at least 6 months of information were available. The names and locations of the 12 stations from which data were used (five in the Baltimore area, five in the Washington, DC area, and two in the northwest part of the state) are shown in Figure 1. A brief description of each station can be found in the appendix.

METEOROLOGICAL DATA

Analysis of the monthly CO data for the individual sites showed significant diurnal variations in concentrations as well as month-to-month and station-to-station variations. These variations are compared with variations in wind speed for Baltimore later in this report. Mixing height variations can also be important in evaluating air pollution problems (4,5), and the available mixing height information (6) for the Washington-Baltimore area include calculated morning and afternoon mixing heights and ventilation factors (depth of the mixing layer multiplied by the average speed in the layer). These mixing heights are not to be considered absolute numbers but only relative indicators of vertical mixing. This condition is particularly true in the early morning when, assuming an urban hear island of 9°F, the calculated mixing height is low (for example, 100 meters or less). Such a low height indicates the likelihood of a high degree of thermal stability near the ground in urban as well as rural areas.

TRAFFIC PATTERNS

Concurrent data on the diurnal variation of traffic flow at the individual pollutant monitoring sites are not available. The Bureau of Traffic Engineering of Maryland (11) operates 39 continuous-count stations; four stations were selected as being representative of the areas of concern in this study. The diurnal variation in 1973 traffic flow, in percentages, is shown in Table 1. The three counting stations on Interstate-695 (the Beltway around Baltimore) are representative of the ten CO sampling sites in the Washington and Baltimore areas. (The counting station west of the Baltimore-Harrisburg Expressway is only 2 miles west of the CO monitoring station at Towson and the counting station south of U. S. 1 is 4 miles northwest of Linthicum). The fourth station shows the traffic pattern in a Hagerstown suburb and is representative of the CO sampling sites in Hagerstown and Cumberland.

The traffic data in Table 1 show that the lowest hourly traffic flow, generally 1 percent or less of the 24-hour flow, occurs from 2 to 5 AM. Then the traffic increases and attains a peak of about 6.6 percent between 7 and 8 AM. The traffic remains around 5 percent per hour from 9 AM to 3 PM and then increases to a plateau-like peak for about 3 hours. This afternoon peak is higher than the morning peak. During the early evening and nighttime, the traffic flow gradually decreases reaching its lowest point in the early morning hours. The traffic pattern at the Hagerstown station differs from the others in that the morning peak is not as high and the traffic in the evening is a little greater.

RESULTS

DIURNAL VARIATIONS OF CO

Data for nine of the stations shown in Figure 1 met the criteria discussed earlier for this study. Figure 2 shows time from midnight to midnight as the abscissa and concentrations in parts per million (ppm, by volume; 1 ppm = 1.146 milligrams per cubic meter, under standard conditions) as the ordinate for these stations. Average hourly concentrations are plotted as points at the starting time of the observation. Examination of these data reveals a more complicated relationship among factors causing diurnal pollutant variations than the observation (12) that peak concentrations coincide with peak traffic flows; the correlation between the diurnal variation in CO concentrations at Linthicum and the traffic at the I-695 station south of U. S. 40 is 0.39 for January and only 0.05 for July. The sunrise and sunset marks in Figure 2 reveal a tendency for the peak concentrations to correlate with the times of these phenomena. Another interesting feature of the results is that Bethesda, a station located about one-quarter mile from heavy traffic, shows relative concentration peaks similar to those of the curbside station at Cumberland (see station description in Appendix). These detectable peaks observed away from the sources suggest that CO rapidly spreads over the urban area.

The patterns of the diurnal concentration curves for the individual stations over the study period vary from little month-to-month consistency at Essex (Figure 2) to consistent, double-humped curves with morning and afternoon peaks at Gaithersburg, Cumberland, Hagerstown, and Hyattsville. At a majority of the stations, however, there is good month-to-month consistency. Because most stations have individual, unique characteristics, no one station is representative of the area shown in Figure 1.

Another characteristic that is consistently found at a majority of stations is the progressive shift of the morning peak to earlier times in the first half of the year and to later times from July to November. A similar progressive shift at a majority of stations is not seen in the afternoon data because: (1) peaks are sometimes difficult to detect (Linthicum), (2) double peaks occur at times (Baltimore), and (3) the month-to-month shift of the peak is inconsistent at some places (Linthicum, Hagerstown, and Hyattsville). A reversal of the shift pattern is seen at three stations (Gaithersburg, Bethesda, and Cumberland) in that the peaks move progressively to later times in the early half of the year and to earlier times from June through November. A fairly consistent pattern among the stations is for the higher peak values to occur in the colder part of the year with the extreme peak generally occuring in the morning in January.

Wind Speed and Mixing Height

The general pattern of concentration variation (Figure 2) shows a peak in the morning followed by a rapid decrease; relatively low concentrations in the forenoon and most of the afternoon; another high value in the afternoon or evening; and, finally, a slow decrease in concentrations through the night. In an attempt to explain this general pattern, the first phenomenon sought was one that would allow for diluting the concentrations produced by the moderate-to-heavy traffic of midday to the same values as those associated with the light traffic of early morning (see Table I). Wind speed is an obvious phenomenon that would contribute to this result. The climatological wind speed data for Baltimore (10)(Figure 3) show the variation of low speeds (0-3 mi/hr) and high speeds (13-24 mi/hr and 25 mi/hr and greater) for each midseason month. The dots in Figure 3 show the 1973 average frequencies of winds in excess of 12 mi/hr (high speed), based on the three-hourly observations currently available (13). The 1973 diurnal variation of high speed differs from the climatological summary but shows the typical low frequency at night, the increasing frequency in the forenoon with a peak around noon, and the rather sharp decrease in frequency in the late afternoon. Thus, the wind speeds allow for a limited amount of horizontal transport in the morning; then in the forenoon, they provide greater volumes of air for dilution and downwind transport. Finally in the afternoon and evening, there is progressively less wind for dilution and transport. The higher frequency of strong winds in April probably contributes to the resulting low concentrations shown in April graphs in Figure 2.

Combined with the wind speed in markedly affecting the concentrations of pollutants is vertical mixing -- the depth (height) of the surface-based layer through which the pollutants will be readily dispersed (4). Mixing height data for 1973 for urban areas in the vicinity of Washington, DC (6) are shown in Table 2. The monthly values are averages of daily values calculated according to a standard procedure (14) for each workday. (No weekend data are available.) Listed in the table are mixing heights, average wind speed in the mixing layers, and ventilation factors (layer thickness times speed) for the morning and early afternoon (that is, the maximum mixing height, corresponding to the maximum surface temperature). In the morning, the calculated mixing heights were usually low by factors of 2.5 to 9, compared with the calculated maximum afternoon heights. The high average mixing heights and wind speeds on April mornings are probably prime causes of the lack of marked peaks in early morning concentrations (see Figure 2).

Unfortunately, these mixing height data give only an indication of how limited the mixing is in the morning and how extensive it is at its maximum; the temporal change in vertical mixing is not shown. This temporal change is directly related to thermal stability. The typical urban pattern (4) shows that thermal instability is restricted to a relatively shallow surface-based layer (400 meters or less over most of the nation) until a few hours after sunrise. Shortly thereafter, as the surface temperatures continue to increase, the height of the top of the layer of marked instability increases rapidly and along with the surface temperature, levels off at around 2 to 3 PM. Thereafter, the mixing heights increase very little until about an hour before sunset. Near sunset, as the ground cools, vertical mixing is inhibited and the condition persists until shortly after the following sunrise. Enhanced vertical mixing begins latest in the day during the winter months and is a contributing factor in the extreme concentration peaks (Figure 2) observed on winter mornings. Vertical mixing through a deep layer persists for only a few daylight hours each day during the winter months; this is probably a prime cause of high average concentrations during the mornings of the winter months.

Apparent Dependence of Concentrations on Meteorology and Traffic

The diurnal variations of CO concentrations have been seen to depend on a combination of the traffic flow and the dilution patterns. In January, peak concentrations generally occur around 7 to 8 AM, the time of peak traffic flow. In the forenoon, although the traffic decreases to a moderate flow, the CO concentrations drop rapidly as the wind speeds increase and vertical mixing takes place to increasingly greater heights. By the middle of the day, the increased speeds and mixing heights are sufficient enough to lower concentrations produced by the moderate mid-morning traffic (about 50 percent of that during the morning peak) to levels similar to those that occur in the pre-dawn hours (when the traffic is about 10 percent of that in the middle of the day). At about 3 PM, the traffic volume increases, the wind speeds decrease, and shortly thereafter, the layer of enhanced vertical mixing is reduced. (The change from unstable to stable is marked by a change from a deep layer with vigorous vertical mixing to a shallow layer with suppressed mixing). The concentrations increase until they reach a maximum at around 5 to 6 PM, the time of peak afternoon traffic flow. Thereafter, the concentrations decrease gradually as the ventilation is markedly reduced and the traffic count decreases. The changes from January to June show the peak concentrations in the morning gradually shifting to earlier times and those of the afternoon and evening shifting to later times. From June to November the respective shifts are in the opposite directions. These shifts follow the times of sunrise and sunset, which in turn govern the beginning and ending of solar-induced thermal instability and the onset of relatively strong daytime winds.

Comparison of Parameters in One Area

Simultaneous CO, mixing height, wind speed, and traffic observations for one site for a month are not available. There are, however, representative monthly CO, wind speed, and traffic data for the Linthicum area. The CO data are from Linthicum (EPA data bank); the climatological wind data are from Friendship International Airport (13), which is 2 miles to the southwest of Linthicum; and the traffic data (11) are from an Interstate-695 location, which is 4 miles to the northwest of Linthicum. The urban mixing height data calculated for the Washington-Baltimore area are considered representative of the Linthicum area.

Figure 4 shows the diurnal variation of the four parameters for January and October 1973. The curves connect points that are averages for an hour plotted at the ending time of the hour. Certain assumptions had to be made with regard to mixing height because only two values are given for each day. These assumptions were: (1) the morning mixing height value was representative of the hours from sunset until an hour after sunrise, (2) the maximum mixing height occurred at 2 PM and remained stationary until an hour before sunset, (3) the change in mixing height from an hour after sunrise until the maximum occurred was linear, and (4) the change from the maximum mixing height to that which prevailed throught the evening and nighttime was discontinuous. These assumptions are in accord with the diurnal variation of mixing heights described earlier. (As stated earlier, the mixing height values should be interpreted qualitatively; they are generally inversely proportional to atmospheric stability.)

During the early morning hours in January, the traffic flow and CO concentration curves appear to be very similar in shape, with the peak in concentrations following the traffic flow peak by 1 hour. In the forenoon, the concentrations decrease by about 70 percent, whereas the traffic flow decreases by only 30 percent. Simultaneously with those decreases, the frequency of high speed ($>$12 mi/hr) winds increases and mixing heights extend to progressively greater heights; these meteorological factors combine to allow for substantial dilution of the concentrations. During the early afternoon, the increase in the mixing height and decrease in the frequency of high speed winds combine to lower the concentrations only a slight amount. In the late afternoon and early evening, both the traffic flow and CO concentrations show marked increases with the start of a prolonged plateau-like peak in concentrations, which follows the traffic flow peak by 2 hours. The delay in the peaking of concentrations occurs because the traffic flow increases to its maximum at the same time that the mixing height and winds are allowing considerable dilution of the emissions; the peaking in concentrations occurs after the mixing heights and wind speeds decrease to nighttime low values. During the last hours of one day and the earliest hours of the next, the CO concentrations decrease rather slowly although the traffic flow decrease is rapid. The CO concentrations with minimum traffic flow are about the same as they are in the middle of the afternoon.

The results of October are similar to those for January. The major differences are the displacements of the times of peak CO concentrations. In the morning, the displacement from January to October is to earlier hours and in October the peak concentration coincides with the peak traffic flow. The difference between the January and October meteorology in the morning occurs because enhanced vertical mixing, as shown by the initial increase in mixing heights, starts at an earlier time in October. In the afternoon, the shift of peak CO concentrations from January to October is to later hours, and the time delay between peak traffic flow and peak concentrations in October is 4 hours. This afternoon displacement of the concentration peak coincides with the displacement toward later hours, from January to October, of the time when vertical mixing subsides (shown by the time when the discontinuity in mixing height occurs).

To determine the statistical significance of the several variables on the variation of the CO concentrations, a correlation analysis was applied to the January data in Figure 4. The simple correlation factors between concentrations and frequency of winds greater than 12 mi/hr, traffic and mixing height were -0.27, 0.39, and -0.34, respectively. The multiple correlation was 0.72, meaning that 52 percent of the variance in CO concentrations was explained by these three variables. This correlation is significant at the 10 percent level.

DETAILED DATA ON POLLUTED PERIODS

A previous report (15) sought out the times of day of the greatest CO concentrations for 8-hour periods in Baltimore and concluded that the nighttime hours were most frequently associated with the highest 8-hour CO concentrations. Because that conclusion is inconsistent with the findings of this investigation, the meteorology that occurred on the five worst days at the most polluted station (in the previous report) was evaluated. It was found that relatively wet weather and high relative humidities prevailed on all 5 days, indicating that water vapor may have been a cause of the recorded high concentrations. (All moisture problems in the Maryland network have been corrected; the data for the 12 stations used in this investigation have been reported to be free of moisture problems by each local official responsible for collecting the data).

Meteorological Differences Between Clean and Polluted Workweeks

The data from the Maryland network were examined to find a 2-week period during which a relatively clean workweek (one with relatively low CO concentrations) was followed by a relatively polluted workweek and for which an abundance of data was available. Two such periods, one in January and the other in October, were found. The Daily Weather Maps (10), three-hourly weather observations for Baltimore and Washington (9), and the calculated mixing heights (6) for the periods were gathered and the differences noted.

Data from nine stations are used in the January comparison of the clean (January 8-12) and polluted (January 15-19) workweeks. The resulting differences in hourly concentrations for each combined 5-day period are seen in Figure 5. Combining the observations for each hour did little to minimize the marked differences in concentrations. At almost all stations and for a large majority of hours, the concentrations during the polluted week are markedly greater and the greatest differences are observed at the times of the peak concentrations.

A high pressure area centered over the middle of the United States dominated the weather over Maryland during the clean workweek, January 8-12. Aloft there were westerly winds, and the surface winds at Washington National Airport and Baltimore's Friendship Airport were generally light northwesterly through the week. the average temperature for the period was about 10°F colder than normal. The sky was clear and the visibility was 10 miles or more for most of the week.

A high pressure area over the eastern United States was the major feature of the weather during the polluted workweek, January 15-19. On Friday January 19, a cold front was situated just west of Maryland. The flow aloft showed that air was being brought in from the southwest. The surface winds at both airports were northwesterly on Monday but southwesterly the rest of the week. The average temperatures started out 1°F to 2°F warmer than normal and rapidly increased to 13°F to 15°F warmer than normal by the end of the week. Approximately a quarter-inch of rain fell on Friday afternoon. The visibility was only a little less than the previous week (lowest reported visibility 6 miles) and most days were cloud-free.

The urban mixing height data are shown in Table 3. The morning mixing heights and wind speeds are seen to be markedly less in the polluted week than in the relatively clean week. The ventilation factors at the time of maximum mixing heights show that there was relatively little relief in the afternoon during the polluted week, whereas there was much greater ventilation during the clean week.

To determine the statistical significance of the variables on the variation of CO concentrations, a correlation analysis was applied to the CO data for Linthicum in Figure 5, the mixing heights in Table 3, the concurrent hourly wind speeds for Baltimore Airport, and the traffic counts for Station 14 shown in Figure 1. The simple correlations between CO concentrations and wind speed, traffic, and mixing height were -0.63, 0.13, and -0.38 respectively. The multiple correlation was 0.73, indicating that the three parameters explained 53 percent of the variance in concentrations. This correlation is significant at the 5 percent level according to an f-test.

Data from 11 stations for the October period were available in sufficient quantity to make comparison of the clean workweek (October 15-19) with the polluted workweek (October 22-26). The results are seen in Figure 6. At a majority of stations, practically all hours showed markedly higher concentrations, and the differences were largest during the evening. At Riviera

Beach, Silver Spring, and Gaithersberg, practically all the differences were at times of the peaks, and at these times the concentrations were markedly greater during the polluted week.

A cold front passed through Maryland late on Monday, October 15, 1973, and a high pressure center dominated the weather from Tuesday through Friday. The flow aloft over Maryland was generally westerly throughout the period. The temperature started out warmer than normal but became colder with the passage of the front, averaging about 5°F below normal. There was precipitation at Baltimore and at Washington with the passage of the front on Monday. Except for one observation during a rain shower, all visibilities were 15 miles or greater, and except for six observations there were no clouds at Baltimore. The visibility and cloud observations at Washington were very similar to those of Baltimore except that the visibility was never less than 10 miles.

A high pressure center remained over the eastern United States through almost all of the polluted workweek. Late on Friday, October 26, a cold front passed over Maryland. The flow aloft over the area was initially from the west, about 10 knots, but then became light and variable. No precipitation occurred during the period, and although the temperatures started out colder than normal they became warmer than normal, by about 4°F, most of the week. There were no clouds and the visibilities were relatively low (but never less than 2 miles) throughout the period.

The urban mixing heights and ventilation factor data (6) are shown in Table 4. The morning mixing heights and ventilation factors were much greater during the clean workweek than during the polluted workweek; there was generally a four-fold advantage in the ventilation.

The simultaneous observations of concentrations, mixing heights, wind speeds, and traffic for the Linthicum area for the October period were analyzed to determine the statistical significance. The simple correlation with concentrations and wind speed, traffic, and mixing height were -0.51, 0.11, and -0.41 respectively. The multiple correlation was 0.68, indicating that 46 percent of the variance is explained by the three parameters. This correlation is significant at the 5 percent level.

SUMMARY

1. The average diurnal variation of CO concentrations tends to show a peak near the beginning of the normal workday, followed by a rapid decrease and leveling off that persists until about midafternoon; then a rapid increase to high values that are maintained for about 3 hours in the evening; and then a gradual decrease to low values in the early morning. The low values of midday and early morning are comparable.

2. The diurnal variation of CO concentrations is not well correlated with the diurnal variation in traffic density.

3. The diurnal variation of wind speed or the frequency of winds above 12 mi/hr, mixing height, and traffic density explain about 50 percent of the variance in CO concentrations on a monthly basis and when a polluted workweek is compared with a clean workweek.

4. The diurnal variation of concentration consistently shows marked peaks that persist for 4 hours or less. Averaging CO concentrations for 8-hour periods minimizes the acute exposure that frequently persists for several hours.

5. A comparison of the diurnal variation of concentrations between a curbside station and one in a metropolitan area that was remote from traffic indicated there was little difference between the two sites: the CO appears to readily move away from the sources and blanket the entire area.

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APPENDIX

SITE DESCRIPTIONS OF CARBON MONOXIDE MONITORING STATIONS

Each site description, except Cumberland, is based on a site visit. The Average Daily Traffic (ADT) counts are based on 1973 data that was provided by the Traffic Inventory Section of the State Highway Division of the Maryland Department of Transportation. All the sampling intakes were 10 feet above the ground except where noted otherwise.

1. Gaithersburg-Sampling intake is 35 feet above the street level on the side of a building, about 75 feet from the nearest curb of Highway 355 (ADT-27,000 vehicles) and 150 feet from an intersection with a traffic light.

2. Silver Spring-Sampling device is in a park about 50 feet north of the nearest edge of Highway I-495 (ADT 89,800 vehicles).

3. Bethesda-Sampling device is in a meadow about 100 yards from the nearest local traffic (a few hundred cars a day), 0.25 mile from Old Georgetown Road (ADT 35,000 vehicles) and 0.5 mile from Rockville Pike (ADT 42,900 vehicles).

4. Linthicum-Sampling device is in a 20-car, school yard, parking field about 80 feet from the nearest local traffic (probably less than 100 cars a day) and 200 yards from Highway I-695 (ADT 60,000 vehicles). Friendship Airport is about 2.0 miles to the southwest of this station.

5. Baltimore (Calvert and 22nd Sts)-Sampling device is in a 100-car parking field about 90 feet from Calvert St. (No ADT) and 50 feet from 22nd St. (No ADT). Calvert St. is a major, one-way throughfare that carries heavy outbound traffic in the afternoon.

6. Essex-Sampling device is in a 10-car parking field about 10 feet from the nearest local traffic (a few hundred cars a day) and 100 yards north of Eastern Blvd. (ADT 36,000 vehicles).

7. Cumberland-Sampling device is in a grassy field 20 feet from the curb of Industrial Blvd. (ADT 21,500 vehicles).

8. Hagerstown-Sampling device is at rear portion of a 50-car parking field about 175 feet from U. S. Highway 11N. (ADT 10,000 vehicles) and 175 feet from Maryland Highway 64 (ADT 10,000).

9. Hyattsville-Sampling intake is 10 feet above the ground but below the level of the nearby road. Sampling device is in a meadow 75 feet from the nearest edge of Highway 410 (ADT 30,000 vehicles).

10. Towson-Sampling intake is 12 feet above ground on the top, rear end of a service building on a college campus, next to a large wooded area. The closest road, Highway I-695 (ADT 76,500 vehicles) is about 150 yards to the north of the sampling station.

11. Suitland-Sampling device is adjacent to a 500-car parking field 150 feet southwest of Suitland Road (ADT 18,900 vehicles). Station is 0.3 mile from Silver Hill Road (ADT 34,000 vehicles) and 0.5 mile from Suitland Parkway (ADT 18,500 vehicles).

12. Riveria Beach-Sampling devices is in a 20-car, school yard, parking field about 10 feet from the nearest local traffic (a few hundred cars a day) and 0.25 miles from a major throughfare, Fort Smallwood Road (ADT 14,734 vehicles).

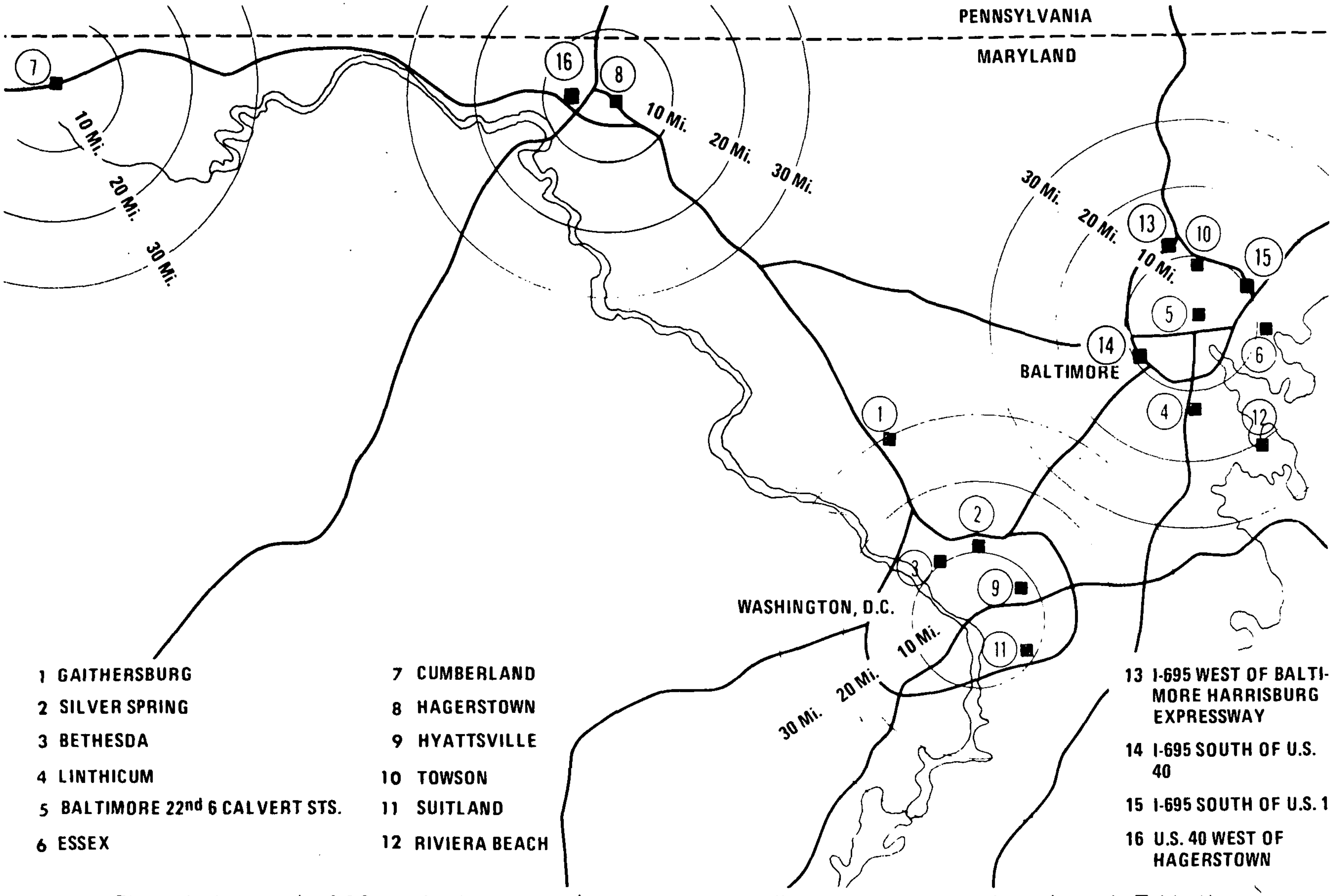

Figure 1. Locations of CO monitoring stations (numbers corresponding to names and numbers shown in Table 1).

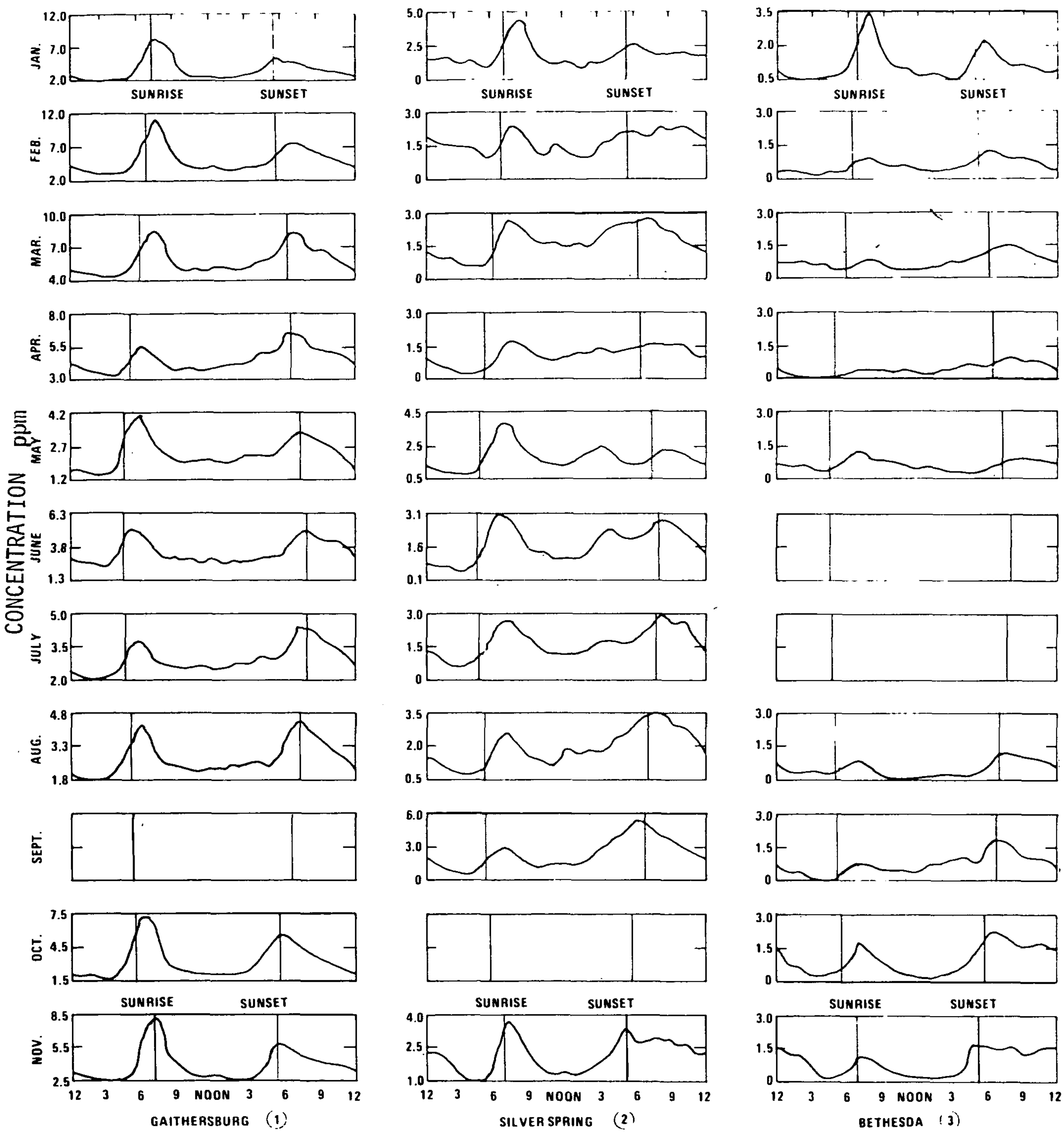

Figure 2. Diurnal variation of CO concentrations by month, Maryland stations, 1973.

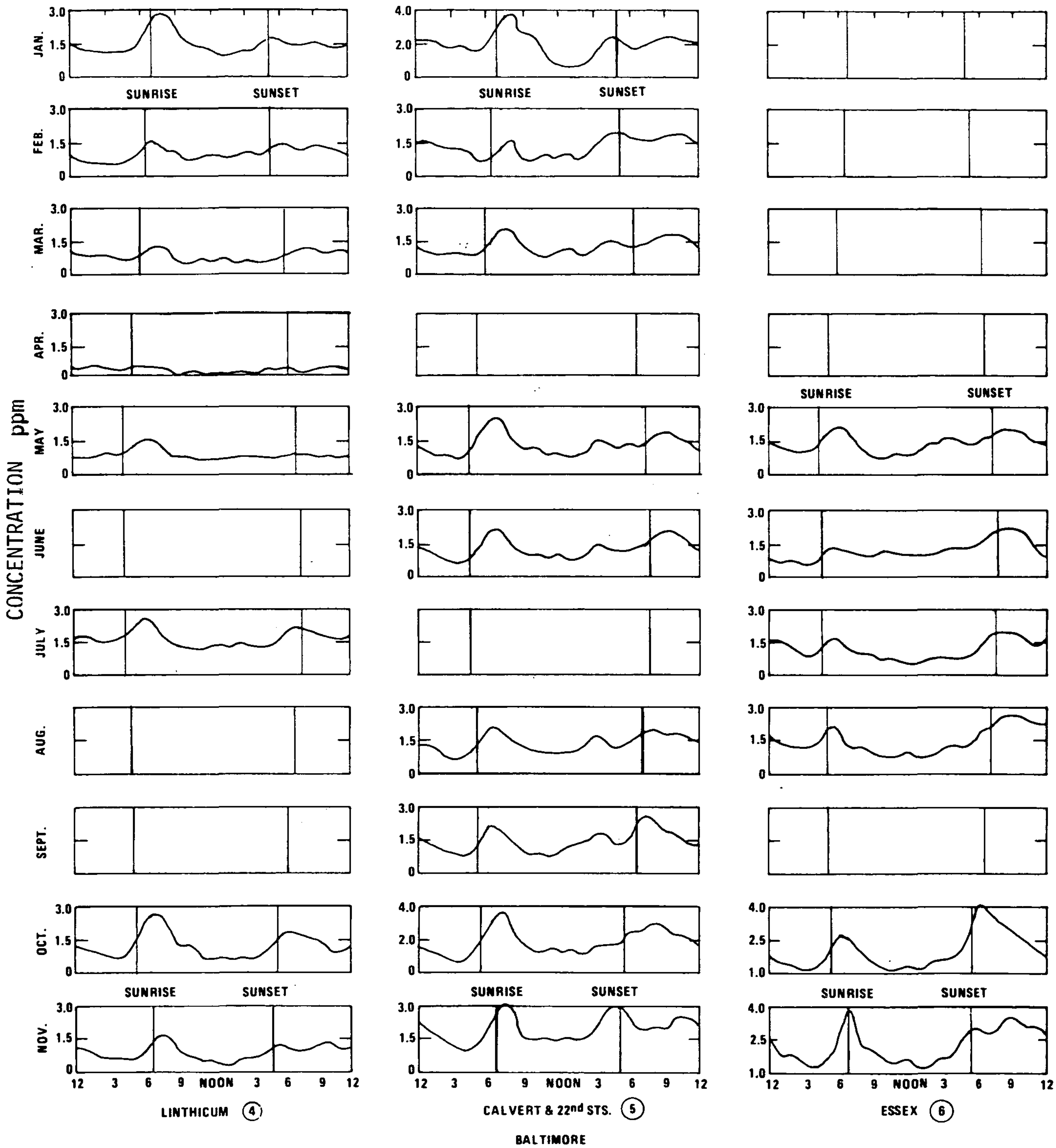

Figure 2. (continued) Diurnal variation of CO concentrations by month, Maryland stations, 1973.

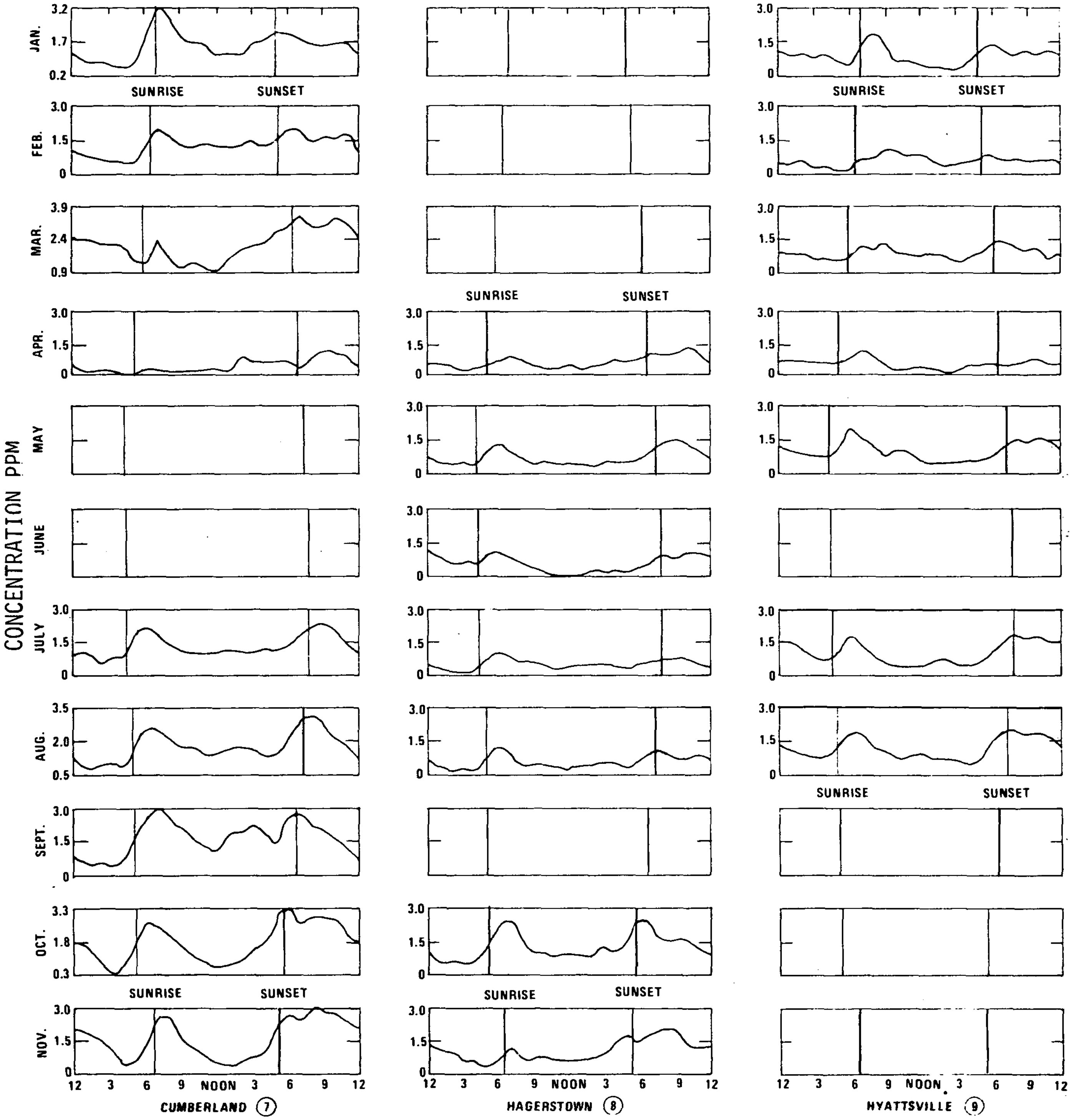

Figure 2. (continued) Diurnal variation of CO concentrations by month, Maryland stations, 1973.

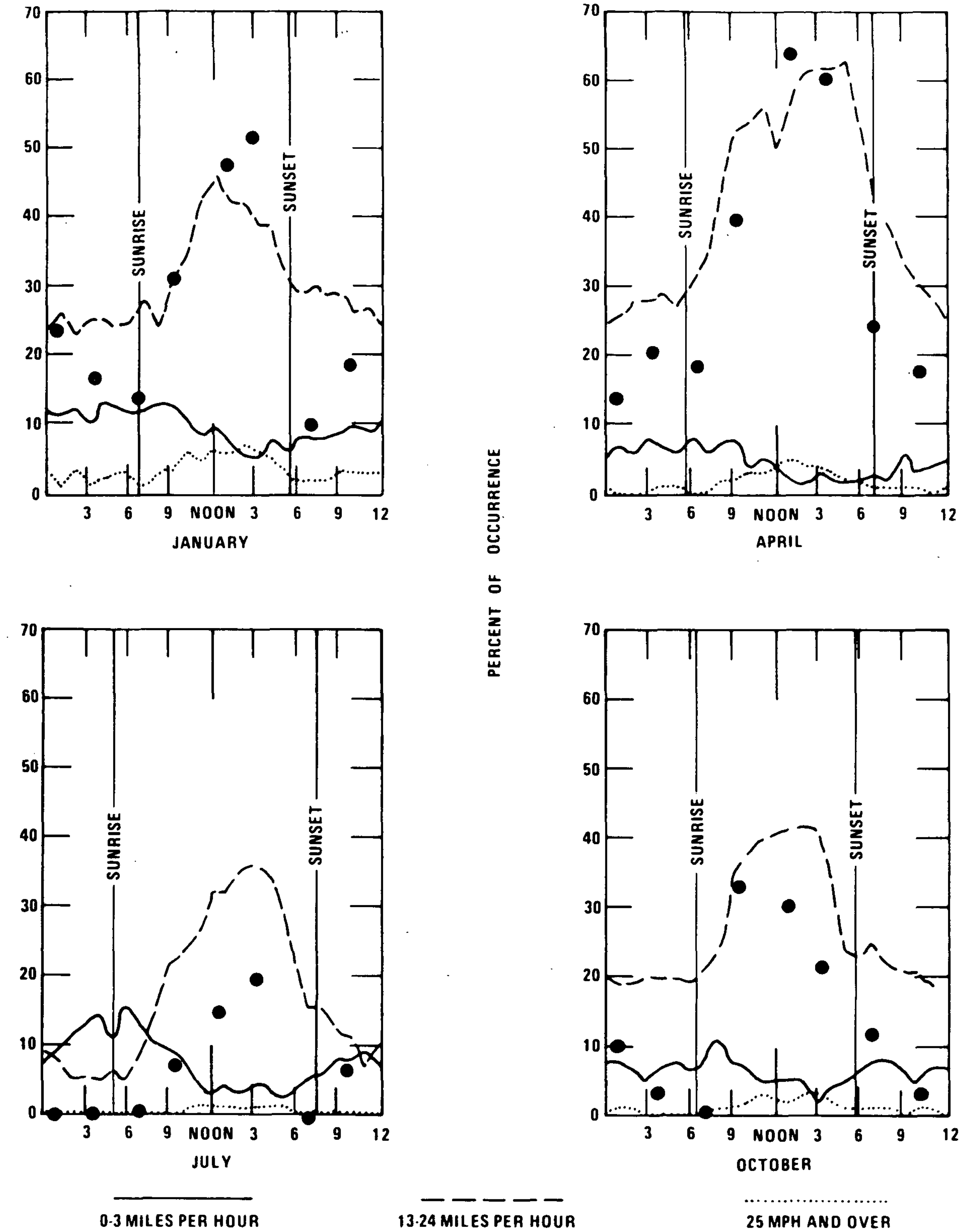

Figure 3. Diurnal variation of occurrence of selected wind speed ranges Baltimore, 1951 1960.

(●=FREQUENCY OF SPEEDS GREATER THAN 12 IN 1973
BASED ON 3-HOURLY OBSERVATIONS)

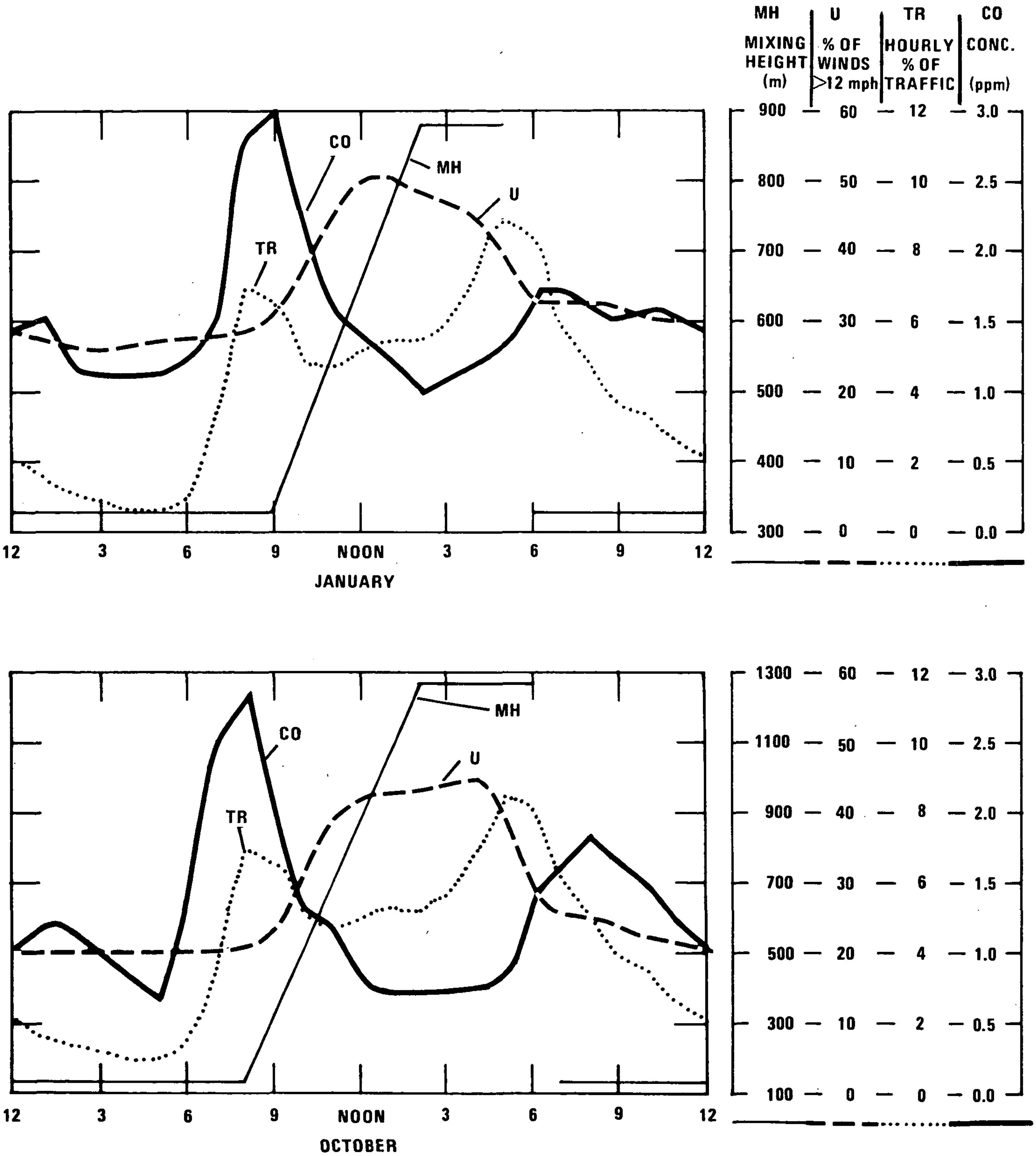

Figure 4. Diurnal variations of mixing heights, frequency of wind speeds greater than 12 mph, traffic flow and CO concentrations (hourly data plotted at hour ending time - eastern standard), 1973, Linthilum Area.

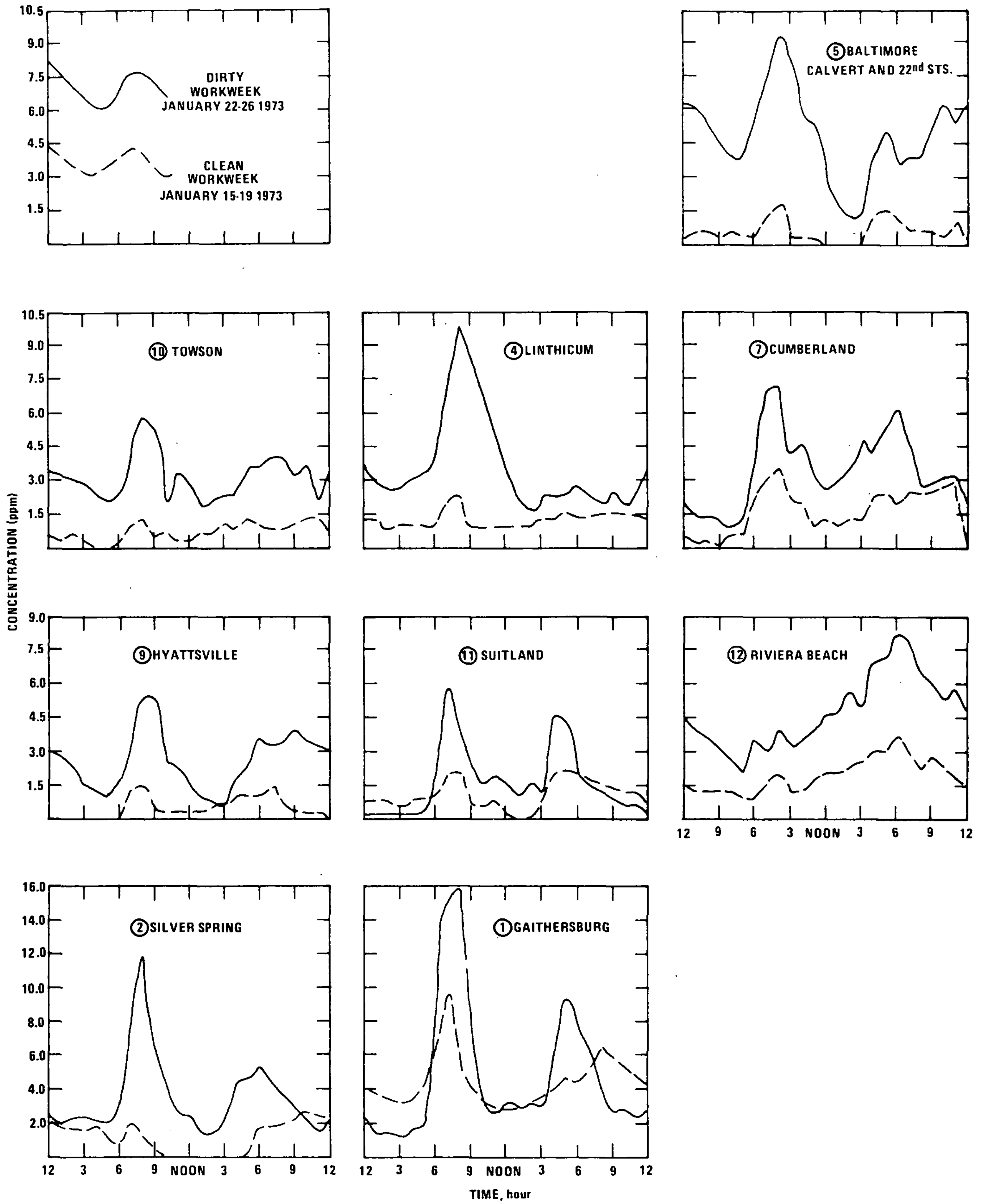

Figure 5. Comparison of diurnal variations in CO concentrations. A clean workweek vs a dirty workweek, January, 1973, Maryland stations.

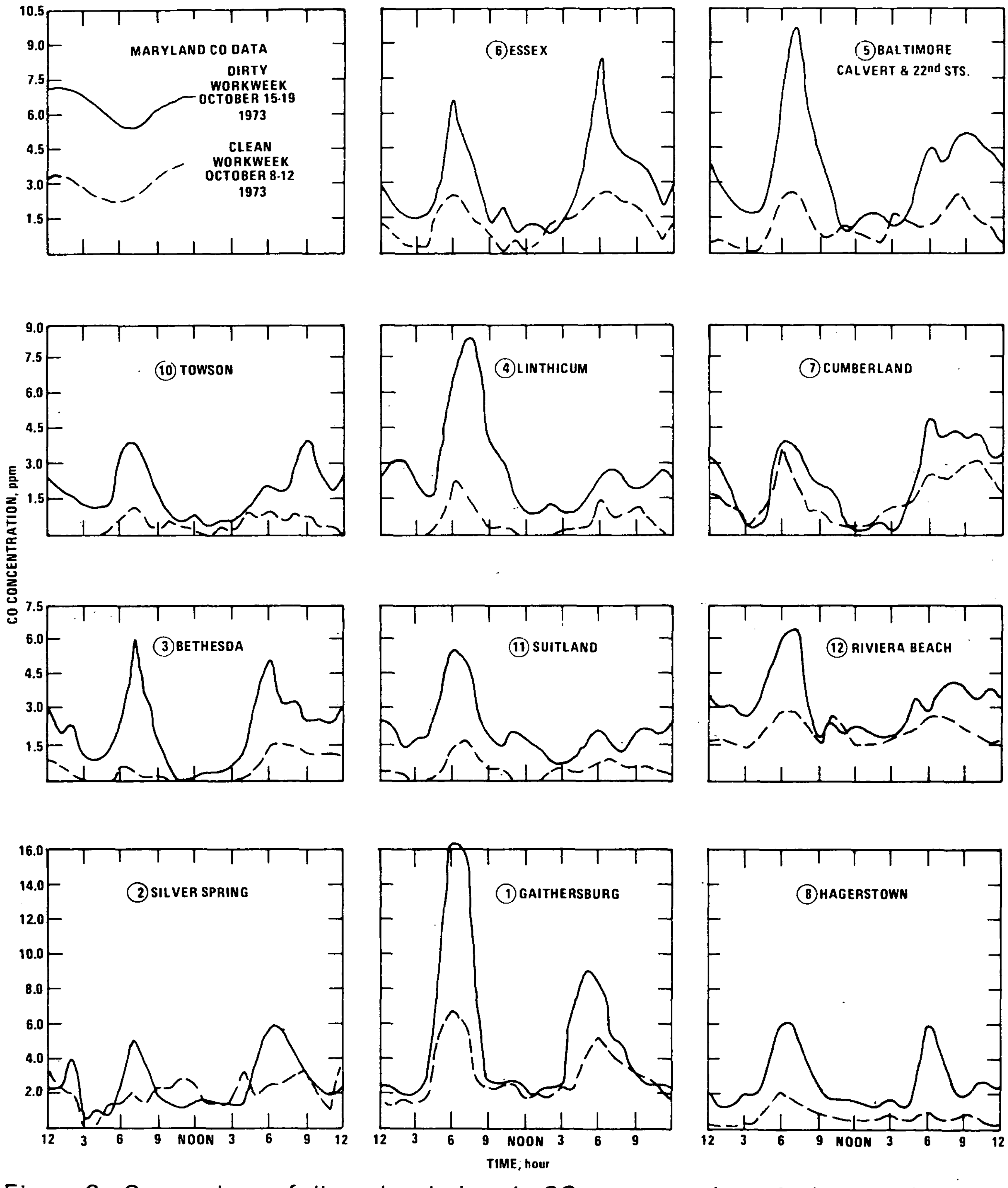

Figure 6. Comparison of diurnal variations in CO concentration. A clean workweek vs a dirty workweek, October 1973, Maryland stations.

Table 1. ANNUAL AVERAGE HOURLY PERCENTAGE OF TOTAL VEHICULAR TRAFFIC AT FOUR MARYLAND HIGHWAY STATIONS, 1973[a].

	Location[b]			
Hour of day	I-695 West of Baltimore Harrisburg Expressway (13)	I-695 South of U. S. 40 (14)	I-695 South of U. S. 1 (15)	U. S. 40 West of Hagerstown (16)
12-1 AM	1.6	1.7	1.9	2.0
1-2	1.1	1.1	1.3	1.5
3-4	0.5	0.6	0.6	0.5
4-5	0.5	0.6	0.6	0.5
5-6	1.1	1.0	1.4	1.2
6-7	3.6	3.6	4.4	4.0
7-8	7.0	6.7	7.5	5.3
8-9	6.8	6.3	6.0	4.7
9-10	5.2	5.0	4.4	4.6
10-11	4.9	4.8	4.3	4.7
11-12	5.1	5.1	4.5	5.1
12-1PM	5.3	5.3	4.8	5.5
1-2	5.3	5.3	5.0	5.5
2-3	5.7	5.6	5.5	5.9
3-4	6.8	6.8	6.6	7.0
4-5	8.2	8.4	8.3	8.1
5-6	7.8	7.8	7.9	7.0
6-7	5.7	5.9	5.7	6.2
7-8	4.6	4.9	4.8	5.4
8-9	3.8	4.0	4.0	4.5
9-10	3.5	3.6	3.8	4.3
10-11	2.8	2.8	3.1	3.1
11-12	2.3	2.3	2.6	2.6

[a]The Maryland Department of Transport describes the first three stations as roads with consistent yearly traffic (little difference among the 12 months) and the Hagerstown road as one with a consistent yearly traffic load and a moderate seasonal traffic peak.

[b]The numbers in parentheses correspond to the site identification numbers in Figure 1.

Table 2. CALCULATED URBAN MONTHLY AVERAGE MIXING HEIGHTS AND VENTILATION FACTORS FOR WASHINGTON, DC, AREA, 1973.

	Morning conditions			Afternoon conditions		
Month	Morning mixing height, m	Speed in mixing layer, m/sec	Ventilation[a] m^2/sec	Maximum mixing height, m	Speed in mixing layer, m/sec	Ventilation[a] m^2/sec
Jan	332	6.0	1,992	882	7.8	6,880
Feb	346	5.7	1,972	1,045	7.8	8,151
Mar	369	5.2	1,919	969	7.5	7,268
Apr	556	7.4	4,114	1,618	9.0	14,562
May	359	4.6	1,651	1,883	9.0	16,947
Jun	395	2.8	1,106	1,483	4.5	6,674
Jul	312	3.3	1,030	1,704	4.8	8,179
Aug	431	3.3	1,422	1,788	4.4	7,867
Sep	482	4.2	2,024	1,517	5.8	8,799
Oct	360	3.9	1,404	1,568	6.5	10,192
Nov	389	5.6	2,178	1,470	9.2	13,524

[a]Mixing height times wind speed.

Table 3. CALCULATED URBAN MIXING HEIGHT AND VENTIALTION FACTORS FOR THE WASHINGTON, DC, AREA FOR JANUARY 1973.

	Morning conditions			Afternoon conditions		
Day of Month	Morning mixing height, m	Speed in mixing layer, m/sec	Ventilation[a] m^2/sec	Maximum mixing height, m	Speed in mixing layer, m/sec	Ventilation[a] m^2/sec
8	420	6.7	2,814	650	5.7	3,705
9	480	5.7	2,736	1,350	8.6	11,610
10	120	4.9	588	1,320	6.4	8,448
11	100	3.6	360	1,290	9.6	12,384
12	480	7.7	3,696	1,470	8.8	12,936
15	90	(0.5)[b]	(45)[b]	355	8.6	3,050
16	310	4.1	1,271	230	7.9	1,817
17	50	2.1	105	210	5.3	1,113
18	40	0.5	20	130	4.6	598
19	80	5.1	408	280	6.5	1,820

[a]Mixing height times wind speed.

[b]Value in parentheses indicates estimated speed. Reported speed was zero.

Table 4. CALCULATED URBAN MIXING HEIGHT AND VENTILATION FACTORS FOR THE WASHINGTON, DC, AREA FOR OCTOBER 1973.

	Morning conditions			Afternoon conditions		
Day of Month	Morning mixing height, m	Speed in mixing layer, m/sec	Ventilation[a] m^2/sec	Maximum mixing height, m	Speed in mixing layer, m/sec	Ventilation[a] m^2/sec
15	170	4.3	731	2,300	11.5	26,450
16	1,040	11.6	12,064	1,380	11.8	16,284
17	1,020	8.0	8,160	2,300	10.4	23,920
18	270	3.4	918	1,970	10.9	21,473
19	540	4.0	2,160	2,000	5.0	10,000
22	180	(0.5)[b]	(90)[b]	1,200	4.0	4,800
23	140	1.0	140	1,220	2.0	2,440
24	100	1.0	100	1,150	4.4	5,060
25	170	3.1	527	1,550	4.3	6,665
26	170	3.3	561	1,800	7.1	12,780

[a]Mixing height times wind speeds.

[b]Value in parentheses indicates estimated speed. Reported speed was zero.

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16. ABSTRACT

Although pollutant emission patterns play important roles, they cannot adequately explain the diurnal variations in carbon monoxide concentrations found in urban areas. In this study, hourly data from a large network of carbon monoxide monitoring stations, with instrumentation corrected for moisture interference, are analyzed and compared with traffic flow and meteorological conditions at several locations in Maryland. The meteorological phenomena that appear to be important in explaining the diurnal variations involve the ventilation effects resulting from variable wind speeds and mixing heights.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
* Air pollution *Carbon monoxide * Meteorological data * Traffic surveys * Diurnal variations * Wind velocity * Mixing * Height		13 B 07 B 04 B 13 B 13 M
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