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Project Summary

Carbon Monoxide Concentrations in Four U.S. Cities During the Winter of 1981

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Portable monitors were used to measure time averaged personal exposures (10 to 30 min) to carbon monoxide. Data were collected from January through March 1981 in four cities where carbon monoxide ambient levels in excess of National Ambient Air Quality Standards have been reported: Stamford, CT; Los Angeles, CA; Phoenix, AZ; and Denver, Co. In each city, personal exposures were measured in three typical microenvironment types: indoor, commuting, and residential driving. These measurements were made in the vicinities of fixed monitoring stations that recorded ambient levels of carbon monoxide.

The highest indoor personal exposures were recorded in Denver (arithmetic mean value of 6.1 ppm). The highest commuting and residential driving exposures were recorded in Los Angeles (11.4 ppm and 7.6 ppm, respectively). Except in Stamford, personal exposures during commuting and residential driving activities were higher than fixed-site ambient concentrations. Indoor exposures were lower than fixed-site concentrations in all cities except Denver.

For the four cities, the linear relationships between simultaneous fixed-site and personal exposure measurements were inconclusive. Any relationship that may exist between these two types of measurements is probably very complex. The exposure vs. fixed-site linear relationships were further complicated in this study by the large distances separating many measurements of the personal exposures and fixed-site concentrations.

Ambient concentrations were highest during the morning (7 to 8 a.m.) and evening (4 to 6 p.m.) hours, with average hourly peak levels of approximately 6 ppm. An exception to this pattern was observed in Stamford where average levels of 10 to 12 ppm were recorded at one fixed site.

This Project Summary was developed by the Environmental Monitoring Systems Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Ambient levels of carbon monoxide (CO) are regulated according to the National Ambient Air Quality Standards (NAAQS). The Office of Mobile Sources is responsible for regulating motor vehicle emissions -- the major source of CO in the urban environment. When the NAAQS for CO are violated, the states involved must effect State Implementation Plans (SIPs) to reduce the ambient levels to meet the NAAQS. The fundamental premise is that when a CO standard is violated at an urban monitoring station, the people in the area surrounding the station also are exposed to CO levels above the NAAQS, therefore, a SIP is necessary. However, actual human CO exposures in various indoor and outdoor activity patterns are affected by highly localized phenomena and may be significantly different from ambient CO levels recorded at fixed stations that are sparsely distributed in urban areas. These phenomena include vehicle emissions, smoking, and indoor ventilation conditions. Accordingly, the "CO Winter Studies" were designed to collect personal CO exposures in microenvironments located in the vicinity of fixed monitoring stations. The data from the two types of measurements were compared to determine if individuals were exposed to the CO levels indicated by the fixed monitoring stations. For the purposes of this study, microenvironments are defined to be specific locations with air space of homogeneous CO concentration. Microenvironment types are groups of similar microenvironments.

Procedure

The study was conducted during an 8-wk period in the winter (January to March) of 1981 in four U.S. cities where ambient CO levels above the NAAQS had been observed. Miniature portable monitors were used to measure time averaged exposures to CO for 10 to 30 min time periods. In each city, personal exposures were measured in three common microenvironment types: Indoor, commuting, and residential driving. The cities and the contractors that performed the monitoring were: Stamford, CT (GCA Corp., Technology Division); Los Angeles, CA (Science Applications, Inc.); Phoenix, AZ (Systems, Science and Software, Inc.), and Denver, CO (PEDCo Environmental, Inc.). Stamford was selected because of the high occurrence of CO fixed-site measurements in excess of the 8-h NAAQS standard of 9 ppm. These measurements are caused by the monitors' location near a busy intersection. Los Angeles was chosen beause the average commute time is greater than the national average of about 20 min. Also, a 9-person pilot study using personal exposure monitors has been conducted in Los Angeles. Phoenix was chosen because, unlike most cities, the highest CO ambient levels are measured during the evening hours. These CO levels may be a result of evening atmospheric inversions that occur before the evening rush hour traffic period. Denver was selected because of its high elevation above sea level. At Denver's altitude, more automobile exhaust may be released into the air due to inadequate adjustment of vehicle engines to the lower levels of oxygen available for fuel combustion.

Results

Descriptive statistics for each microenvironment type within each city are presented in Table 1. The personal exposures within each microenvironment type were matched by time to the concentration recorded at the nearest fixed site in each city. For Stamford, summary statistics are provided for each of the two fixed sites. For Los Angeles, the personal exposures are matched to the nearest fixed site. For Phoenix and Denver, the indoor and commuting personal exposures are compared

Table 1. *Summary Statistics: Personal Exposures and Fixed-Site Concentrations by Microenvironment Type for Four U.S. Cities*

		Data source[a]								
		Stamford[b]			*Los Angeles[c]*		*Phoenix[d]*		*Denver[d]*	
Microenvironment type	*Statistic*	*Personal Exposure*	*Fixed Site 1*	*Fixed Site 2*	*Personal Exposure*	*Fixed Site*	*Personal Exposure*	*Fixed Site*	*Personal Exposure*	*Fixed Site*
Indoor	*Sample size*	659	659	659	1239	1239	380	380	1953	1953
	Geometric mean	3.0	5.0	1.3	2.3	3.3	0.3	1.6	4.2	4.2
	Arithmetic mean	5.6	6.4	2.0	3.2	4.2	2.0	2.7	6.1	5.0
	Standard deviation	8.0	3.8	2.2	2.5	3.2	2.2	2.5	4.8	3.3
	Median	2.7	6.8	1.0	2.6	3.0	1.5	2.0	5.0	4.0
	Range	0-61	0-25	0-12	0-18	1-21	0-17	0-13	0-58	1-24
	Correlation coefficient		0.14	0.03		0.47		0.48		0.33
Commuting	*Sample size*	1341	1341	1341	96	96	839	839	3584	3584
	Geometric mean	4.9	6.6	1.8	15.2	4.0	4.7	2.6	7.9	5.5
	Arithmetic mean	6.3	9.3	2.8	16.4	5.2	6.4	3.7	10.7	6.4
	Standard deviation	4.7	5.7	2.9	6.2	4.0	4.7	3.0	7.6	3.9
	Median	5.2	9.6	1.9	15.5	4.0	5.3	2.5	9.0	5.7
	Range	0-38	0-25	0-16	3-42	1-21	0-50	0-16	0-55	1-27
	Correlation coefficient		0.12	0.27		-0.06		0.47		0.24
Residential driving	*Sample size*	577	577	577	807	807	58	58	526	526
	Geometric mean	1.8	4.9	1.3	6.2	3.1	5.3	1.1	4.2	2.0
	Arithmetic mean	2.6	6.2	2.0	7.6	4.0	6.3	3.1	6.0	2.9
	Standard deviation	2.9	3.8	2.0	5.0	2.9	3.1	2.4	5.1	2.2
	Median	2.0	6.3	1.0	7.0	3.0	6.4	3.6	4.5	2.4
	Range	0-39	0-29	0-8	1-38	1-16	0-14	0-9	0-45	0-10
	Correlation coefficient		0.08	0.26		0.41		0.34		0.02

[a]Averaging times of personal exposure and fixed data are not equal.
[b]Summary statistics are provided for each of the two fixed sites.
[c]Personal exposures are matched to the nearest fixed site.
[d]Indoor and commuting personal exposures are compared to data from the urban fixed site. Residential driving exposures are compared to the urban-residential fixed site.

to data from the urban fixed site; the residential driving exposures are compared to the urban-residential fixed site.

The majority of the personal exposures were not continuous in time. However, the fixed site monitors usually recorded continuous 1-h averages. Thus, the summary statistics presented in Table 1 were obtained by comparing personal exposures that were averaged over a portion of a given hour to hourly averages. This procedure introduces a fictitious replication into the analysis because a given fixed hourly average is repeated for every personal exposure. Any possible effects of this replication should be negligible when comparing the arithmetic means of each type of measurement because of the large number of personal exposures in each microenvironment type (see sample sizes in Table 1). However, it is important when comparing ranges and standard deviations that the averaging time be held constant due to the potential for CO levels to rapidly increase or decrease under conditions found in urban environments. Thus, some of the statistical results from comparing personal exposures that usually included only a portion of a given hour to hourly averages should be viewed with caution. Except for Stamford, each personal exposure arithmetic mean was higher than the corresponding fixed-site mean during commuting and residential driving. In addition, the indoor mean for Denver is higher than the fixed-site mean. The arithmetic means and median values indicate that the highest indoor exposures were measured in Denver. As expected, the highest commuting and residential driving exposures were measured in Los Angeles. Stamford fixed monitoring station 1, which is located near heavy construction activity, recorded the highest fixed-site concentrations.

The sample correlation coefficients, which provide an empirical measure of the linear association between the personal exposure and fixed-site measurements, are very low (<0.5). The square of the correlation coefficient multiplied by 100 provides a percentage measure of the total sample variation that is accounted for in the linear relationship. As measured by the square of the correlation, none of the linear relationships are strong within any of the microenvironment types. Any relationship that may exist between these two types of measurements is probably very complex and cannot be adequately described by a simple linear relationship. The exposure vs. fixed-site relationships were further complicated in this study by the large distances separating many of the personal exposures and fixed-site measurements.

Plots of the hourly fixed-site arithmetic means vs. hour of day (Figures 1 through 5) indicate that the highest CO concentrations occurred in the morning and evening hours. The morning peak occurred at approximately 8:00 a.m. and the evening peak varied from city to city. As expected, the evening peak occurred much later in Phoenix (around 10 p.m.). Also, the Phoenix evening peak concentration exceeded that of the morning peak, unlike the pattern observed in the other cities. Again, Stam-

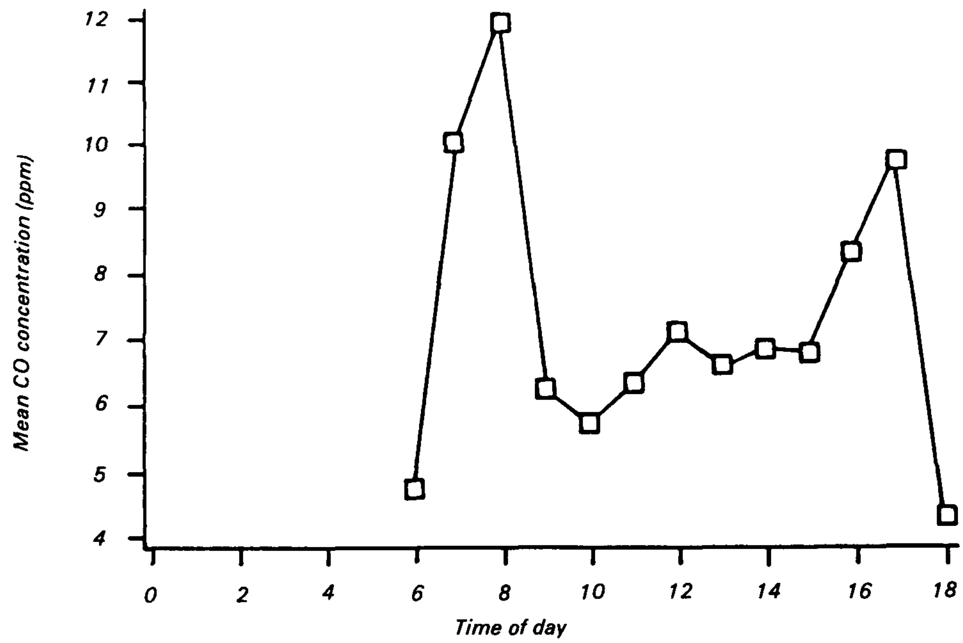

Figure 1. *Hourly arithmetic means recorded in fixed-site monitoring station 1 located near a construction site and busy intersection in Stamford*

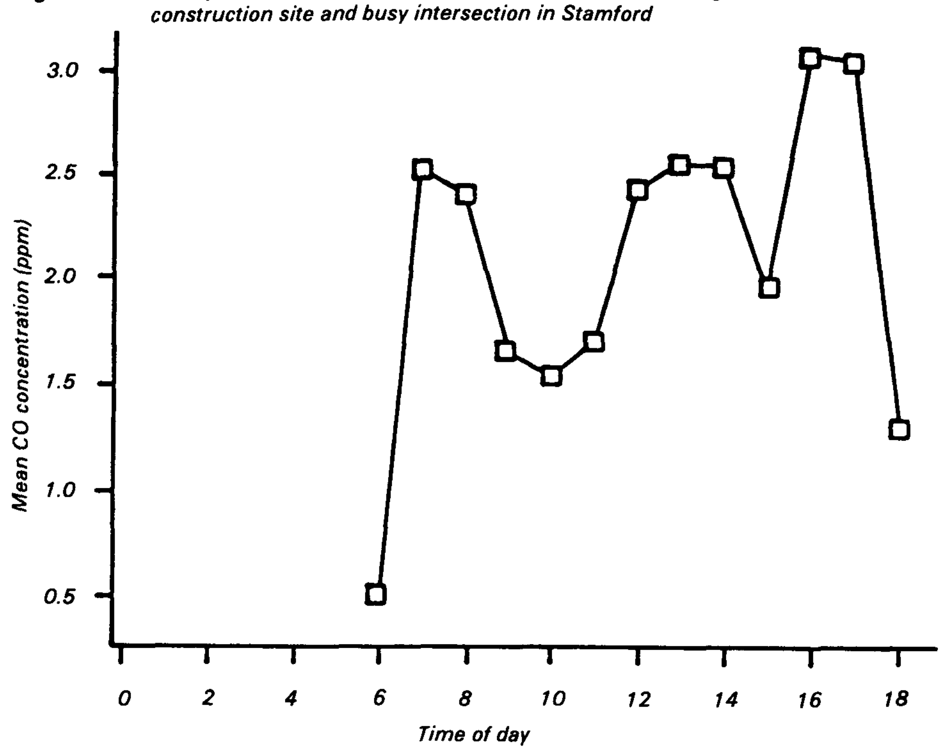

Figure 2. *Hourly arithmetic means recorded at fixed-site monitoring station 2 located diagonally across the intersection from station 1 in Stamford*

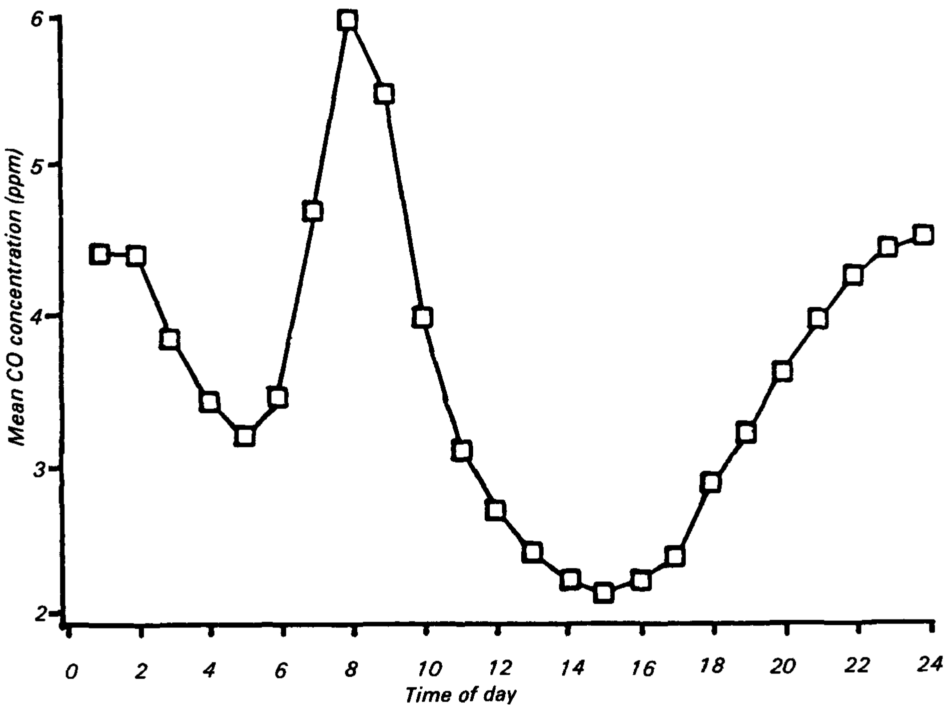

Figure 3. *Hourly arithmetic means recorded at 10 fixed-site monitoring stations in Los Angeles*

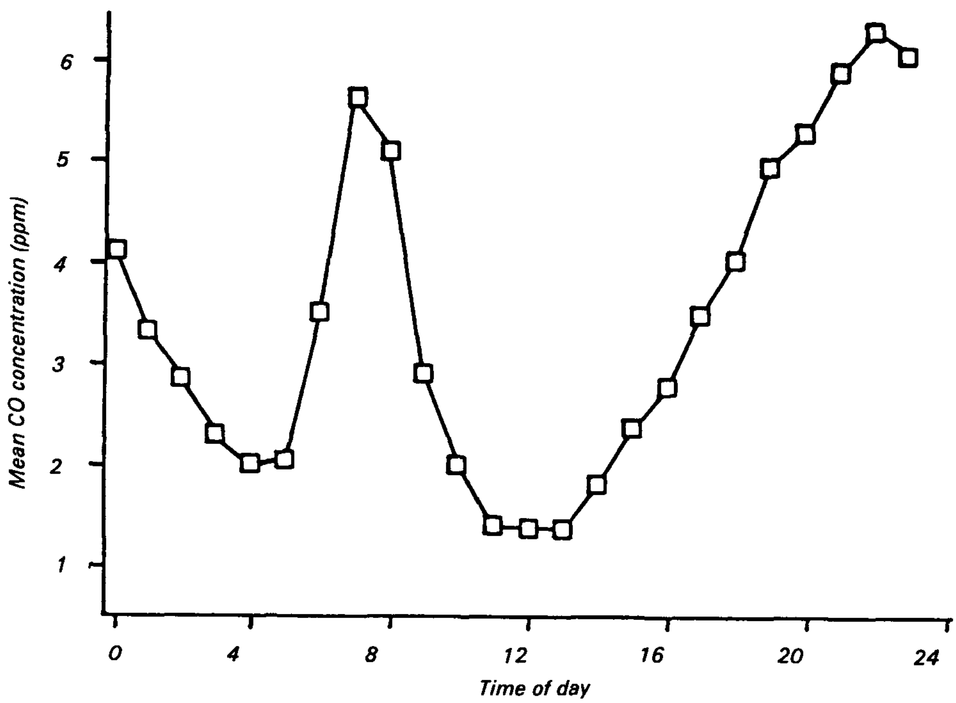

Figure 4. *Hourly arithmetic means recorded at the urban fixed-site monitoring station in Phoenix*

ford monitoring station 1 recorded the highest hourly mean concentrations. The morning and evening peak levels were approximately 6 ppm in the other three cities.

An indirect approach was used to estimate the exposure of a typical commuting office worker. A time-weighted average exposure (equation 1) was calculated for the following activities: morning commute to office, work at office, midday eating and shopping, and evening commute to home. The time periods used to determine average estimates for each activity were 8-12 a.m. and 1-5 p.m. for work at the office, 7-9 a.m. for the morning commute, and 4-6 p.m. for the evening commute. The midday hours used for the eating and shopping activities varied from city to city due to the different monitoring procedures used in each city. Although the morning and evening commute time periods overlap the assumed office hours, these times were used to provide a representative estimate of the average CO levels of these activities.

$$\text{time weighted average exposure} = \frac{\sum_{i=1}^{n} CO_i \cdot t_i}{\sum_{i=1}^{n} t_i} \qquad (1)$$

where
- n = number of measurements recorded during an activity time period for the entire study
- t_i = averaging time of exposure (min)
- CO_i = average exposure for averaging time t_i

Table 2 shows the time-weighted average exposures in each of the five activities and the estimated maximum 8-h average exposure for a commuting office worker in each city. The 8-h average value is a time-weighted combination of the commuting (maximum of the morning and evening commute averages), office, store and restaurant average exposures. These values were computed by the following equation:

$$\text{maximum 8-h average} = 1/8\,(\text{maximum commuting exposure}) + 6/8\,(\text{office exposure}) + 1/16\,(\text{restaurant exposure} + \text{store exposure}) \qquad (2)$$

This weighted combination assumes a 1-h commuting time, 6 hours in the office, 1/2-h in a restaurant, and 1/2-h shopping time during the total time period of 8-h. Due to the high CO commuting levels, the commuting office worker in Los Angeles received the highest average exposure. This exposure (8.2 ppm) is slightly under the current 8-h standard. The time-weighted average indoor and commuting exposures in Los Angeles also are considerably higher than in the other three cities.

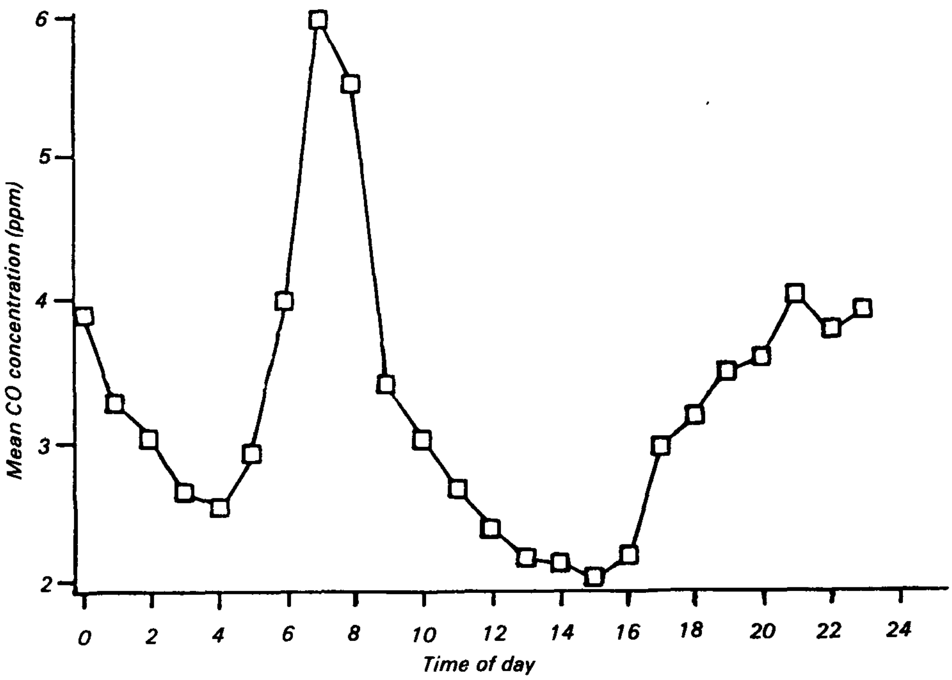

Figure 5. *Hourly arithmetic means recorded at the urban-residential fixed-site monitoring station in Denver*

Table 2. *Average Exposure of the Commuting Office Worker in Each City*

	Average exposure (ppm)					
City	Morning Commute	Office	Restaurant	Store	Evening Commute	Estimated for 8-h
Los Angeles	17.8	6.9	7.1	5.8	15.2	8.2
Denver	13.9	5.1	6.8	5.2	11.5	6.3
Stamford	6.8	3.0	5.1	2.4	6.0	3.6
Phoenix	10.9	1.9	3.4	1.6	6.9	3.1

Conclusions

The findings of this study of CO concentrations in Stamford, Los Angeles, Phoenix, and Denver are summarized below:

- Except in Stamford, personal exposures during commuting and residential driving were higher than fixed-site ambient concentrations (arithmetic mean values).
- Except in Denver, indoor exposures were lower than fixed-site ambient concentrations (arithmetic mean values).
- The highest indoor exposures were found in Denver (arithmetic mean value of 6.1 ppm).
- The highest commuting and residential driving exposures were found in Los Angeles (arithmetic mean values of 16.4 ppm and 7.6 ppm, respectively).
- Hourly fixed-site arithmetic mean ambient concentrations in all four cities were highest in the morning (7 to 8 a.m.) and evening rush hours (4 to 6 p.m.). Except for a fixed monitoring station located near a construction site and busy intersection in Stamford, where peak levels were 10 to 12 ppm, morning and evening peak levels were approximately 6 ppm.
- In all four cities, regressing personal exposures on simultaneous fixed-site ambient concentrations resulted in inconclusive linear relationships. Any relationship that may exist between these two types of measurements is probably very complex and cannot be adequately described by a simple linear relationship.
- The highest estimated 8-h average exposure for a commuting office worker was found in Los Angeles (8.2 ppm).

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The complete report, entitled "Carbon Monoxide Concentrations in Four U.S. Cities During the Winter of 1981," (Order No. PB 83-224 907; Cost: $10.00, subject to change) will be available only from:

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