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Ambient Versus Predicted Carbon Monoxide Levels

by

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Introduction

MOBILE2 is a computer program that calculates emission factors for hydrocarbons, carbon monoxide, and oxides of nitrogen for highway motor vehicles. The program uses the calculation procedures described in the Compilation of Air Pollution Emission Factors: Highway Mobile Sources(1), to calculate emission factors for eight individual vehicle types in three regions of the country. These emission estimates depend upon various conditions, such as ambient temperature and vehicle usage. MOBILE2 can estimate emission factors for any calendar year between 1970 and 2020.

Various groups have tried to characterize the accuracy of the MOBILE2 emission factors model by comparing its emissions results to air quality measurements during the 1970-80 period. This report shows that such comparisons are sensitive to the input assumptions used to generate the emissions results.* It also compares the reduction in carbon monoxide (CO) tailpipe emissions predicted by the MOBILE2 model to the reduction in ambient levels as they were measured by the nation's network of carbon monoxide monitors. The comparison is made only for ambient CO since that pollutant, more so than the others, is the result of emissions from motor vehicles.

The ambient CO concentrations used in this investigation were taken from SAROAD. SAROAD is the acronym for the Storage and Retrieval of Aerometric Data system maintained by EPA. This system contains information collected by federal, state, and local agencies on various pollutants and hazardous chemicals, including carbon monoxide.

Discussion

Figure 1 shows the second highest eight hour moving average CO level from SAROAD and demonstrates how significant the improvement in U.S. cities' air quality has been during the decade of the 70s. The second highest eight hour moving average CO level was used because that is the present form of the National Ambient Air Quality Standard (NAAQS) for CO. On each of the figures in this report the vertical axis represents the summation of all the CO changes from the previous and current years. Since very few monitors measure data continuously from 1970 to 1980, the change is expressed as the difference in the base 10 logarithms of the recorded concentrations from one year to the previous year. For example, the 1970-1971 level is calculated from the logarithm of the 1971 second highest eight hour moving average CO level measured by each monitor subtracted from the logarithm of the corresponding 1970 monitor level. These changes are then accumulated over all years. The logarithms are

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*While the assumptions used in this report may be appropriate for certain local projections, national comparisons of alternate control strategies have, heretofore, required the use of standard Federal Test Procedure conditions.

used since they are symmetric, while calculations based upon percentage differences are not symmetric. For example, if during a three-year period ambient concentrations are recorded as 20 ppm, 10 ppm, and 20 ppm, the net difference based on logarithms is zero. Based on a percentage calculation, the cumulative difference would be plus 50 percent (10-20/20=-50%; 20-10/10=+100%; -50%+100%=+50%).

Figure 1 also shows the reduction in fleet emissions calculated from MOBILE2 under the standard conditions associated with the Federal Test Procedure (FTP). These reductions are calculated by the same procedure that was used to ascertain the changes in ambient carbon monoxide so that a comparison between the two would be consistent. Such a comparison suggests that, over the past decade, tailpipe emissions as predicted by MOBILE2 have declined more than ambient concentration levels.

There are, however, several aspects of the underlying MOBILE2 model and SAROAD data used to construct Figure 1 that should be noted to properly interpret this figure.

1. The driving patterns associated with the elevated CO concentrations represented in Figure 1 may not be reflected by the FTP cycle.

2. Most violations of the CO National Ambient Air Quality Standard occur during the months of November, December, and January when temperatures are substantially colder than the 68°F - 86°F range associated with the standard Federal Test Procedure*.

3. The rush hour traffic often associated with high ambient CO concentrations may consist mostly of passenger vehicles rather than the standard mix of vehicles assumed by MOBILE2.

4. The number of monitors fluctuates over time. For instance, only 43 monitors measured CO in both 1970 and 1971. This contrasts with 178 monitors in 1973 and 1974 and with 247 monitors in 1979 and 1980. (See Table 1.)

5. MOBILE2 does not account for growth in the number of vehicle miles traveled. It strictly calculates the grams of pollutant emitted per mile traveled.

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*Seventy-five degrees Fahrenheit has been used throughout this report to characterize the FTP temperature range.

The effects of each of these factors are addressed in the remaining parts of this paper. It is important to realize that the discussion is presented in terms of a sensitivity analysis. The operative factors at any individual monitoring site may be different. The purpose is really to point out that a straight FTP MOBILE2-ambient CO comparison may be insufficient.

1. Driving Cycle

The Federal Test Procedure was developed in 1970 to model a typical urban driving cycle (2,3). As defined, the driving cycle is composed of two parts: the start-up phase and the stabilized phase. The start up phase can either be a cold start or a warmed-up start. The morning rush hour traffic on major roads and in the central business district is probably best characterized by the stabilized phase since vehicles will have warmed up by the time they reach these heavy traffic areas. The evening rush hour may be best characterized either by the cold start plus stabilized phases (if most traffic consists of people returning to their homes after working a full eight hour day) or by the hot start plus stabilized phases (if most traffic consists of people returning from short trips into the city). Figure 2 displays the reduction in tailpipe emissions associated with each of four driving patterns.

Of the four patterns, the stabilized phase of the Federal Test Procedure may best characterize the driving patterns associated with elevated CO concentrations. By the time the morning suburban traffic reaches the central business district, most of the vehicles will have warmed up. And in the afternoon, when vehicles that have sat in parking lots all day get started and reach congested roadways they, too, will have warmed up. Afternoon cold start emissions away from the ambient monitor may be important from the standpoint that such emissions tend to increase background CO levels. See references 4 and 5 for a discussion of this effect.

2. Ambient Temperature

Another concern that one might have with the comparison depicted in Figure 1 is that most elevated CO levels of the carbon monoxide standard are recorded during November, December, and January. To assess the potential effect of cold temperature, it was first necessary to determine the temperatures that actually prevailed during periods of high ambient CO concentrations. Table 2 lists the 30-year average temperatures during November, December, and January at all of the Standard Metropolitan Statistical Areas (SMSAs) in which there were CO monitors. The overall average temperature in low-altitude, 49-state areas was 39.7°F(6), a value substantially below the standard Federal Test Procedure's range of 68°F - 86°F. Figure 3 shows that slightly less improvement in stabilized fleet CO emissions occurred at colder temperatures than occurred in this FTP temperature range.*

3. Vehicle Type

Another concern that might be expressed in the comparison of MOBILE2 predictions to "real world" ambient carbon monoxide levels is that the rush hour traffic often associated with high concentration levels may consist mostly of passenger vehicles. The default mix of vehicle types contained in MOBILE2 may not really be representative of rush hour traffic. Figure 4 shows the improvement in CO emissions averaged (1) over all vehicle types and (2) over only personal passenger vehicles. The two curves in the figure are both for stabilized operation at 40°F. As Figure 4 shows, personal passenger vehicles are estimated to have experienced a somewhat greater reduction in tailpipe CO emissions than has the combined vehicle fleet.

Notice, too, that by 1980 the lower curve in Figure 4 is essentially at the same position in that figure (-0.22) as is the lower curve in Figure 1. That is, the net effect of the adjustments considered heretofore is zero. While the net effect of adjusting for specific local conditions may not be zero, this analysis suggests that standard FTP conditions may, indeed, be appropriate for national analyses.

4. Screening of Monitor Data

Monitoring data, like all other data, is subject to a variety of errors. Due to limitations on the resources available for this project, it was not possible to screen extensively all of the monitoring data that went into this report. The total data set consists of over ten million, eight-hour moving average observations. Since the level of the CO NAAQS is not to be exceeded more than once per year, the most important eight-hour average each year is the second highest. Thus, the 10 million observations from the original set were first reduced to approximately 1000 second high values. Of these, four values of greater than 70 mg/m^3 were then deleted on the basis that the highest confirmed CO value since 1977 has been 38.5 mg/m^3. While a few values higher than 38.5 mg/m^3 were recorded prior to 1977, those values greater than 70 mg/m^3 definitely appeared to be anomalous. The resulting data set is labeled "edited" in Figure 5. From this edited set a subset was constructed that excludes all observations for which there was more than a 10 mg/m^3 change during two consecutive years. That data set is labeled "edited and screened" in Figure 5.

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*Since MOBILE2 rounds input temperatures to whole degrees Fahrenheit, the cold temperature curve of Figure 3 has been labeled "40°F".

Three possibilities are offered to explain changes greater than 10 mg/m^3 during two consecutive years. The first possibility is data error. Examining the time series for suspect data reveals that, in many instances, a large change in one direction in one year is offset by an equally large change in the opposite direction in the following year. This is the predominate reason why the two curves in Figure 5 are so similar. The second explanation offered is that traffic patterns may have shifted from one year to the next. Such a shift may have occurred because of intentional traffic control measures by the local government. It may also have been the result of independent decisions rendered by the area's drivers. For example, drivers may want to avoid an intersection that has become more congested over time or an area undergoing road or building construction. The third possibility offered to explain large one-year differences in ambient concentration levels is a change in monitor calibration procedures. If any of these three possibilities occurred, they would confound the comparison of reduction in ambient concentrations to reduction in emissions.

5. Monitor Selection

Since the lower two curves in Figure 6 are similar, one can infer that monitors within SMSAs have recorded about the same reduction in ambient CO concentrations as have the monitors within non-SMSA areas. However, if the monitors within SMSAs that measure the highest second high CO concentrations are compared without regard to whether the monitors are the same for each comparison, then ambient CO concentration levels may not have improved quite as much as would first appear. The curve labeled "mixed SMSA monitors" shows the reduction recorded under this circumstance.

As mentioned previously, one explanation for the difference in estimated reductions is that traffic may have shifted away from one monitor toward another. Ideally, a set of identical monitors each surrounded by a constant volume of traffic could be found. Such a set would allow one to isolate the effect of reduced emissions on ambient CO concentrations. Unfortunately, too few monitors come close to satisfying this criterion.

6. Growth in Vehicle Miles Traveled

Traffic in the vicinity of the ambient monitors may or may not have appreciably shifted. However, it has increased. Nationwide, personal passenger vehicle miles traveled (VMT) grew at an overall rate of 2.3 percent per year during the past decade.(7) Figure 7 shows the increase in VMT from 1970 to 1980. Traffic designated as "urban" by the Federal Highway Administration (FHwA) grew at a greater rate than traffic designated as "rural".

Growth in vehicle miles traveled is an important factor to consider in any comparison of MOBILE2 and the "real world", since the emission trends predicted by MOBILE2 are expressed simply in grams of CO emitted per mile traveled. MOBILE2 itself, without VMT growth, overpredicts the reduction in ambient carbon monoxide levels.

According to the FHwA (8), there are two components of urban growth. One component is geographic area, the other is traffic density. During the past decade those locations designated urban have come to encompass larger geographic areas. In addition, other areas once designated rural, are now designated urban. Meanwhile, traffic density within the core urban areas has also increased.

It is important to consider both components when examining their effect on ambient air quality. On one hand, it can be argued that expansion of an urban area may increase background carbon monoxide levels. That, in turn, may increase peak carbon monoxide concentrations during CO episodes.(5) Accepting this argument would lead one to adjust MOBILE2 emission factors by the full 2.3 percent annual growth rate. On the other hand, it could also be argued that only an increase in traffic density will tend to increase ambient CO levels. Accepting this alternate argument would lead one to adjust the emission factors by less than 2.3 percent.

Summary

Figure 8 shows the effect of combining the assumptions made in the previous sections. The second highest eight-hour moving average CO levels measured by SAROAD monitors in the nation's low altitude, 49-state regions were edited for potentially bad data and screened for outliers. The resulting data set is plotted in Figure 8. Also plotted are the data from the second highest averages within SMSAs. These two curves are then compared with the predictions from MOBILE2, adjusted for nationwide urban growth shown in Figure 7, and for personal passenger vehicles operating in a stabilized mode at wintertime temperatures in the same low altitude, 49-state regions. As can be seen from the figure, the cumulative reduction in ambient CO predicted from MOBILE2 emission factors and growth in urban VMT is greater than that recorded by the "mixed" SMSA monitors but less than that recorded by the "matched" monitors.

It is also possible to compare the two ambient concentration curves with two additional adjusted MOBILE2 curves. These latter two curves adjust the MOBILE2 emission factors by the growth rate assumptions currently used by EPA in air quality analyses performed in support of regulations and in responses to congressional requests for information. The lower of the two curves assumes that personal passenger VMT increases at a rate of 0.4 percent, while the higher curve assumes that VMT increases at a 2.4 percent per year rate. While the 2.4 percent per year rate is close to the historical average, the 0.4 percent rate reflects the possibility that only traffic in the immediate vicinity of the monitors influences the measurements recorded by them. Since many monitors are located in central business districts and since many of the traffic corridors in those districts operate near capacity, traffic may not be able to increase there at the same rate it can in the rest of the city. Indeed, the most recent EPA responses to congressional requests for analysis of the low altitude CO problem have indicated a preference for the assumption that personal passenger VMT will grow at a 0.4 percent annual rate. Adjusting for this fairly modest growth rate, it appears that MOBILE2 characterizes the ambient monitoring data fairly well.

References

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2. Kruse, R. and Huls, Development of the Federal Urban Driving Schedule, U.S. Environmental Protection Agency, SAE Paper 730553, May, 1973.

3. Huls, Evolution of Federal Light Duty Mass Emission Regulations, U.S. Environmental Protection Agency, SAE Paper 730554, May, 1973.

4. Delman, A., CO Hot Spot Analysis - The Uses and Limitations of Emission Inventories, Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, D.C., April 1982.

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6. Ruffner, J., Frank Bair, editors, The Weather Almanac, Second Edition, Avon Book, 1979.

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8. Personal communication with J. Thwing, Federal Highway Administration, U.S. Department of Transportation, February 12, 1982.

Figure 1
Low Altitude, 49-States

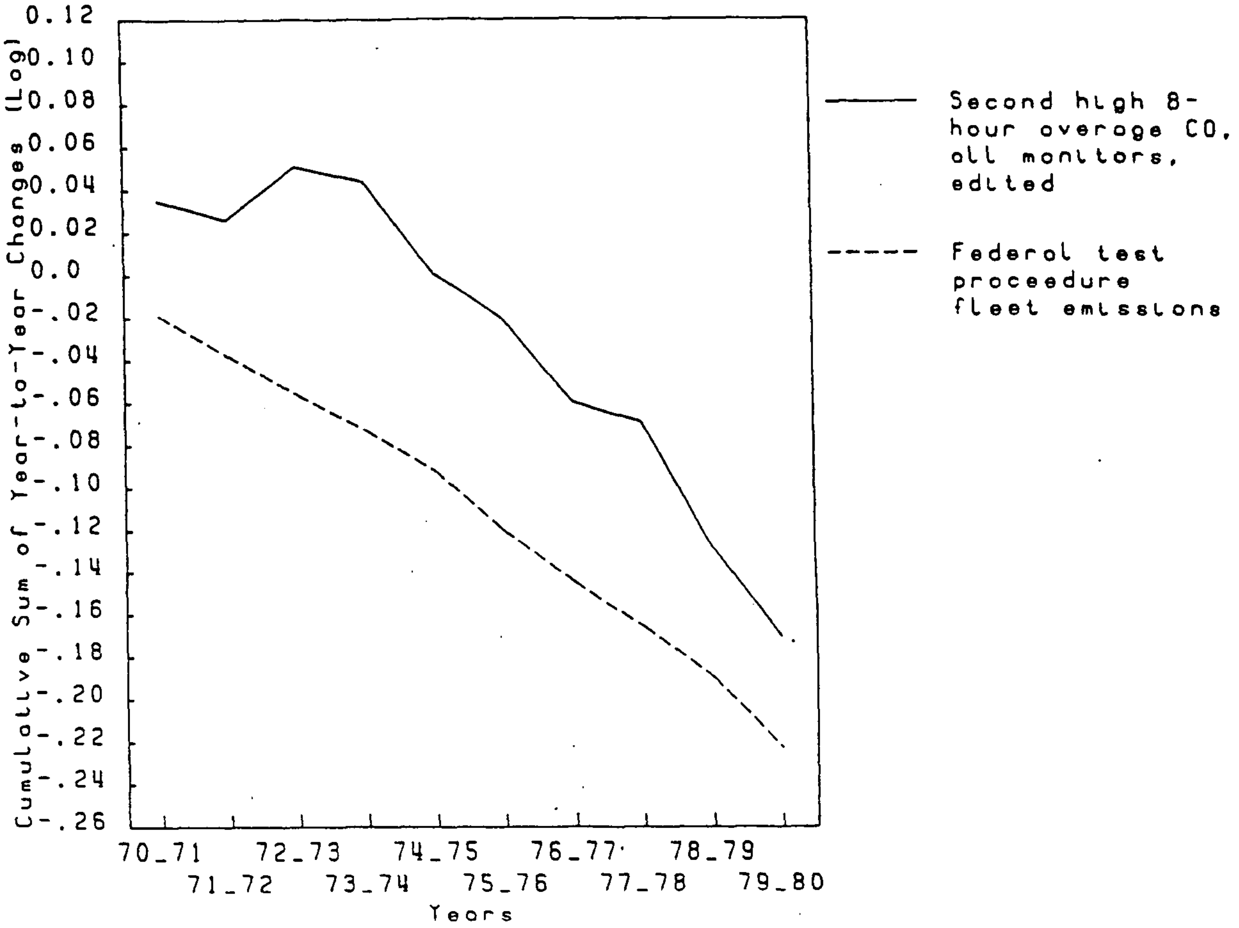

Figure 2
Driving Patterns, 75 F, Fleet Emissions

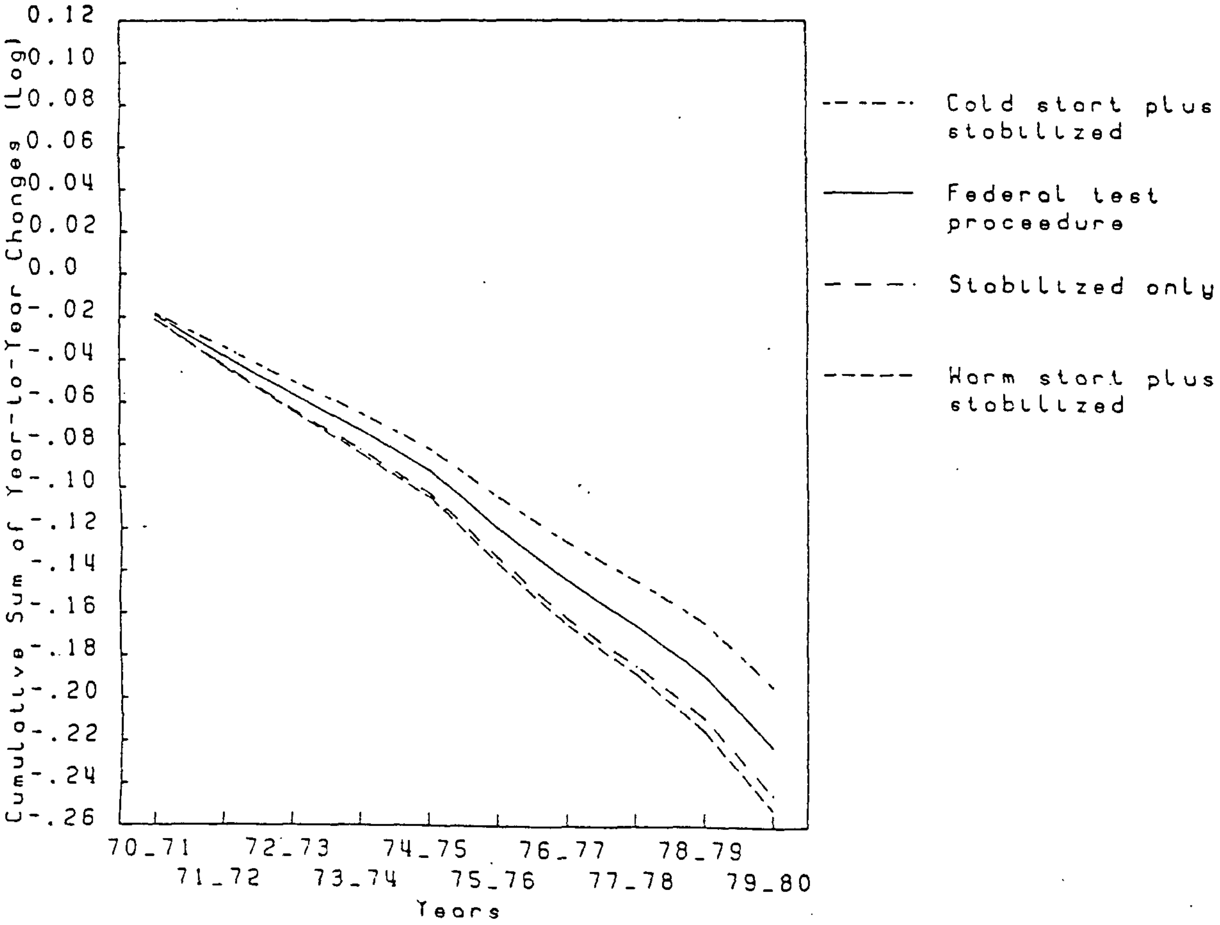

Figure 3
Stabilized Driving, Fleet Emissions

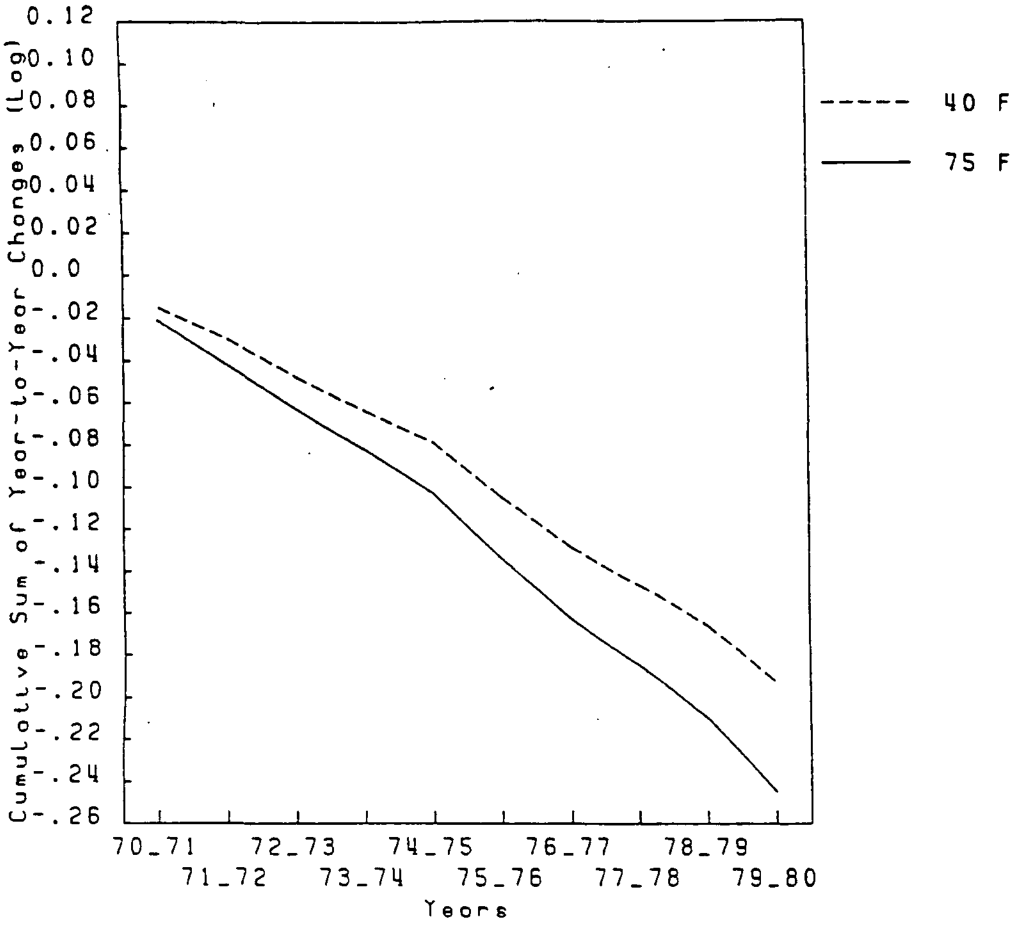

Figure 4
Stabilized Driving at 40 F

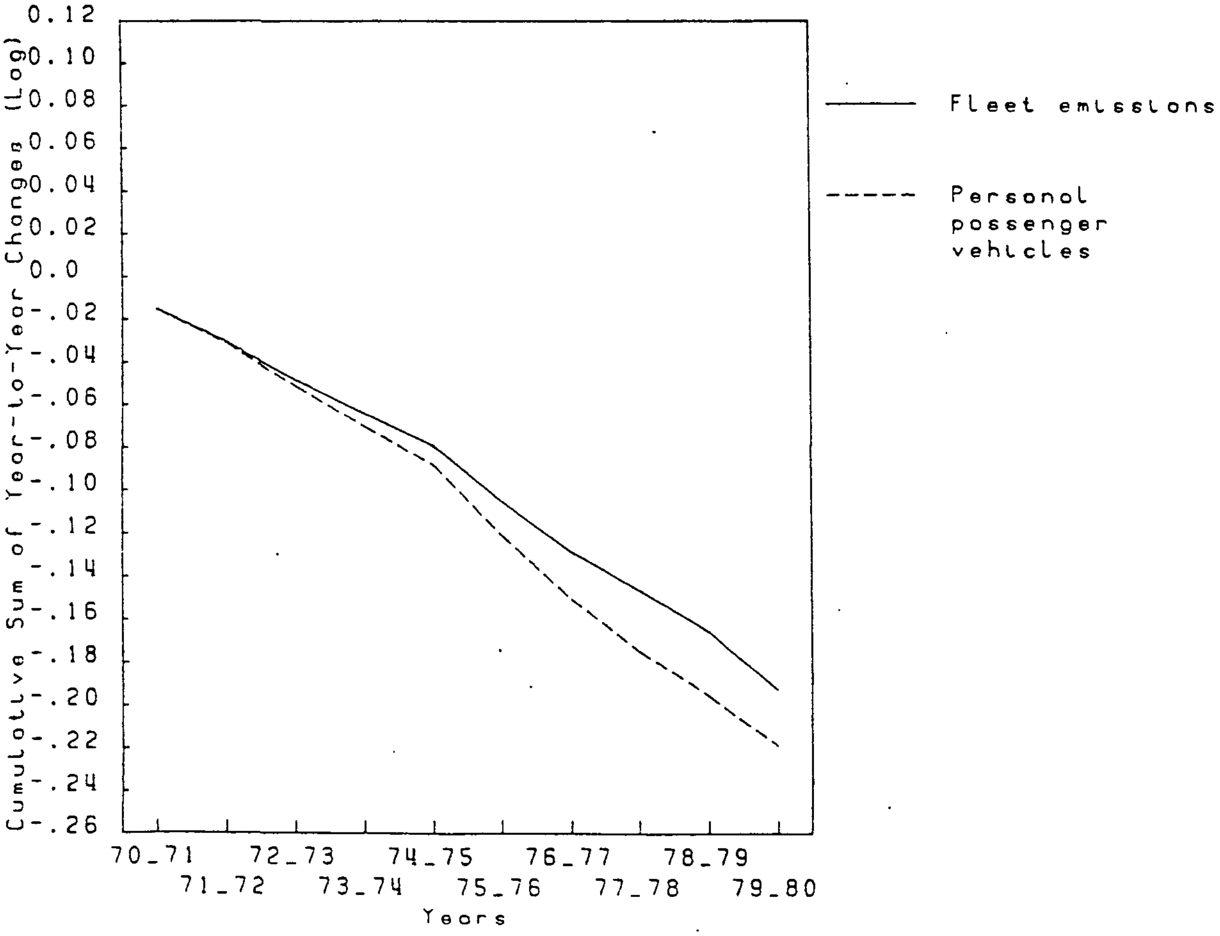

Figure 5
Screening of Monitor Data

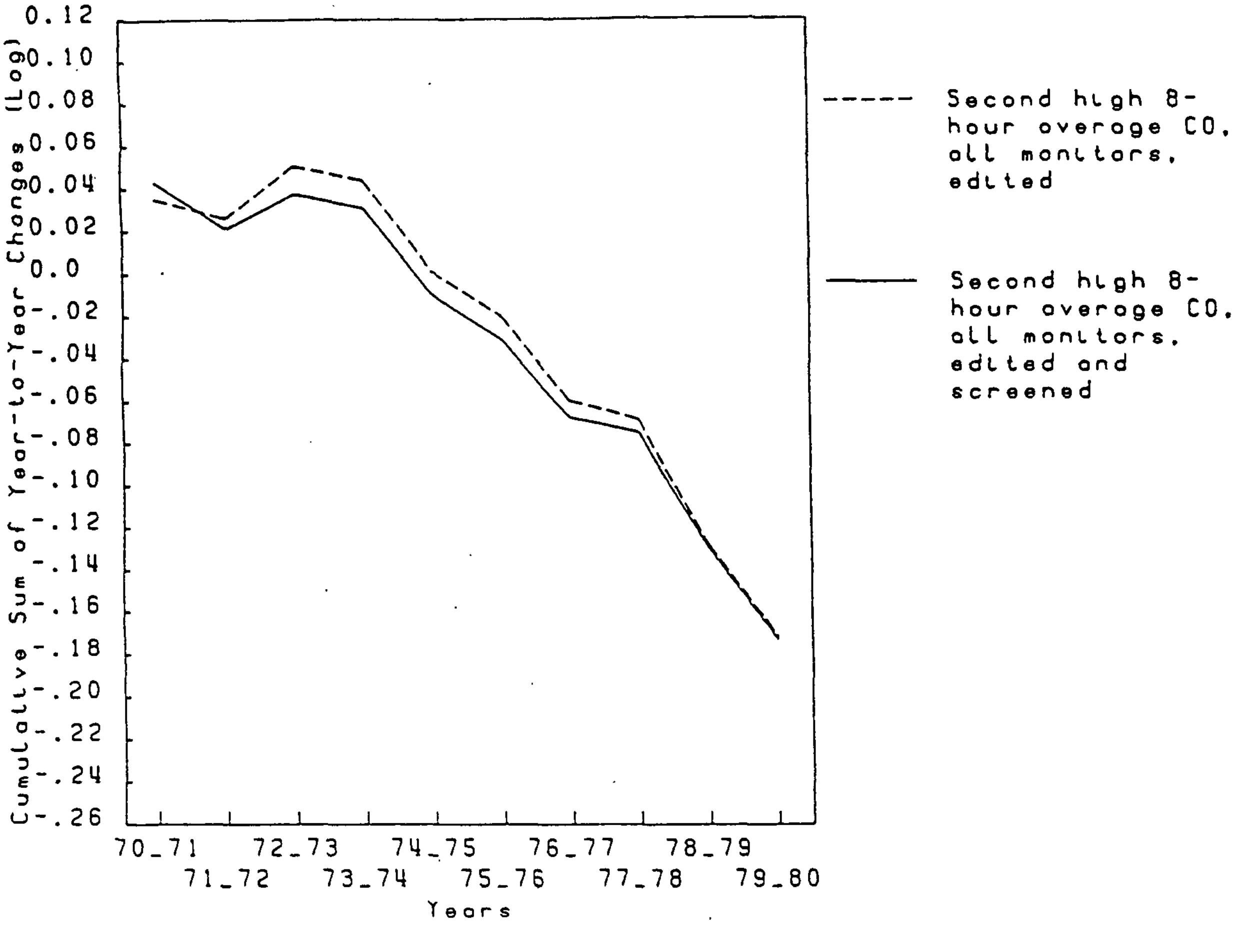

Figure 6
Monitor Selection, Low Altitude, 49-States

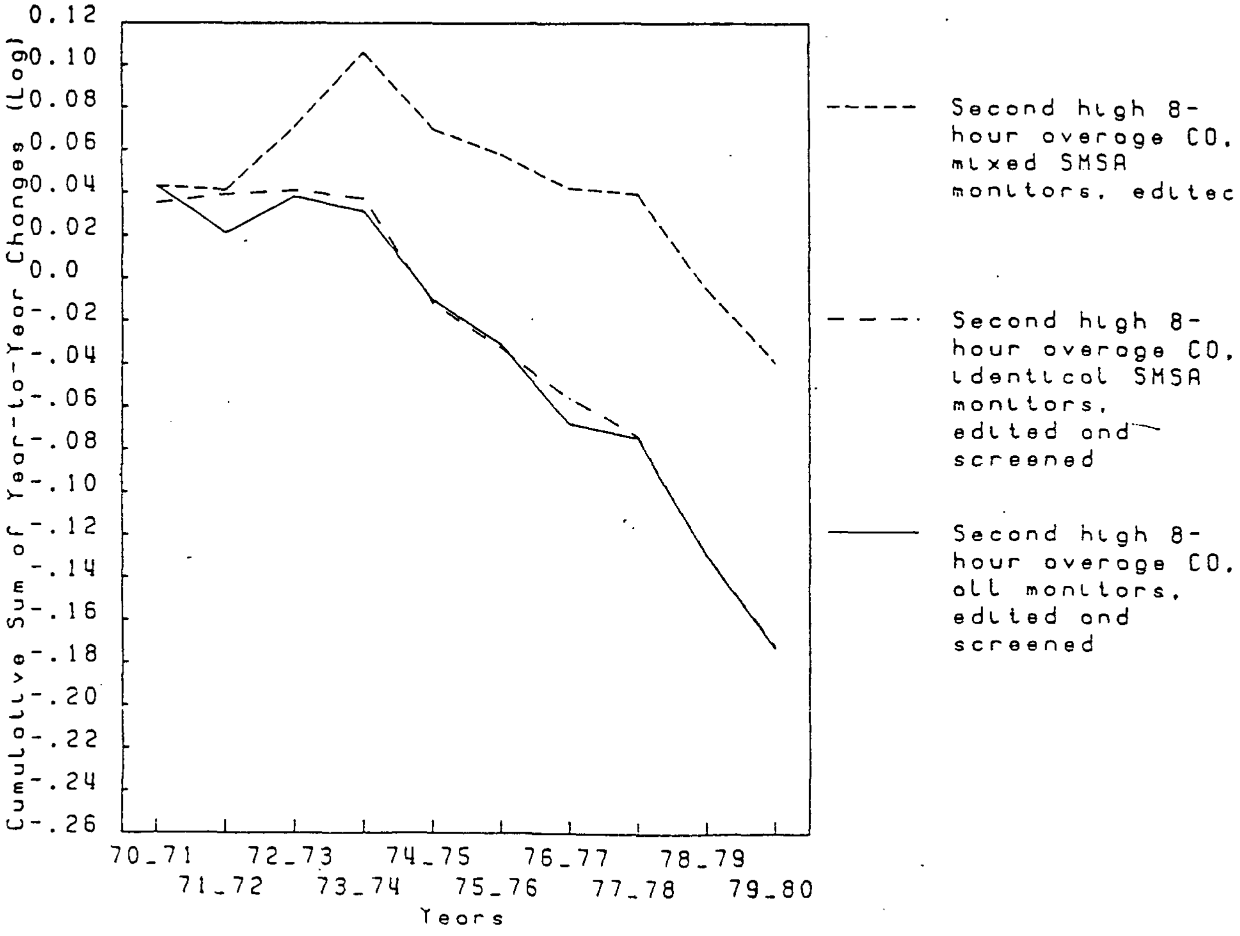

Figure 7
Nationwide Personal Passenger VMT Growth

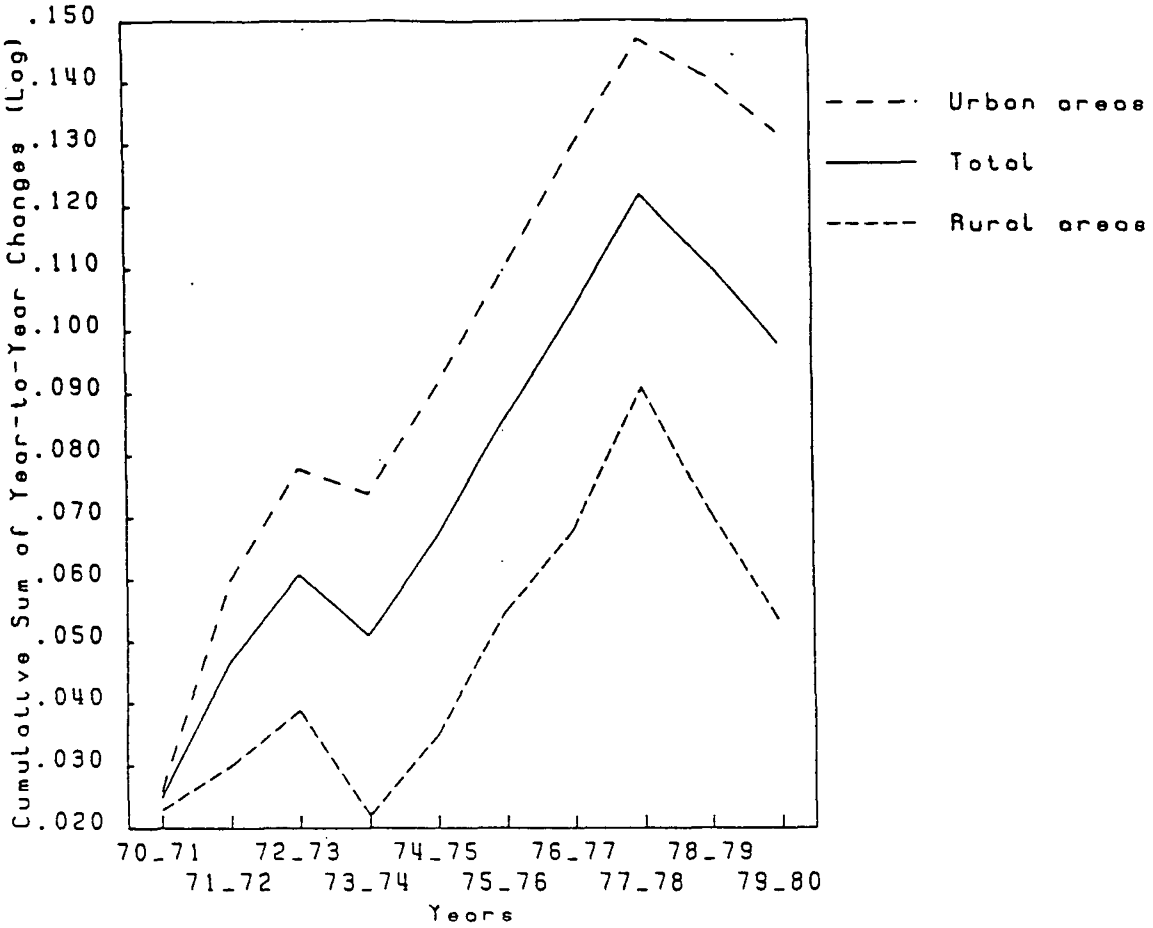

Figure 8
Stabilized Driving, 40 F, Low Altitude, 49-States

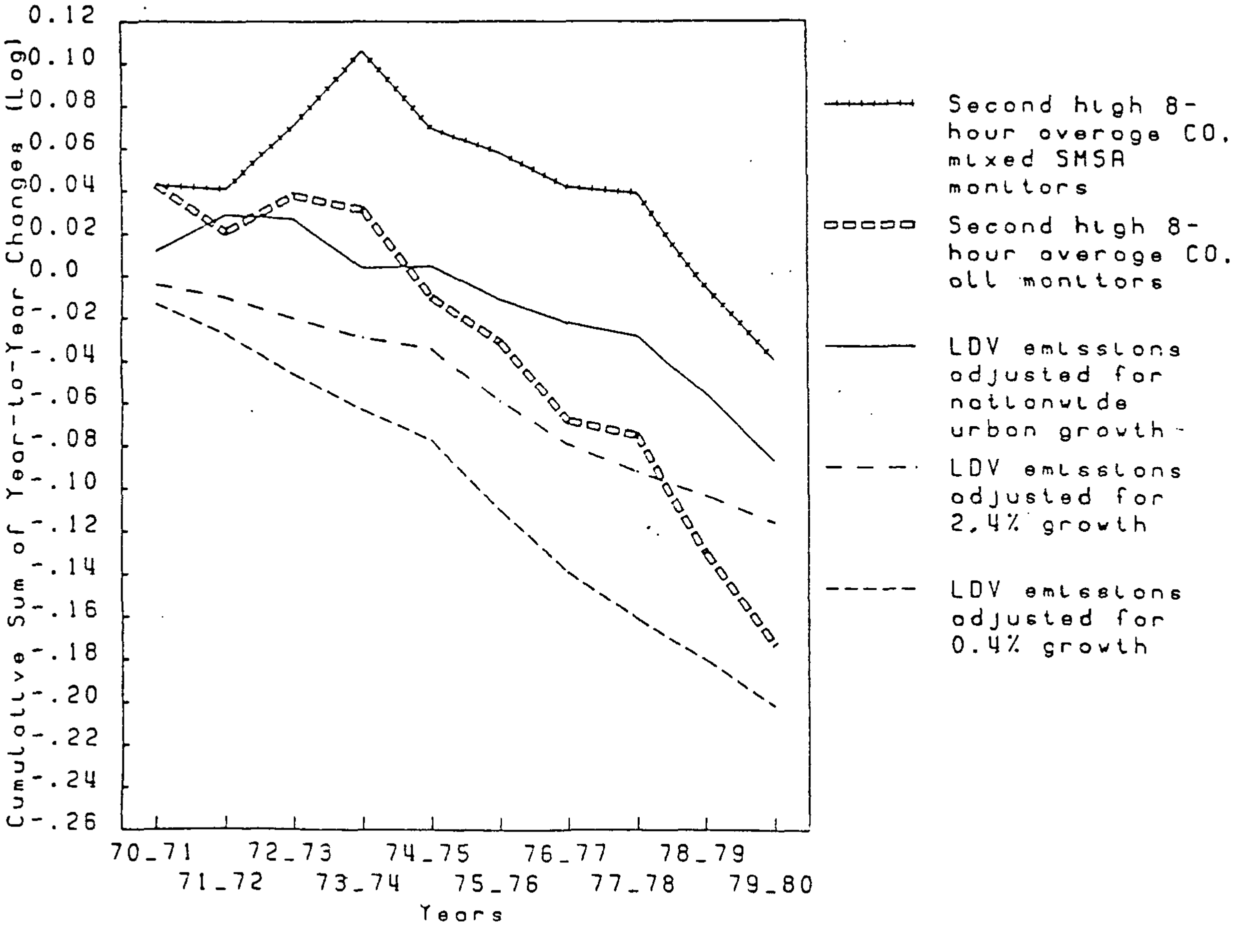

Table 1

Number of Monitors

	Years									
Description	70-71	71-72	72-73	73-74	74-75	75-76	76-77	77-78	78-79	79-80
All monitors, edited	43	101	132	178	236	269	270	246	252	247
All monitors, edited and screened	39	90	128	165	227	267	261	241	249	243
Identical SMSA monitors, edited	13	35	47	60	83	102	97	92	99	95
Identical SMSA monitors, edited and screened	12	35	47	57	80	102	95	91	99	95
Mixed SMSA monitors, edited	18	51	69	89	111	128	133	133	135	136

Table 2

Monthly Winter Temperature

Urban Area	State	30-Year Average Temperature (F)		
		Nov	Dec	Jan
Anchorage	AK	21.1	13.0	11.8
Birmingham	AL	52.1	45.2	44.2
Huntsville	AL	M	M	M
Mobile	AL	58.5	52.9	51.2
Phoeniz	AZ	59.5	52.5	51.2
Tuscon	AZ	58.5	52.0	50.9
Anaheim-Santa Ana-Garden Gro	CA	M	M	M
Bakersfield	CA	M	M	M
Fresno	CA	53.5	45.8	45.3
Los Angeles-Long Beach	CA	62.7	58.1	56.7
Modesto	CA	M	M	M
Oxnard-Simi Valley-Ventura	CA	M	M	M
Riverside-San Bernardino-Ont	CA	M	M	M
Sacramento	CA	53.0	45.8	45.1
Salinas-Seaside-Monterey	CA	M	M	M
San Diego	CA	60.8	56.7	55.2
San Francisco-Oakland	CA	57.4	52.0	50.9
San Jose	CA	M	M	M
Santa Barbara-Santa Maria-Lo	CA	M	M	M
Santa Rosa	CA	M	M	M
Stockton	CA	M	M	M
Vallejo-Fairfield-Napa	CA	M	M	M
Colorado Springs	CO	37.5	31.0	28.6
Denver-Boulder	CO	39.4	32.6	29.9
Fort Collins	CO	M	M	M
Fort Wayne	CO	M	M	M
Greeley	CO	M	M	M
Pueblo	CO	M	M	M
Bridgeport	CT	M	M	M
Hartford	CT	41.3	28.2	24.8
New Britain	CT	M	M	M
New Haven-West Haven	CT	M	M	M
New London-Norwich	CT	M	M	M
Norwalk	CT	M	M	M
Stamford	CT	M	M	M
Waterbury	CT	M	M	M
Washington,-DC	DC	48.0	37.4	35.6
Fort Lauderdale-Hollywood	FL	M	M	M
Jacksonville	FL	M	M	M
Miami	FL	72.2	68.3	67.2
Orlando	FL	66.6	61.5	60.3
Pensacola	FL	M	M	M
Tallahassee	FL	M	M	M
Tampa-St. Petersburg	FL	66.8	61.6	60.4
West Palm Beach-Boca Raton F	FL	M	M	M
Atlanta	GA	51.4	43.5	42.4
Honolulu	HI	76.5	73.7	72.3
Cedar Rapids	IA	M	M	M
Des Moines	IA	37.8	25.0	19.4
Dubuque	IA	M	M	M
Boise City	ID	39.8	32.1	29.0
Chicago	IL	40.4	28.5	24.3
Davenport-Rock Island-Moline	IL	M	M	M
Peoria	IL	39.9	28.0	23.8
Springfield	IL	41.9	30.5	26.7
Gary-Hammond-East Chicago	IN	M	M	M
Indianapolis	IN	41.7	30.9	27.9
Terre Haute	IN	M	M	M
Lawrence	KC	M	M	M
Topeka	KC	42.9	31.8	28.0
Wichita	KC	44.8	34.5	31.3
Evansville	KY	M	M	M
Huntinton-Ashland	KY	M	M	M
Lexington-Fayette	KY	44.6	35.5	32.9
Louisville	KY	45.0	35.6	33.3
Owensboro	KY	M	M	M
Baton Rouge	LA	M	M	M
New Orleans	LA	60.1	54.8	52.9
Boston	MA	45.2	33.0	29.2
Lowell	MA	M	M	M
Pittsfield	MA	M	M	M
Springfield-Chicopee-Holyoke	MA	M	M	M
Worcester	MA	M	M	M
Baltimore	MD	46.1	35.3	33.4
Lewiston-Auburn	ME	M	M	M
Detroit	MI	41.1	29.6	25.5
Grand Rapids	MI	38.7	27.4	23.2
Muskegon-Norton Shores-Muske	MI	M	M	M
Saginaw	MI	M	M	M
Duluth-Superior	MN	28.4	14.4	8.5
Minneapolis-St. Paul	MN	32.4	18.6	12.2
Rochester	MN	M	M	M
St. Cloud	MN	M	M	M
Kansas City	MO	43.6	32.3	27.8
Springfield	MO	M	M	M
St. Louis	MO	45.0	34.6	31.3
Jackson	MS	55.3	48.9	47.1
Billings	MT	M	M	M
Great Falls	MT	M	M	M
Lincoln	NB	M	M	M
Omaha	NB	40.0	28.0	22.6
Sioux City	NB	M	M	M
Asheville	NC	46.3	38.7	37.9
Charlotte-Gastonia	NC	M	M	M
Greensboro-Winston-Salem-Hig	NC	M	M	M
Raleigh-Durham	NC	50.0	41.2	40.5
Manchester	NH	M	M	M
Nashua	NH	M	M	M
Allentown-Bethlehem-Easton	NJ	M	M	M
Atlantic City	NJ	46.0	35.1	32.7
Jersey City	NJ	M	M	M
Long Branch-Asbury Park	NJ	M	M	M

Table 2 (Continued)

Monthly Winter Temperature

		30-Year Average Temperature (F)		
Urban Area	State	Nov	Dec	Jan
New Brunswick-Perth Amboy-Sa	NJ	M	M	M
Newark	NJ	46.2	34.5	31.4
Paterson-Clifton-Passaic	NJ	M	M	M
Philadelphia	NJ	M	M	M
Trenton	NJ	M	M	M
Vineland-Millvile-Bridgeton	NJ	M	M	M
Wilmington	NJ	M	M	M
Albuquerque	NM	44.5	36.2	35.2
Las Cruces	NM	M	M	M
Las Vegas	NV	53.3	45.2	44.2
Reno	NV	M	M	M
Albany-Schenectady-Troy	NY	39.6	25.9	21.5
Binghamton	NY	M	M	M
Buffalo	NY	39.8	27.9	23.7
Elmira	NY	M	M	M
Nassau-Suffolk	NY	M	M	M
New York	NY	47.4	35.5	32.2
Poughkeepsie	NY	M	M	M
Rochester	NY	40.5	28.3	24.0
Syracuse	NY	41.0	28.1	23.6
Utica-Rome	NY	M	M	M
Akron	OH	M	M	M
Canton	OH	M	M	M
Cincinnati	OH	44.6	34.4	32.1
Cleveland	OH	41.6	30.3	26.9
Columbus	OH	41.7	30.7	28.4
Dayton	OH	M	M	M
Hamilton-Middletown	OH	M	M	M
Springfield	OH	M	M	M
Steubenville-Weirton	OH	M	M	M
Toledo	OH	39.6	28.0	24.8
Youngstown-Warren	OH	M	M	M
Oklahoma City	OK	49.2	40.0	36.8
Tulsa	OK	49.4	39.8	36.6
Eugene-Springfield	OR	M	M	M
Portland	OR	45.3	40.7	38.1
Salem	OR	M	M	M
Erie	PA	M	M	M
Harrisburg	PA	43.8	32.6	30.1
Johnstown	PA	M	M	M
Lancaster	PA	M	M	M
Northeast Pennsylvania	PA	M	M	M
Pittsburg	PA	44.1	33.3	30.6
Reading	PA	M	M	M
York	PA	M	M	M
Providence-Warwick-Pawtucket	RI	43.3	31.5	28.4
Charleston-North Charleston	SC	56.3	49.3	48.6
Columbia	SC	M	M	M
Greenville-Spartanburg	SC	M	M	M
Chattanooga	TN	M	M	M
Johnson City-Kingsport-Brist	TN	M	M	M
Knoxville	TN	49.2	41.5	40.6
Memphis	TN	50.9	42.7	40.5
Nashville-Davidson	TN	48.4	40.4	38.3
Austin	TX	M	M	M
Beaumont-Port Arthur-Orange	TX	M	M	M
Corpus Christi	TX	M	M	M
Dallas-Fort Worth	TX	55.8	47.9	44.8
El Paso	TX	51.6	44.4	43.6
Galveston-Texas City	TX	M	M	M
Houston	TX	61.1	54.6	52.1
Odessa	TX	M	M	M
San Antonio	TX	59.7	53.2	50.7
Provo-Orem	UT	M	M	M
Salt Lake City-Ogden	UT	39.1	30.3	28.0
Newport News-Hampton	VA	M	M	M
Norfolk-Virginia Beach-Ports	VA	51.6	42.3	40.5
Richmond	VA	49.0	39.0	37.5
Roanoke	VA	46.7	37.4	36.4
Seattle-Everett	WA	44.6	40.5	38.2
Spokane	WA	35.5	29.0	25.4
Tacoma	WA	M	M	M
Yakima	WA	M	M	M
Appleton-Oshkosh	WI	M	M	M
Green Bay	WI	M	M	M
Jamesville-Beoit	WI	M	M	M
Madison	WI	34.7	21.9	16.8
Milwaukee	WI	36.5	24.2	19.4
Racine	WI	M	M	M
Charleston	WV	45.4	36.2	34.5
Wheeling	WV	M	M	M