

NDP-001/R1



CDIC NUMERIC DATA COLLECTION

Atmospheric CO₂ Concentrations—Mauna Loa Observatory, Hawaii 1958–1986

*Environmental Sciences Division at Oak Ridge National Laboratory
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NDP-001/R1

ATMOSPHERIC CO₂ CONCENTRATIONS - MAUNA LOA
OBSERVATORY, HAWAII 1958-1986

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Bacastow, R. B., C. D. Keeling, and T. P. Whorf. 1985. Seasonal amplitude increase in atmospheric CO₂ concentration at Mauna Loa, Hawaii, 1959-1982. Journal of Geophysical Research 90 (D6):10,529-10,540.

Keeling, C. D., R. B. Bacastow, A. E. Bainbridge, C. A. Ekdahl, Jr., P. R. Guenther, L. S. Waterman, and J. F. S. Chin. 1976. Atmospheric carbon dioxide variations at Mauna Loa Observatory, Hawaii. Tellus 28(6):538-551.

Keeling, C. D., R. B. Bacastow, and T. P. Whorf. 1982. Measurements of the concentration of carbon dioxide at Mauna Loa Observatory, Hawaii. pp. 377-385 in W.C. Clark, Ed., Carbon Dioxide Review: 1982, Oxford University Press, New York.

Keeling, C. D. 1983. The global carbon cycle: What we know and could know from atmospheric, biospheric, and oceanic observations. pp. II.3-II.62 in Proceedings: Carbon Dioxide Research Conference: Carbon Dioxide, Science and Consensus. CONF-820970, U.S. Department of Energy, Carbon Dioxide Research Division, Washington, D.C.

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Note: The values listed in the tables are preliminary data provided to the Carbon Dioxide Information Center for dissemination by Dr. C.D. Keeling.

CDIC NUMERIC DATA PACKAGE
ABSTRACT

1. NUMERIC DATA PACKAGE NAME

NDP-001/R1: Atmospheric CO₂ Concentrations - Mauna Loa
Observatory, Hawaii 1958-1986.

2. CONTRIBUTOR

C. D. Keeling
Scripps Institution of Oceanography
University of California
La Jolla, California 92093

3. CITATION OF THE PACKAGE

The Carbon Dioxide Information Center (CDIC) recommends the following citation for those citing or referencing this package:

Keeling, C.D. 1986. Atmospheric CO₂ concentrations - Mauna Loa
Observatory, Hawaii 1958-1986. NDP-001/R1, Carbon Dioxide
Information Center, Oak Ridge National Laboratory, Oak
Ridge, Tennessee.

4. HISTORICAL BACKGROUND INFORMATION

Daily atmospheric carbon dioxide (CO₂) concentrations have been measured since March 1958 at Mauna Loa Observatory, Hawaii. These measurements constitute the longest, continuous record of atmospheric CO₂ concentrations available in the world. The Mauna Loa Observatory site (19.5 N, 155.6 W, and elevation of 3400m) is one of the most favorable locations for measuring undisturbed air and minimizes the possible influence of vegetation or human activities on atmospheric CO₂ concentrations.

5. SOURCE AND SCOPE OF THE DATA

Since 1958, CO₂ concentrations at Mauna Loa Observatory have been obtained using a nondispersive, dual detector, infrared gas analyzer. Air samples are obtained from air intakes at the top of four 7m towers and one 27m tower. Four samples are collected every hour from air intakes on the taller tower and from one of the 7m towers. Air is sampled from one tower intake for 10 minutes, followed by a second tower intake for 10 minutes, and then from a reference gas for 10 minutes. Air flow through the intakes registers a voltage on the infrared gas analyzer which then records the concentrations on a strip chart recorder. (The air intakes are operating continuously but the air is shunted when not being analyzed by the infrared gas analyzer.)

Two intakes are used in the sampling to help detect possible contamination that would be shown by significant differences in CO₂ concentrations between the two intakes.

Those involved in the monitoring project have attempted to improve sampling techniques, reduce possible contamination sources, and adjust data to represent uncontaminated, true conditions throughout the twenty-eight year sampling period. The gas analyzer is calibrated by standardized CO₂-in-nitrogen reference gases twice daily. Flask samples are taken twice a month for comparison to the data recorded using the infrared gas analyzer. Data are scrutinized daily for possible contamination and archived on magnetic tape for further scrutiny and adjustment.

Daily, monthly, and annual averages are computed for the Mauna Loa data after deletion of contaminated samples and readjustment of the data. These averages have shown a steady rise in annual average concentration from 316 parts per million by volume (ppmv) in 1959 to 346 ppmv in 1986.

6. APPLICATIONS OF THE DATA

The continuous collection of atmospheric CO₂ concentrations at Mauna Loa Observatory constitutes the longest, continuous record of CO₂ concentrations available. This record provides scientific documentation for the degree of change in atmospheric CO₂ concentrations over the past 28 years. The Mauna Loa data are extremely useful to modelers attempting to project future CO₂ concentrations, climate scenarios, and vegetation responses to increased levels of CO₂. The Mauna Loa record is considered to be a reliable indicator of the regional trend in the concentration of atmospheric CO₂ in the middle layers of the troposphere. The steady rise in atmospheric CO₂ concentration shown by this record has been widely interpreted as a global trend.

7. LIMITATIONS AND RESTRICTIONS OF THE DATA

Possible ambient error sources at Mauna Loa include volcanic, vegetative, and man-made effects (e.g., vehicular traffic, and industry). Daily peaks in measured concentrations occur because of complex wind currents. Downslope winds often transport CO₂ from distant volcanic vents causing elevations in measured CO₂ concentrations. Upslope winds during afternoon hours are often low in CO₂ because of photosynthetic depletion occurring in outlying sugarcane fields and forests. Vehicular traffic problems (since corrected) caused exaggerated elevations in 1971. Despite these sources of error and contamination, considerable effort has been made to alleviate and detect these sources.

The imprecision in measuring reference gases approaches 0.1 ppmv and is rarely greater than 0.2 ppmv. However, agreement differences less than 0.5 ppmv between flasks and analyzers or between different analyzers on a short-term basis are difficult to obtain. Monthly averages from May 1964 to January 1969 may be

in error by as much as 1.0 ppmv; but since 1970, systematic error probably does not exceed 0.2 ppmv. The precision of monthly averages is approximately 0.5 ppmv. In summary, monthly and annual averages of the Mauna Loa data are statistically robust and serve as a precise, long-term record of atmospheric CO₂ concentrations.

8. KEYWORDS

MONITORING, CONTINUOUS, CARBON DIOXIDE CONCENTRATIONS, SECULAR TRENDS, SEASONAL VARIATIONS, SPATIAL VARIATIONS.

9. CONTENTS OF THE DATA PACKAGE

The package contains reprints of pertinent literature (a), four tables listing CO₂ concentrations, and four graphs illustrating the Mauna Loa atmospheric CO₂ concentration data. Magnetic tapes are available that include a descriptive file (page 7), a FORTRAN data retrieval program to read and list the data (page 8), and four data files containing Mauna Loa atmospheric CO₂ concentrations. The four files contain two variables, year (IYEAR) and CO₂ concentration (CONC), which are formatted as follows:

```
70          READ(N1,70)IYEAR(I),(CONC(I,J),J=1,12)
          FORMAT(I4,1X,12F6.2)
```

a. Literature included in the package:

- Bacastow, R. B. and C. D. Keeling. 1981. Atmospheric carbon dioxide concentration and the observed airborne fraction. pp. 103-112 in B. Bolin, Ed., Carbon Cycle Modelling, SCOPE 16. John Wiley and Sons, New York.
- Bacastow, R. B., C. D. Keeling, and T. P. Whorf. 1985. Seasonal amplitude increase in atmospheric CO₂ concentration at Mauna Loa, Hawaii, 1959-1982. Journal of Geophysical Research 90 (D6):10,529-10,540.
- Keeling, C. D., R. B. Bacastow, A. E. Bainbridge, C. A. Ekdahl, Jr., P. R. Guenther, L. S. Waterman, and J. F. S. Chin. 1976. Atmospheric carbon dioxide variations at Mauna Loa Observatory, Hawaii. Tellus 28(6):538-551.
- Keeling, C. D., R. B. Bacastow, and T. P. Whorf. 1982. Measurements of the concentration of carbon dioxide at Mauna Loa Observatory, Hawaii. pp. 377-385 in W.C. Clark, Ed., Carbon Dioxide Review: 1982. Oxford University Press, New York.
- Keeling, C. D. 1983. The global carbon cycle: What we know and

could know from atmospheric, biospheric, and oceanic observations. pp. II.3-II.62 in Proceedings: Carbon Dioxide Research Conference: Carbon Dioxide, Science and Consensus. CONF-820970, U.S. Department of Energy, Carbon Dioxide Research Division, Washington, D.C.

b. Background information

Bacastow, R. B. 1979. Dip in the atmospheric CO₂ level during the mid-1960's, Journal of Geophysical Research 80:3109-3114.

Keeling, C.D., A.F. Carter, and W.G. Mook. 1984. Seasonal, latitudinal, and secular variations in the abundance and isotopic ratios of atmospheric CO₂, 2. Results from oceanographic cruises in the tropical Pacific Ocean. Journal of Geophysical Research 89:4615-4628.

Pales, J. C. and C. D. Keeling. 1965. The concentration of atmospheric carbon dioxide in Hawaii. Journal of Geophysical Research 70(24):6058-6076.

Pearman, G. I. and P. Hyson. 1981. The annual variation of atmospheric CO₂ concentration observed in the Northern Hemisphere. Journal of Geophysical Research 86:9839-9843.

10. HOW TO OBTAIN THE PACKAGE

This document contains listings of the atmospheric CO₂ concentrations from Mauna Loa Observatory, Hawaii for the years 1958-1986. These data are also available on 9-track, magnetic tapes from CDIC. Requests for magnetic tapes should include any specific instructions for transmitting the data required by the user to access the data. Requests should be addressed to the:

Carbon Dioxide Information Center
Oak Ridge National Laboratory
Post Office Box X
Oak Ridge, Tennessee 37831-6050
Telephone (615) 574-0390
FTS 624-0390

11. DATE OF ABSTRACT

September 1986

Each numeric data package (NDP) assembled by CDIC goes through a process of assuring the quality of the data. This process includes review(s) by the contributors of the data to ensure that, in compiling the data, CDIC does not misrepresent or inaccurately describe the data. NDPs are not distributed without the written consent of the contributors.

MAGNETIC TAPE CONTENTS

Description	Mode	Logical Records	DCB Parameters	
1. General Descriptive Information File	EBCDIC	36	FB	10800 80
2. FORTRAN Data Retrieval Code	EBCDIC	34	FB	10800 80
3. Mauna Loa Average Monthly Atmospheric CO ₂ Concentrations (1958 - 1986)	EBCDIC	29	FB	10800 80
4. Mauna Loa Average Monthly Atmospheric CO ₂ Concentrations with the Seasonal Effects Removed (1958 - 1986)	EBCDIC	29	FB	10800 80
5. Mauna Loa Fitted Function Average Monthly Atmospheric CO ₂ Concentrations Adjusted to the 15th of the Month (1958 - 1986)	EBCDIC	29	FB	10800 80
6. Mauna Loa Fitted Function Average Monthly Atmospheric CO ₂ Concentrations Adjusted to the 15th of the Month (1958 - 1986)	EBCDIC	29	FB	10800 80

Total Records 286

MAGNETIC TAPE DESCRIPTIVE FILE

DATASET TITLE: Atmospheric CO₂ Concentrations - Mauna Loa Observatory, Hawaii 1958-1986.

AUTHOR: C. D. Keeling
Scripps Institute of Oceanography
University of California
La Jolla, CA 92093

SCOPE OF THE DATA: The measurements constitute the longest daily record of atmospheric CO₂ concentrations obtained anywhere in the world. The monthly-average mole fraction of CO₂ in water-vapor-free air is given from 1958 through October, 1986, except for a few interruptions.

DATA FORMAT: The data are atmospheric concentrations of carbon dioxide at Mauna Loa Observatory, Hawaii, in ppmv. Four sets of data are provided, each differing in the way they were treated and adjusted by the author. Two variables are defined; IYEAR and CONC. These variables are read by the following format: FORMAT (I4,1X,12F6.2). The year by concentration output is formatted as: FORMAT (1H,I4,2X,12F7.2). Missing values are represented in the data sets by 0.00.

REFERENCES

- Bacastow, R. B., and C. D. Keeling. 1981. Atmospheric carbon dioxide concentration and the observed airborne fraction. pp. 103-112 in B. Bolin, Ed., Carbon Cycle Modelling, SCOPE 16. John Wiley and Sons, New York.
- Bacastow, R. B., C. D. Keeling, and T. P. Whorf. 1985. Seasonal amplitude increase in atmospheric CO₂ concentration at Mauna Loa, Hawaii, 1959-1982. Journal of Geophysical Research 90 (D6):10,529-10,540.
- Keeling, C. D., R. B. Bacastow, A. E. Bainbridge, C. A. Ekdahl, Jr., P. R. Guenther, L. S. Waterman, and J. F. S. Chin. 1976. Atmospheric carbon dioxide variations at Mauna Loa Observatory, Hawaii. Tellus 28(6): 538-551.
- Keeling, C. D., R. B. Bacastow, and T. P. Whorf. 1982. Measurements of the concentration of carbon dioxide at Mauna Loa Observatory, Hawaii. pp. 377-385 in W. C. Clark, Ed., Carbon Dioxide Review: 1982. Oxford University Press, New York.
- Keeling, C. D. 1983. The global carbon cycle: What we know and could know from atmospheric, biospheric and oceanic observations. pp. II.3-II.62 in Proceedings: Carbon Dioxide Research Conference: Carbon Dioxide, Science and Consensus. CONF-820970, U. S. Department of Energy, Carbon Dioxide Research Division, Washington, D. C.

FORTRAN IV DATA RETRIEVAL PROGRAM LISTING

```

C THIS FORTRAN PROGRAM WILL READ AND PRINT OUT ANY OF THE 4 DATA FILES
C
C   INPUT UNIT = 12
C
C   OUTPUT UNIT = 6
      DIMENSION IYEAR(30),CONC(30,12)
      K=0
      DO 1 I=1,30
        READ(12,100,END=99) IYEAR(I),(CONC(I,J),J=1,12)
100     FORMAT(I4,1X,12F6.2)
        K=K+1
1       CONTINUE
99      CONTINUE
        WRITE(6,200)
200     FORMAT(1H1,'YEAR   JAN.   FEB.   MAR.   APR.   MAY   ',
1       'JUN.   JUL.   AUG.   SEP.   OCT.   NOV.   DEC.',/1HO)
        DO 2 I=1,K
          WRITE(6,250) IYEAR(I),(CONC(I,J),J=1,12)
250     FORMAT(1H ,I4,2X,12F7.2)
2       CONTINUE
        STOP
        END

```

TABLE 1. Average monthly and annual atmospheric CO₂ concentrations at Mauna Loa Observatory, Hawaii. Monthly concentrations for the years 1958-1984 have been adjusted to the 15th of each month but monthly values for 1986 have not been adjusted to the 15th of the month but instead are the means of the daily averages for that month (sum of the daily averages/# of days in the month when data was recorded). The concentrations are expressed in parts per million by volume (ppmv) and missing values or values which are not available are represented by 0.00. These data are preliminary data which have been provided by Dr. C.D. Keeling.

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	AVE.
1958	0.00	0.00	316.01	317.60	317.84	0.00	316.08	315.16	313.41	0.00	313.51	314.75	0.00
1959	315.58	316.39	316.79	317.82	318.39	318.22	316.68	315.01	314.02	313.55	315.02	315.75	316.10
1960	316.52	317.10	317.79	319.22	320.08	319.70	318.27	315.99	314.24	314.05	315.05	316.23	317.02
1961	316.92	317.76	318.54	319.49	320.64	319.85	318.70	316.96	315.17	315.47	316.19	317.17	317.74
1962	318.12	318.72	319.79	320.68	321.28	320.89	319.79	317.56	316.46	315.59	316.85	317.87	318.63
1963	318.87	319.25	320.13	321.49	322.34	321.62	319.85	317.87	316.36	316.24	317.13	318.46	319.13
1964	319.57	0.00	0.00	0.00	322.20	321.90	320.42	318.60	316.73	317.15	317.94	318.91	0.00
1965	319.73	320.78	321.23	322.49	322.59	322.35	321.61	319.24	318.23	317.76	319.36	319.50	320.41
1966	320.35	321.40	322.22	323.45	323.80	323.50	322.16	320.09	318.26	317.66	319.47	320.70	321.09
1967	322.06	322.23	322.78	324.10	324.63	323.79	322.34	320.73	319.00	318.99	320.41	321.68	321.89
1968	322.30	322.89	323.59	324.65	325.30	325.15	323.88	321.80	319.99	319.86	320.88	322.36	322.72
1969	323.59	324.23	325.34	326.33	327.03	326.24	325.39	323.16	321.87	321.31	322.34	323.74	324.21
1970	324.61	325.58	326.55	327.81	327.82	327.53	326.29	324.66	323.12	323.09	324.01	325.10	325.51
1971	326.12	326.62	327.16	327.94	329.15	328.79	327.53	325.65	323.60	323.78	325.13	326.26	326.48
1972	326.93	327.84	327.96	329.93	330.25	329.24	328.13	326.42	324.97	325.29	326.56	327.73	327.60
1973	328.73	329.70	330.46	331.70	332.66	332.22	331.02	329.39	327.58	327.27	328.30	328.81	329.82
1974	329.44	330.89	331.62	332.85	333.29	332.44	331.35	329.58	327.58	327.55	328.56	329.73	330.41
1975	330.45	330.98	331.63	332.88	333.63	333.53	331.90	330.08	328.59	328.31	329.44	330.64	331.00
1976	331.62	332.45	333.36	334.46	334.84	334.29	333.04	330.88	329.23	328.83	330.18	331.50	332.06
1977	332.80	333.22	334.54	335.82	336.45	335.97	334.65	332.40	331.28	330.73	332.05	333.54	333.62
1978	334.65	335.06	336.32	337.39	337.66	337.56	336.24	334.39	332.43	332.22	333.61	334.78	335.19
1979	335.88	336.43	337.61	338.53	339.06	338.92	337.39	335.72	333.64	333.65	335.07	336.53	336.54
1980	337.82	338.19	339.89	340.56	341.22	340.92	339.26	337.27	335.66	335.54	336.71	337.79	338.40
1981	338.79	340.06	340.93	342.02	342.65	341.80	340.01	337.94	336.17	336.28	337.76	339.05	339.46
1982	340.18	341.04	342.16	343.01	343.64	342.91	341.72	339.52	337.75	337.68	339.14	340.37	340.76
1983	341.32	342.45	343.05	344.91	345.77	345.30	343.98	342.41	339.89	340.03	341.19	342.87	342.76
1984	343.74	344.55	345.28	347.00	347.37	346.74	345.36	343.19	340.97	341.20	342.76	343.96	344.34
1985	344.79	345.79	347.16	348.06	348.63	347.89	346.24	344.45	342.83	342.54	343.95	345.40	345.64
1986	346.12	346.85	347.72	349.30	349.87	349.07	347.54	345.47	344.50	343.91	0.00	0.00	0.00

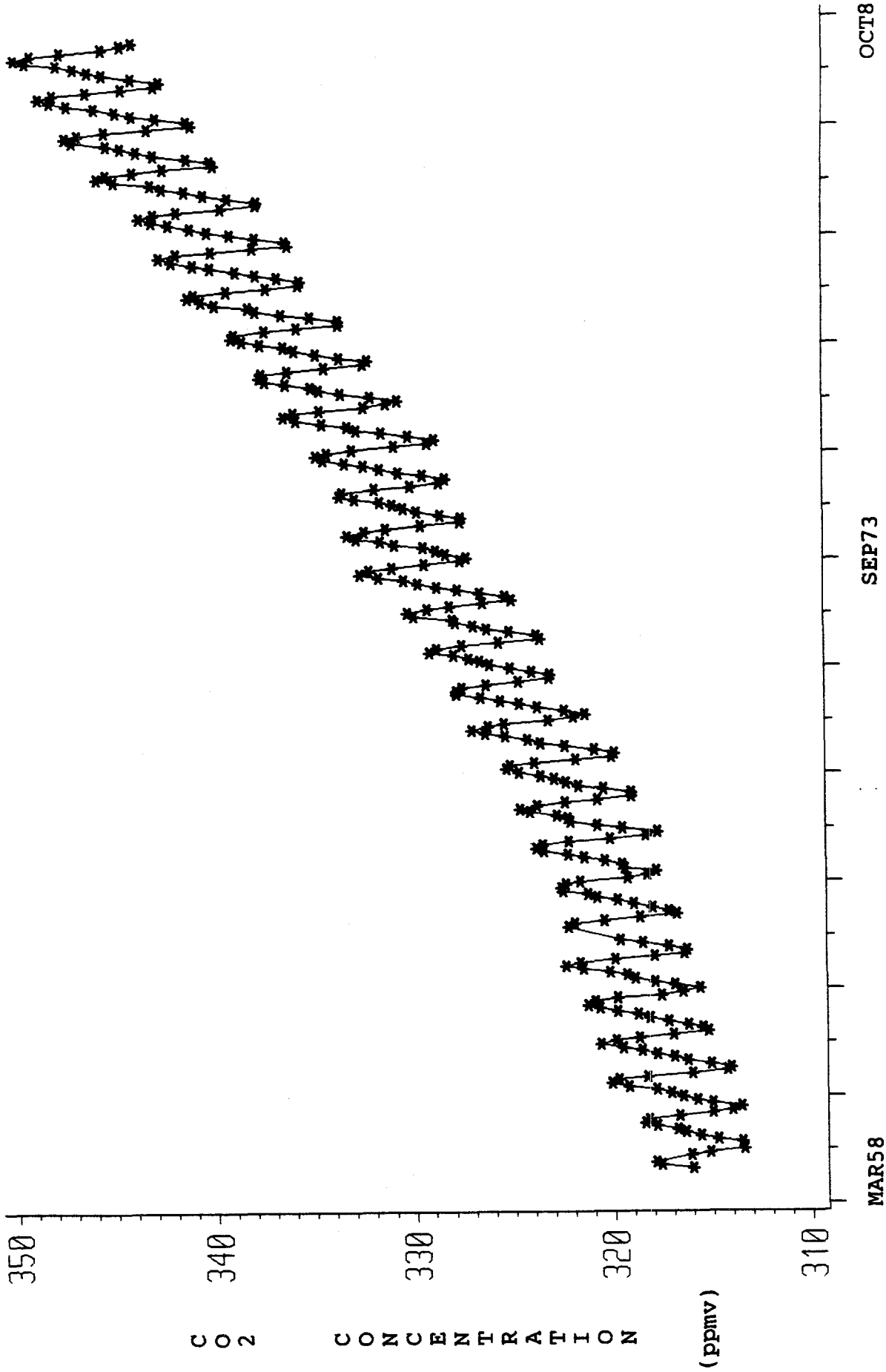


FIGURE 1. Mauna Loa monthly atmospheric CO2 concentrations. The points represent monthly average CO2 concentrations expressed in parts per million by volume (ppmv). Values through December 1985 are adjusted to the 15th of the month. Values for 1986 have not been adjusted to the 15th of the month and represent the mean of the daily averages during a given month (sum of daily averages/# of days in the month). The line drawn through one point to the next and has not had any

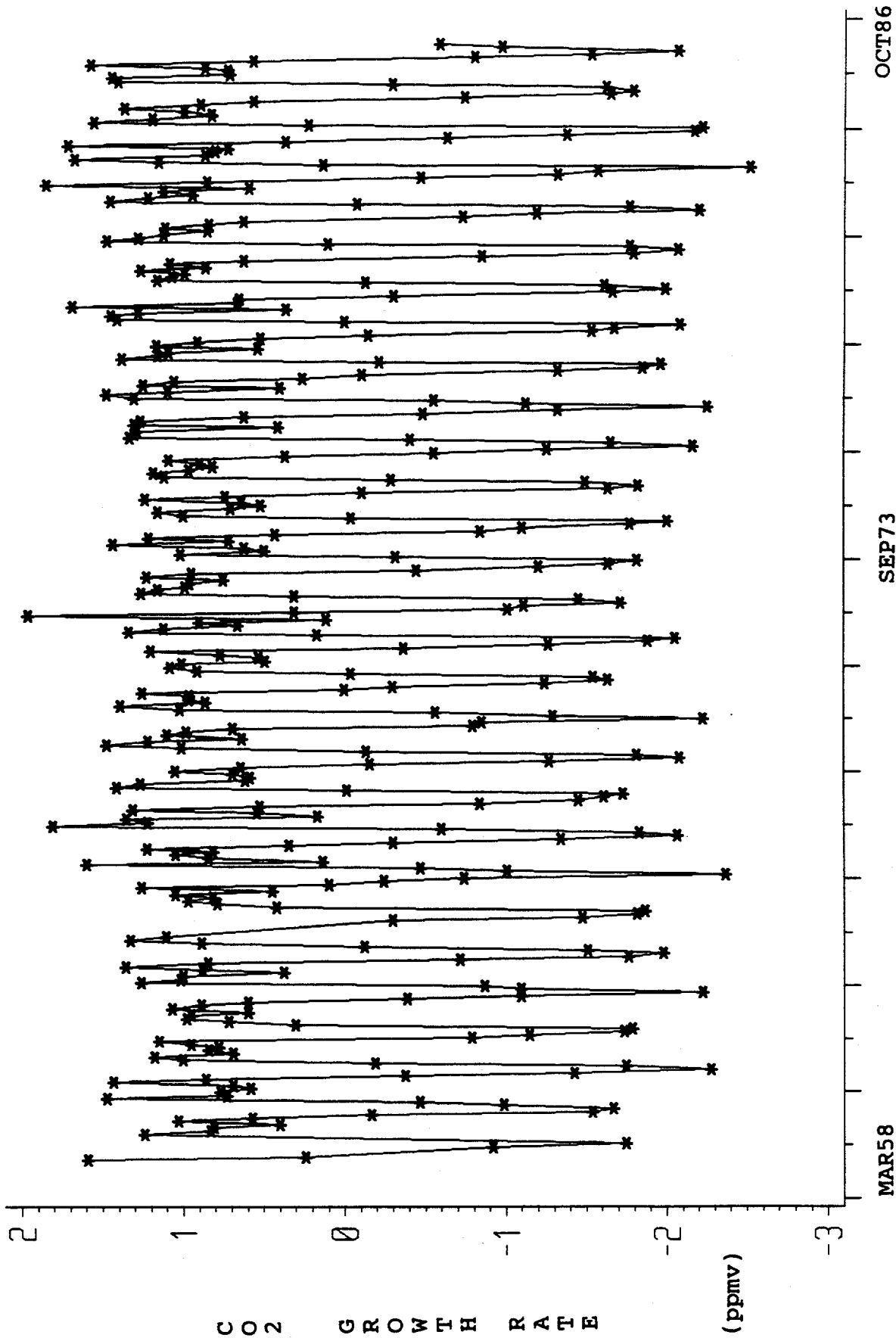


FIGURE 2. Mauna Loa monthly atmospheric CO2 concentration growth rates. The points represent the monthly atmospheric CO2 concentration growth rates or difference between two successive monthly concentrations (value = [FEB81] - [JAN81]) expressed in parts per million by volume (ppmv). The line drawn through the points simply connects one point to the next and has not had any spline smoothing or harmonic functions applied to it.

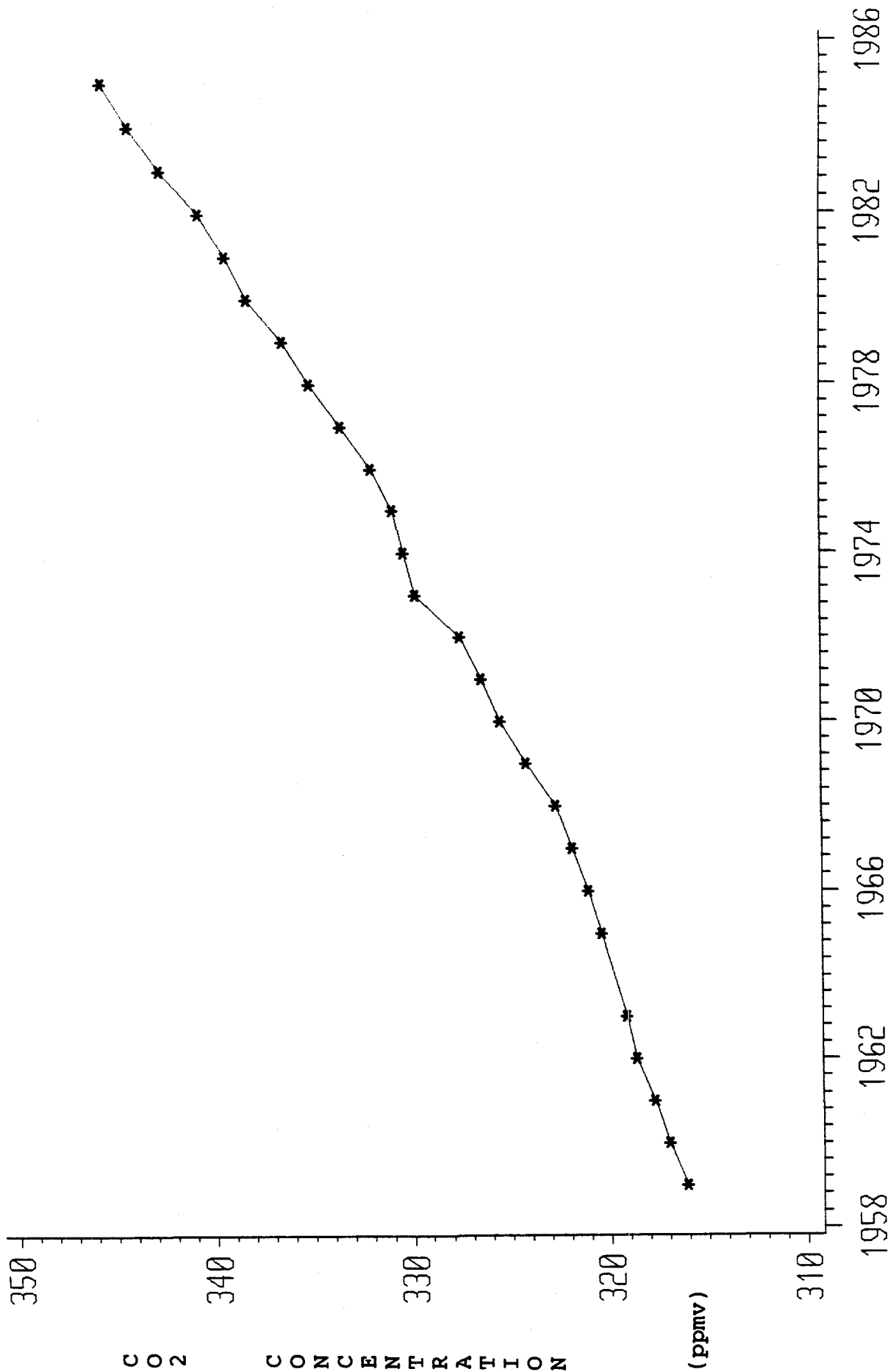


FIGURE 3. Mauna Loa atmospheric CO2 concentration annual averages. The points represent the annual atmospheric CO2 concentrations or difference between two successive yearly concentrations expressed in parts per million by volume (ppmv). The line drawn through the points simply connects one point to the next and has not had any spline smoothing or harmonic functions applied to it.

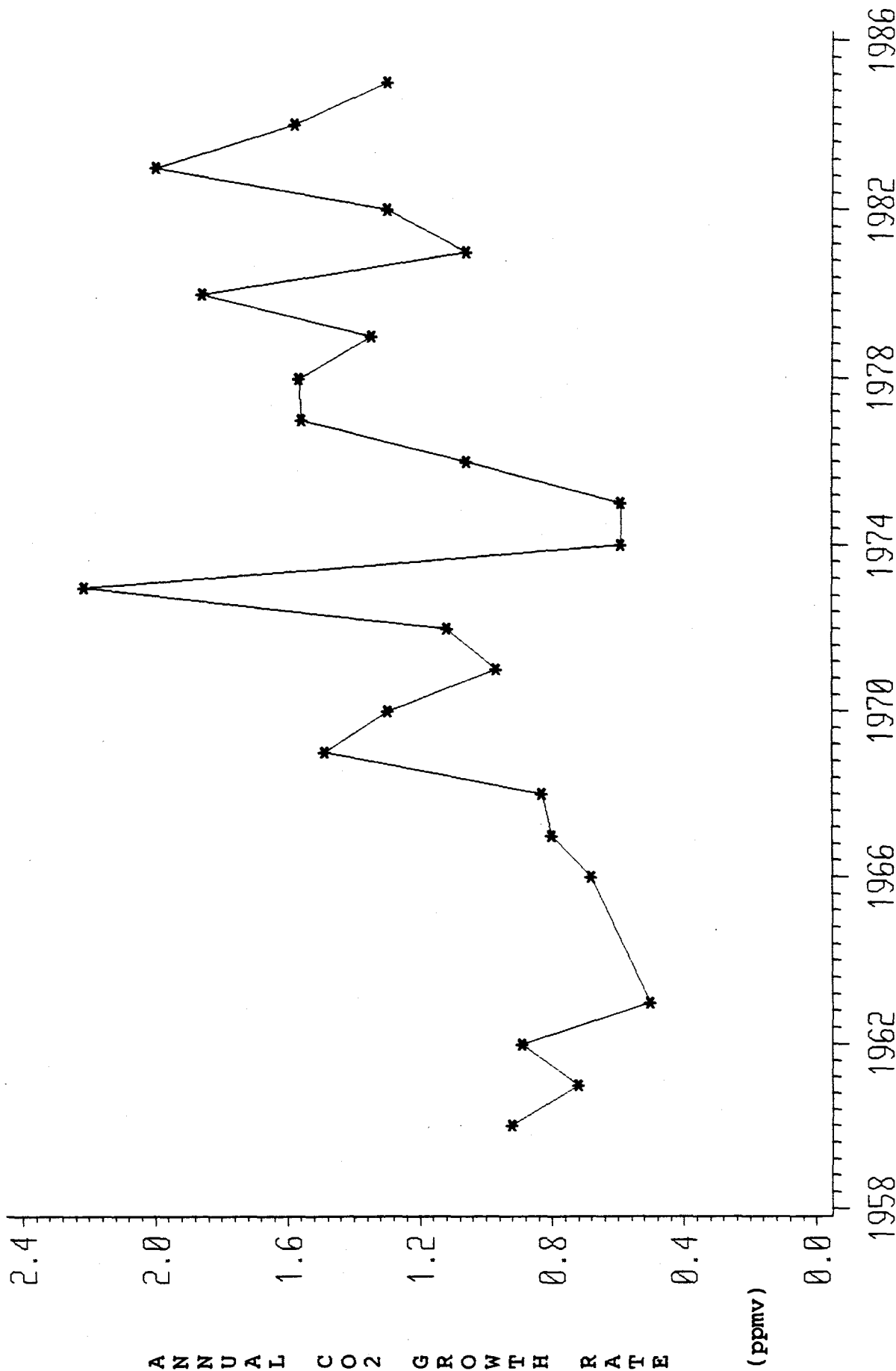


FIGURE 4. Mauna Loa yearly atmospheric CO2 concentration growth rates. The points represent the annual atmospheric CO2 concentration growth rates or difference between two successive yearly concentrations (value = [1982 CO2] - [1981 CO2]) expressed in parts per million by volume (ppmv). The line drawn through the points simply connects one point to the next and has not had any spline smoothing or harmonic functions applied to it.

TABLE 2. Average monthly atmospheric CO₂ concentrations at Mauna Loa Observatory, Hawaii with the seasonal effects removed. The concentrations are expressed in ppmv and missing values are represented by 0.0. These data are preliminary data which have been provided by Dr. C.D. Keeling.

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
1958	0.0	0.0	314.82	315.47	315.23	0.0	315.27	316.15	316.03	0.0	315.36	315.60
1959	315.70	315.88	315.59	315.68	315.76	316.14	315.86	316.02	316.66	316.42	316.88	316.60
1960	316.64	316.58	316.56	317.03	317.43	317.62	317.47	317.03	316.92	316.93	316.92	317.09
1961	317.04	317.23	317.33	317.31	317.97	317.73	317.87	317.98	317.85	318.39	318.07	318.04
1962	318.24	318.19	318.56	318.48	318.59	318.76	318.96	318.59	319.17	318.53	318.75	318.74
1963	318.99	318.72	318.90	319.27	319.62	319.47	319.01	318.91	319.09	319.20	319.05	319.34
1964	319.70	0.0	0.0	0.0	319.47	319.75	319.60	319.67	319.49	320.13	319.86	319.80
1965	319.85	320.24	319.98	320.24	319.83	320.17	320.77	320.29	321.00	320.76	321.30	320.39
1966	320.48	320.85	320.96	321.18	321.03	321.30	321.30	321.15	321.06	320.69	321.43	321.60
1967	322.18	321.69	321.51	321.81	321.83	321.57	321.48	321.80	321.82	322.04	322.39	322.58
1968	322.43	322.34	322.28	322.33	322.48	322.93	323.03	322.90	322.83	322.93	322.87	323.27
1969	323.72	323.67	324.05	324.01	324.19	323.99	324.51	324.24	324.73	324.41	324.35	324.66
1970	324.73	325.02	325.25	325.48	324.96	325.26	325.40	325.76	326.00	326.21	326.03	326.03
1971	326.25	326.06	325.85	325.59	326.27	326.50	326.64	326.76	326.50	326.92	327.16	327.19
1972	327.06	327.27	326.62	327.53	327.34	326.96	327.26	327.56	327.90	328.45	328.61	328.66
1973	328.86	329.13	329.13	329.30	329.74	329.90	330.12	330.51	330.52	330.46	330.36	329.75
1974	329.58	330.32	330.28	330.44	330.34	330.10	330.44	330.70	330.55	330.77	330.64	330.68
1975	330.58	330.39	330.28	330.45	330.66	331.18	330.98	331.22	331.57	331.54	331.54	331.60
1976	331.76	331.87	331.97	331.99	331.85	331.94	332.14	322.04	332.25	332.08	332.29	332.47
1977	332.93	332.63	333.17	333.36	333.44	333.59	333.72	333.55	334.31	334.02	334.18	334.52
1978	334.78	334.47	334.94	334.91	334.63	335.16	335.30	335.55	335.48	335.53	335.76	335.76
1979	336.02	335.83	336.22	336.04	336.01	336.50	336.44	336.88	336.71	336.98	337.23	337.51
1980	337.96	337.59	338.47	338.03	338.15	338.50	338.34	338.47	338.76	338.89	338.87	338.78
1981	338.93	339.46	339.52	339.49	339.56	339.34	339.05	339.12	339.28	339.66	339.95	340.05
1982	340.32	340.43	340.74	340.46	340.52	340.44	340.75	340.71	340.88	341.08	341.34	341.38
1983	341.47	341.84	341.62	342.35	342.63	342.81	343.01	343.60	343.04	343.45	343.40	343.88
1984	343.88	343.94	343.82	344.40	344.21	344.25	344.41	344.43	344.16	344.64	344.99	344.98
1985	344.94	345.17	345.71	345.46	345.45	345.37	345.26	345.66	346.03	346.00	346.19	346.43

TABLE 3. Fitted function average monthly atmospheric CO₂ concentrations at Mauna Loa Observatory, Hawaii adjusted to the 15th of the month. The concentrations are expressed in ppmv and missing values are represented by 0.0. These data are preliminary data which have been provided by Dr. C.D. Keeling.

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
1958	0.0	0.0	316.39	317.40	317.94	317.47	316.27	314.52	312.94	312.75	313.78	314.80
1959	315.57	316.24	316.98	317.99	318.55	318.10	316.93	315.22	313.69	313.58	314.70	315.80
1960	316.63	317.35	318.15	319.19	319.72	319.20	317.93	316.09	314.43	314.22	315.25	316.29
1961	317.08	317.80	318.57	319.64	320.24	319.79	318.60	316.86	315.28	315.15	316.26	317.36
1962	318.18	318.91	319.68	320.73	321.29	320.80	319.55	317.73	316.08	315.88	316.95	318.01
1963	318.81	319.51	320.27	321.30	321.84	321.31	320.01	318.15	316.47	316.27	317.35	318.43
1964	319.22	319.92	320.70	321.73	322.25	321.71	320.43	318.60	316.96	316.80	317.92	319.02
1965	319.84	320.57	321.35	322.42	323.01	322.54	321.30	319.49	317.85	317.69	318.80	319.90
1966	320.71	321.43	322.20	323.26	323.82	323.29	321.98	320.10	318.42	318.24	319.39	320.53
1967	321.37	322.11	322.88	323.94	324.50	323.97	322.67	320.81	319.15	319.01	320.18	321.34
1968	322.19	322.94	323.76	324.86	325.43	324.92	323.63	321.78	320.13	320.02	321.23	322.45
1969	323.39	324.23	325.10	326.26	326.90	326.42	325.15	323.27	321.59	321.43	322.62	323.80
1970	324.70	325.51	326.36	327.52	328.16	327.70	326.45	324.59	322.92	322.77	323.94	325.09
1971	325.93	326.67	327.46	328.57	329.18	328.69	327.40	325.51	323.82	323.66	324.86	326.04
1972	326.90	327.65	328.49	329.62	330.21	329.71	328.44	326.62	325.03	325.02	326.37	327.70
1973	328.74	329.67	330.63	331.90	332.62	332.19	330.92	329.00	327.25	327.03	328.16	329.27
1974	330.08	330.81	331.60	332.70	333.28	332.72	331.34	329.34	327.54	327.31	328.46	329.59
1975	330.42	331.16	331.98	333.13	333.77	333.28	331.97	330.05	328.33	328.19	329.44	330.67
1976	331.57	332.36	333.22	334.36	334.94	334.36	332.97	330.98	329.21	329.07	330.35	331.62
1977	332.61	333.50	334.43	335.69	336.40	335.94	334.64	332.72	330.99	330.87	332.17	333.46
1978	334.43	335.29	336.19	337.40	338.07	337.56	336.21	334.23	332.45	332.29	333.55	334.80
1979	335.74	336.57	337.45	338.66	339.34	338.85	337.52	335.57	333.84	333.76	335.12	336.48
1980	337.52	338.43	339.41	340.66	341.32	340.79	339.41	337.40	335.60	335.46	336.74	338.00
1981	338.94	339.77	340.64	341.81	342.42	341.82	340.37	338.30	336.47	336.32	337.65	338.98
1982	339.98	340.85	341.76	342.99	343.65	343.10	341.69	339.65	337.83	337.70	339.05	340.42
1983	341.48	342.44	343.46	344.83	345.63	345.20	343.88	341.90	340.12	340.00	341.35	342.68
1984	343.66	344.53	345.47	346.70	347.34	346.59	345.31	343.23	341.38	341.25	342.76	343.92
1985	344.92	345.80	346.72	347.97	348.64	348.07	346.63	344.54	342.68	342.53	343.89	345.25

TABLE 4. Fitted function average monthly atmospheric CO₂ concentrations at Mauna Loa Observatory, Hawaii adjusted to the 15th of the month and with seasonal effects removed. The concentrations are expressed in ppmv and missing values are represented by 0.0. These data are preliminary data which have been provided by Dr. C.D. Keeling.

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
1958	0.0	0.0	315.21	315.27	315.34	315.40	315.46	315.52	315.56	315.59	315.62	315.65
1959	315.69	315.73	315.78	315.84	315.92	316.01	316.11	316.22	316.34	316.45	316.55	316.65
1960	316.75	316.84	316.92	317.01	317.07	317.12	317.13	317.12	317.11	317.10	317.11	317.14
1961	317.20	317.27	317.36	317.46	317.57	317.68	317.78	317.88	317.97	318.06	318.14	318.22
1962	318.30	318.39	318.46	318.53	318.60	318.66	318.71	318.75	318.79	318.82	318.85	318.89
1963	318.93	318.98	319.03	319.08	319.13	319.16	319.17	319.18	319.20	319.23	319.26	319.30
1964	319.35	319.39	319.43	319.48	319.52	319.56	319.61	319.67	319.73	319.78	319.84	319.90
1965	319.96	320.03	320.10	320.17	320.26	320.35	320.45	320.54	320.62	320.69	320.75	320.79
1966	320.84	320.89	320.94	320.99	321.04	321.08	321.12	321.16	321.21	321.27	321.35	321.43
1967	321.50	321.56	321.61	321.65	321.70	321.75	321.81	321.88	321.97	322.06	322.16	322.24
1968	322.32	322.39	322.46	322.53	322.61	322.70	322.79	322.88	322.98	323.09	323.22	323.36
1969	323.52	323.67	323.81	323.94	324.06	324.17	324.27	324.36	324.45	324.53	324.62	324.72
1970	324.83	324.95	325.06	325.18	325.30	325.43	325.56	325.69	325.80	325.89	325.97	326.02
1971	326.06	326.10	326.15	326.21	326.30	326.40	326.51	326.61	326.72	326.81	326.90	326.97
1972	327.03	327.09	327.15	327.22	327.31	327.43	327.57	327.75	327.96	328.18	328.41	328.64
1973	328.87	329.10	329.30	329.51	329.70	329.87	330.01	330.12	330.19	330.22	330.22	330.22
1974	330.22	330.23	330.26	330.29	330.33	330.38	330.43	330.47	330.50	330.53	330.54	330.55
1975	330.56	330.58	330.63	330.70	330.80	330.93	331.05	331.19	331.32	331.43	331.54	331.63
1976	331.71	331.78	331.84	331.89	331.95	332.01	332.07	332.14	332.23	332.33	332.45	332.59
1977	332.74	332.91	333.06	333.23	333.39	333.56	333.71	333.87	334.02	334.16	334.30	334.43
1978	334.57	334.70	334.81	334.93	335.04	335.16	335.28	335.39	335.49	335.59	335.69	335.78
1979	335.87	335.97	336.06	336.17	336.29	336.43	336.57	336.73	336.91	337.09	337.28	337.47
1980	337.66	337.83	337.98	338.13	338.25	338.37	338.48	338.60	338.71	338.81	338.90	338.99
1981	339.08	339.16	339.23	339.28	339.32	339.36	339.41	339.48	339.58	339.70	339.84	339.98
1982	340.12	340.24	340.35	340.45	340.54	340.63	340.73	340.84	340.96	341.10	341.26	341.43
1983	341.62	341.83	342.03	342.26	342.49	342.71	342.91	343.10	343.27	343.42	343.57	343.69
1984	343.81	343.91	344.00	344.10	344.18	344.27	344.37	344.46	344.57	344.69	344.81	344.94
1985	345.06	345.18	345.28	345.37	345.46	345.55	345.64	345.75	345.88	346.00	346.14	346.27

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