TRENDS '90

A Compendium of Data on Global Change

ORNL/CDIAC--36

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Contents

ATMOSPHERIC CARBON DIOXIDE CONCENTRATIONS

Historical Record—Atmospheric CO₂ from Ice Cores

Modern Record
U.S. Monitoring Programs and Stations
Scripps Institution of Oceanography

National Oceanic and Atmospheric Administration,
Climate Monitoring and Diagnostics Laboratory
Continuous Monitoring Program

National Oceanic and Atmospheric Administration,
Climate Monitoring and Diagnostics Laboratory
Flask Sampling Program

Spanish Monitoring Station

Italian Monitoring Station

Australian Monitoring Station

Canadian Monitoring Stations

Federal Republic of Germany Monitoring Stations

Contents (cont'd)

GLOBAL AND NATIONAL CO_2 EMISSIONS FROM FOSSIL FUEL BURNING, CEMENT PRODUCTION, AND GAS FLARING

ATMOSPHERIC METHANE CONCENTRATIONS

ATMOSPHERIC METHANE CONCENTRATIONS (cont'd)

Historical Record – Atmospheric CH_4 from Ice Cores

Modern Record

Oregon Graduate Institute of Science and Technology

National Oceanic and Atmospheric Administration, Climate Monitoring and Diagnostics Laboratory Flask Sampling Program

Contents (cont'd)

TEMPERATURE RECORDS

Central Region (cont'd)

East Region

APPENDIXES

Appendix A

Appendix B

Appendix C

Abstract

Boden, T. A., P. Kanciruk, and M. P. Farrell. 1990. TRENDS '90: A Compendium of Data on Global Change. ORNL/CDIAC-36. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 286 pages.

This document is a source of frequently used global change data. This first issue includes estimates for global and national CO_2 emissions from the burning of fossil fuels and from the production of cement, historical and modern records of atmospheric CO_2 and methane concentrations, and several long-term temperature records. Included are tabular and graphical presentations of the data, discussions of trends in the data, and references to publications that provide further information. Data are presented in a two-page format, each dealing with a different data set.

All data are available in digital form from the Carbon Dioxide Information Analysis Center.

Keywords: Air pollution, ambient temperature, atmospheric chemistry, carbon cycle, carbon dioxide, climates, earth atmosphere, geophysical surveys, global aspects, greenhouse effect, meteorology, methane, monitoring regional analysis, temperature monitoring, and temperature surveys.

Foreword

One of the goals of the Carbon Dioxide Information Analysis Center (CDIAC) at Oak Ridge National Laboratory is to provide ready access to data and information pertinent to global changes. CDIAC has attempted to achieve this goal by providing reports, numeric data packages (NDPs), computer model packages (CMPs), and other information center products and services. To date, these activities have been well received and frequently used by a diverse international audience. This new document, *TRENDS '90*, is our effort to widely distribute data critical to climate change issues.

TRENDS '90 is intended to provide a quick reference for important data. The presentation of the data in *TRENDS '90* differs from that in traditional CDIAC NDPs. For *TRENDS '90*, we provide a graphical presentation of data accompanied by an explanation of current trends. *TRENDS '90* also provides critical background information, references, and brief tabular summaries of the data. Detailed NDPs for most data sets cited in *TRENDS '90* can be obtained from CDIAC.

We intend to publish *TRENDS* annually. For some data bases compiled by CDIAC (e.g., CO_2 emissions), *TRENDS* will be the first presentation of the data for the year. This inaugural issue includes data on atmospheric carbon dioxide (CO_2) concentrations; estimates of global and national CO_2 emissions from fossil fuel burning, cement production, and gas flaring; atmospheric methane (CH_4) concentrations; and temperature data. Future issues of *TRENDS* may include data for atmospheric concentrations of other trace gases, land use data, oceanographic data, precipitation records, and output from computer models (i.e., general circulation models, vegetation models, CO_2 and CH_4 emission models, ocean models, and carbon cycle models).

The direction and format of future issues of *TRENDS* will be largely determined by the feedback we receive on this first issue. We encourage you to comment on this issue and suggest data to include in future issues.

The data in *TRENDS '90* are most properly referenced by citing the principal investigators as well as the section (e.g., Atmospheric Methane Concentrations) and subsection (e.g., Amsterdam Island) in which the data are found. The following sample citation for the atmospheric CH_4 concentrations from the NOAA/GMCC flask sampling program at Amsterdam Island is recommended:

Steele, L.P., P.P. Tans, P.M. Lang, R.C. Martin, and K.A. Masarie. 1990. Atmospheric Methane Concentrations, Amsterdam Island. p. 148–49. IN Boden, T.A., P. Kanciruk, and M.P. Farrell, *TRENDS '90: A Compendium of Data on Global Change*, ORNL/CDIAC-36. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

CDIAC acknowledges the support of the international science community in supplying data for creating its NDPs and *TRENDS '90.* CDIAC ensures the quality of the data upon receipt. However, some of the atmospheric CO_2 and CH_4 data are considered preliminary. Users should note table footnotes to avoid misrepresentations of the accuracy of these data. The applications and limitations for most data sets in *TRENDS '90* are documented in greater detail in CDIAC NDPs.

Data supporting *TRENDS '90* as well as all of our NDPs are available from CDIAC in machine-readable form. If you have any questions concerning data contained in this document or would like to discuss a particular aspect of the data's application, please contact CDIAC directly, so that your inquiry can be addressed by one of our technical staff.

Data requests and comments or suggestions concerning *TRENDS* may be sent to:

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On behalf of CDIAC, we welcome you to our newest publication. We hope you find it useful.

–*Michael P. Farrell*, Director
Carbon Dioxide Information Analysis and
Research Program

– *Paul Kanciruk*, Director
Carbon Dioxide Information Analysis Center

Acknowledgments

We gratefully acknowledge those who have contributed their data for inclusion in this document and thereby have made it possible for us to share data with researchers, policymakers, and students. We applaud the willingness of these individuals to allow the Carbon Dioxide Information Analysis Center (CDIAC) to archive and distribute their data.

Our deepest thanks go to Cheryl Buford and Marvel Burtis. Were it not for Cheryl's specialized electronic publishing design, composition, and production skills and Marvel's diligent support efforts, this document could not have been completed. We also thank Rosemary Adams, Dave Ball, John Holbrook, Mitchell Williamson, Jaime Payne, and Tammy White for graphics assistance; Bill Emanuel and Mac Post for suggestions and comments on the graphics; David Fowler for establishing document format; Bob Cushman for comments on document format and content; Gay Marie Logsdon and an editorial

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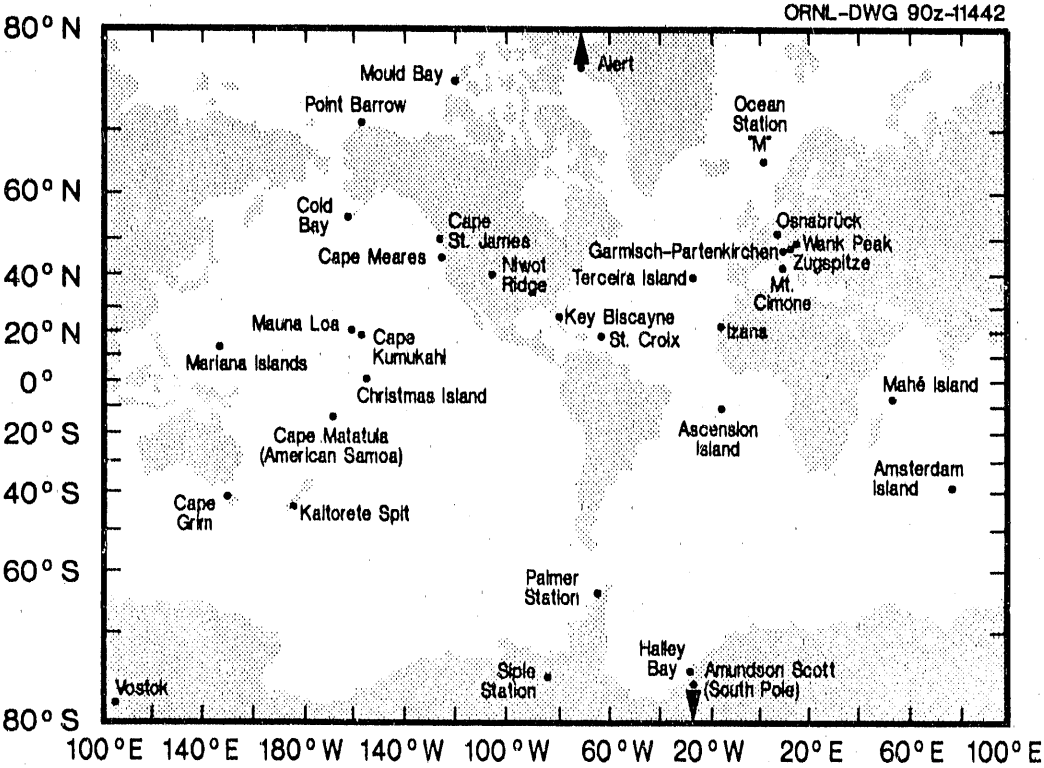
We especially thank Tom Gross, a program manager within the Carbon Dioxide Research Program, for his many years of support of CDIAC activities. Tom's continuing belief in the importance of international exchange of scientific information has been a mainstay for CDIAC progress.

CDIAC is supported by the U.S. Department of Energy's Atmospheric and Climate Research Division, Carbon Dioxide Research Program.

CDIAC is housed in the Environmental Sciences Division (ESD) at Oak Ridge National Laboratory (ORNL). *TRENDS '90* is ESD Publication No. 3430. ORNL is operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under contract DE-AC05-84OR21400.

Atmospheric Carbon Dioxide Concentrations



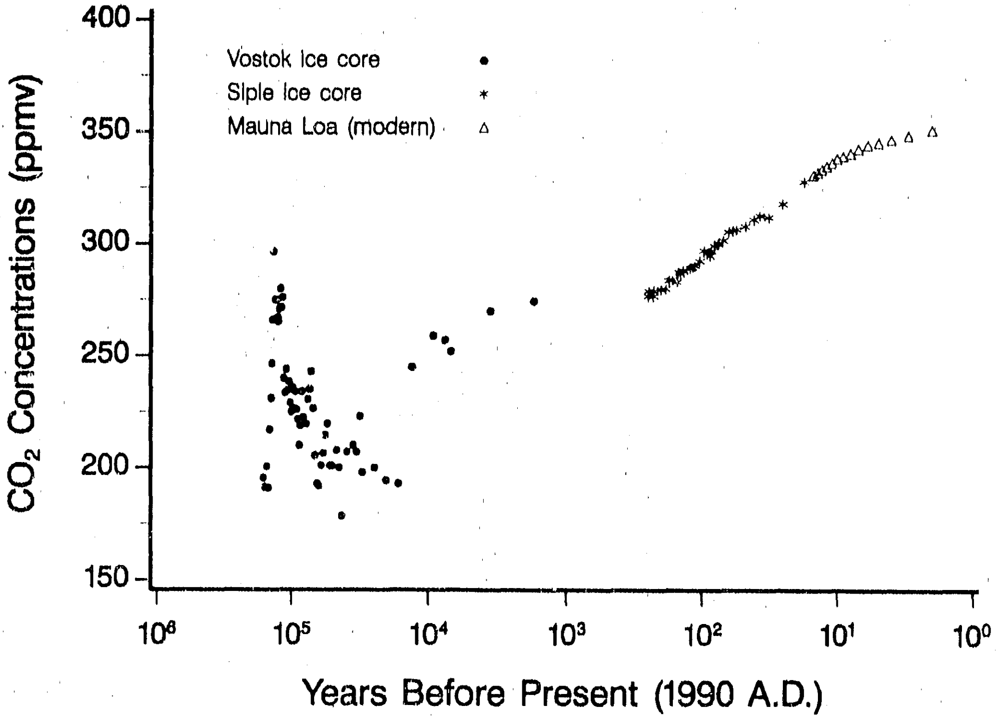
Sampling Stations

Introduction

Precise records of past and present atmospheric CO_2 concentrations are critical to studies attempting to model and understand the global carbon cycle and possible CO_2-induced climate change. Attempts to determine past levels of atmospheric CO_2 concentrations have been made using a variety of techniques, including direct measurements of trapped air in polar ice cores, indirect determinations from carbon isotopes in tree rings, spectroscopic data, and carbon and oxygen isotopic changes in carbonate sediments in deep-ocean cores. The modern period of precise atmospheric CO_2 measurements began during the International Geophysical Year (1958) with Keeling's (Scripps Institution of Oceanography) pioneering determinations at Mauna Loa, Hawaii, and the South Pole. The Mauna Loa record remains the single most valuable CO_2 time series. Since Keeling's initial efforts, other agencies and organizations have implemented programs to monitor background levels of atmospheric CO_2 concentrations. Two of the larger programs are the National Oceanic and Atmospheric Administration's Climate Monitoring and Diagnostics Laboratory (CMDL – formerly Geophysical Monitoring for Climate Change) flask and continuous monitoring networks and the World Meteorological Organization's (WMO's) Background Air Pollution Monitoring Network (BAPMoN).

In the following section, two historical atmospheric CO_2 records derived from ice cores and 39 records of monthly and annual atmospheric CO_2 concentrations from 30 globally distributed sites (see map on facing page) are provided. Collectively, these records document the atmospheric CO_2 record during the past 160,000 years. For the modern record it seemed appropriate to present Keeling's Mauna Loa record first, because it represents the longest continuous modern record available. Most records are indicative of background air conditions in a particular region or location. Some records (e.g., Osnabrück) were collected for other purposes, such as determining local ambient levels of CO_2 for growth chamber studies. The data presented on the pages that follow represent a significant portion, although not all, of the modern and historical atmospheric CO_2 record and provide irrefutable evidence that atmospheric levels of CO_2 concentrations have risen over the past three decades (see figure to right).

The data presented in this section were made available to the Carbon Dioxide Information Analysis Center (CDIAC) by the principal investigator(s) listed for each data record, and CDIAC acknowledges their kind cooperation. We urge readers to credit the principal investigators and their organizations when using these data. Users are encouraged to contact CDIAC before using data for specific model or research exercises. Some of the data are considered preliminary and subject to adjustment (values could change by several parts per million). All the data presented here are available in digitized form from CDIAC.



Annual atmospheric CO_2 concentrations during the past 160,000 years (derived from the Vostok and Siple ice cores and Keeling's Mauna Loa record).

Vostok

BACKGROUND

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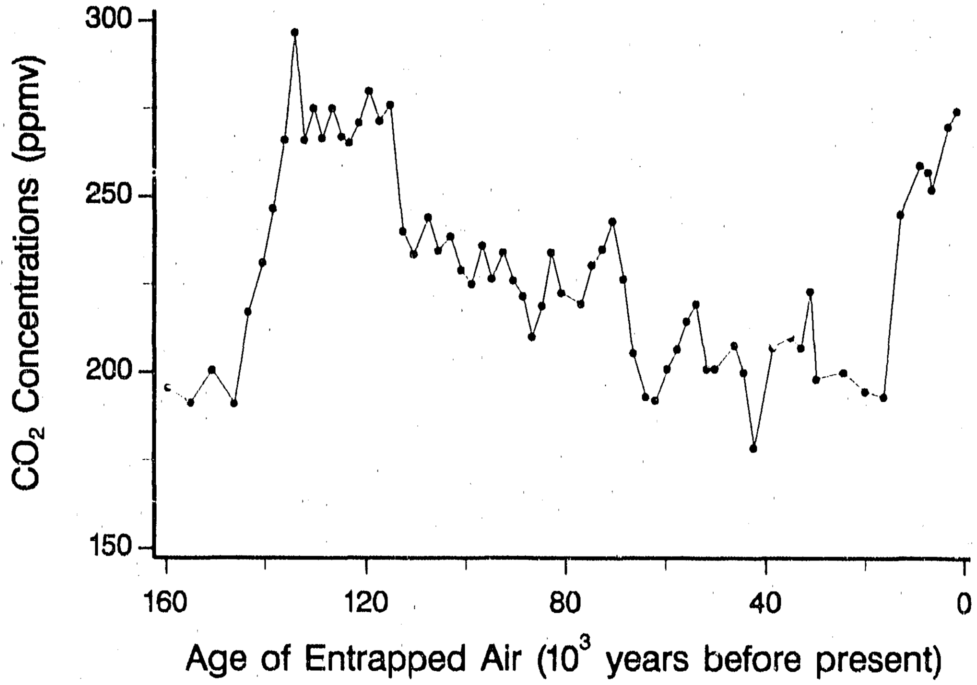
Sponsoring agencies

Commission of the European Communities
CNRS/PIREN
Terres Australes et Antarctiques Francaises
Soviet Antarctic Expeditions

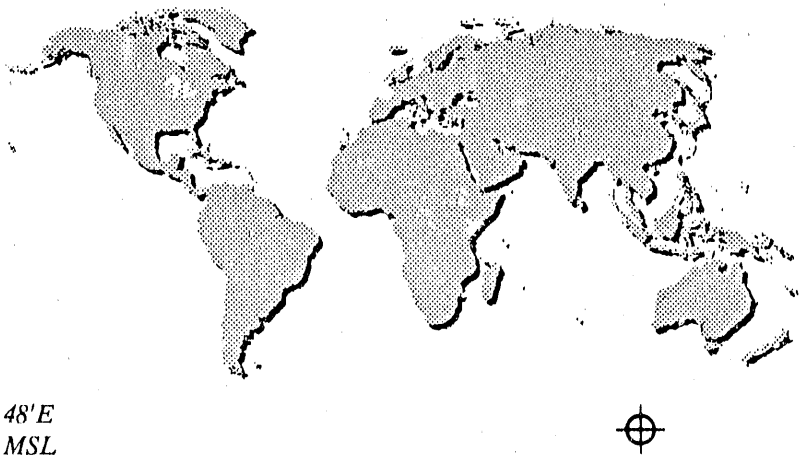
Method – Gas extraction and measurements were performed with the "Grenoble analytical setup" (Barnola et al. 1983) which is based on crushing the ice under vacuum without melting it, expanding the gas released during the crushing in a pre-evacuated sampling loop, and analyzing the CO_2 concentrations by gas chromatography. For further details on the experimental procedures and the dating of the successive ice layers at Vostok, see Barnola et al. (1987) and Lorius et al. (1985).

Calibration gases used – For each ice sample measurement, the analytical system is calibrated with a standard mixture of CO_2 in nitrogen and oxygen.

Data availability – Contact CDIAC for details on data and see Barnola et al. (1987).



Atmospheric CO_2 derived from the Vostok ice core.



Vostok
Antarctica
78° 28′S, 106° 48′E
3488 m above MSL

TRENDS

An atmospheric CO_2 record over the past 160 kyr has been obtained from the 2083-m-long ice core recovered by the Soviet Antarctica Expeditions at Vostok (East Antarctica). This CO_2 record is probably the purest available, covering the last climatic cycle (Barnola et al. 1987). The Vostok ice core data have been compared with other ice core data (Delmas et al. 1980; Neftel et al. 1982) for the past 30–40 kyr and there is good agreement between these records, with all showing low CO_2 values (~200 ppmv) during the Last Glacial Maximum and increased atmospheric CO_2 concentrations associated with the glacial-Holocene transition. Barnola et al. (1987) found that over the 160,000-year time scale there is a high correlation between CO_2 concentrations and Antarctic climate, with significant oscillatory behavior of CO_2 between high levels during interglacial periods and low levels during glacial periods. Barnola et al. (1987) reported that long-term CO_2 changes are dominated by marked glacial-interglacial oscillations between ~190–200 and 260–280 ppmv and that a period of ~20 kyr similar to the orbital precession period appears in the decreasing CO_2 trend covering most of the last glaciation and is supported by spectral analysis.

Vostok

Atmospheric Concentrations of Carbon Dioxide from Ice Cores

Depth (m)	Age of the ice (yr BP)	Mean age of the air (yr BP)	CO_2 concentration (ppmv)
126.4	4,050	1,700	274.5
173.1	5,970	3,530	270.0
250.3	9,320	6,800	252.0
266.0	10,040	7,500	257.0
302.6	11,870	9,140	259.0
375.6	16,350	12,930	245.0
426.4	20,330	16,250	193.0
474.2	24,280	20,090	194.5
525.1	28,530	24,390	200.0
576.0	32,680	29,720	198.0
602.3	34,770	30,910	223.0
625.6	36,600	32,800	207.0
651.6	38,600	34,870	210.0
700.3	42,320	38,660	207.0
748.3	45,970	42,310	178.5
775.2	48,000	44,350	200.0
800.0	49,850	46,220	207.7
852.5	53,770	50,150	201.0
874.3	55,450	51,770	201.0
902.2	57,660	53,860	219.5
926.8	59,670	55,780	214.5
951.9	61,790	57,800	206.5
975.7	63,880	59,770	201.0
1002.5	66,230	62,080	192.0
1023.5	68,040	63,960	193.0
1052.4	70,470	66,540	205.5
1074.8	72,330	68,490	226.5
1101.4	74,500	70,770	243.0
1124.2	76,330	72,690	235.0
1148.7	78,270	74,720	230.5
1175.0	80,320	76,860	219.5
1225.7	84,220	80,900	222.5
1251.5	86,220	82,920	234.0
1274.2	87,980	84,700	218.8
1299.3	89,940	86,680	210.0
1322.5	91,760	88,520	221.5
1349.0	93,860	90,630	226.0
1374.8	95,910	92,700	234.0
1402.5	98,130	94,940	226.5
1425.5	100,000	96,810	236.0
1451.5	102,210	98,950	225.0
1476.1	104,410	101,040	229.0
1499.6	106,610	103,130	238.5
1526.3	109,240	105,620	234.5
1547.0	111,250	107,650	244.0
1575.2	113,850	110,510	233.5
1598.0	115,850	112,700	240.0
1626.5	118,220	115,290	276.0
1651.0	120,170	117,410	271.5
1676.4	122,100	119,500	280.0
1700.9	123,900	121,430	271.0
1726.8	125,730	123,380	265.3
1747.3	127,150	124,880	267.0
1774.1	129,020	126,770	275.0
1802.4	131,030	128,780	266.5
1825.7	132,700	130,460	275.0
1850.5	134,510	132,280	266.0
1875.9	136,450	134,170	296.5
1902.0	138,660	136,170	266.0
1928.0	141,170	138,410	246.5
1948.7	143,440	140,430	231.0
1975.3	146,860	143,370	217.0
1998.0	150,330	146,340	191.0
2025.7	154,980	150,700	200.5
2050.3	159,100	154,970	191.3
2077.5	163,670	159,690	195.5

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Siple Station

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Sponsoring agencies

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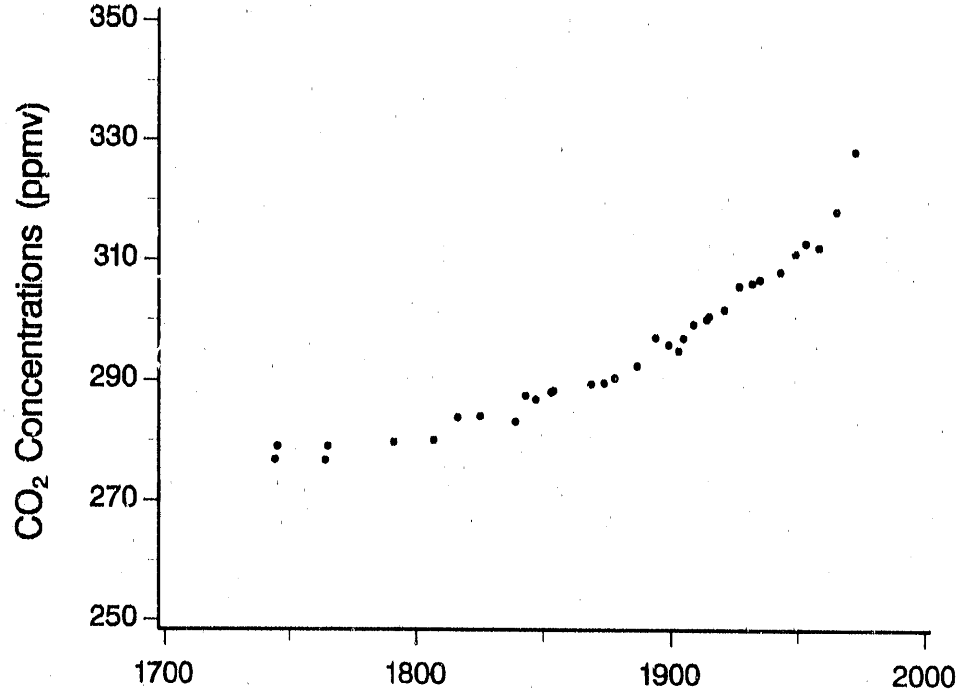
National Science Foundation
Department of Polar Programs
U.S. Department of Energy
Carbon Dioxide Research Program
University of Bern

Period of record — 1734–1983.

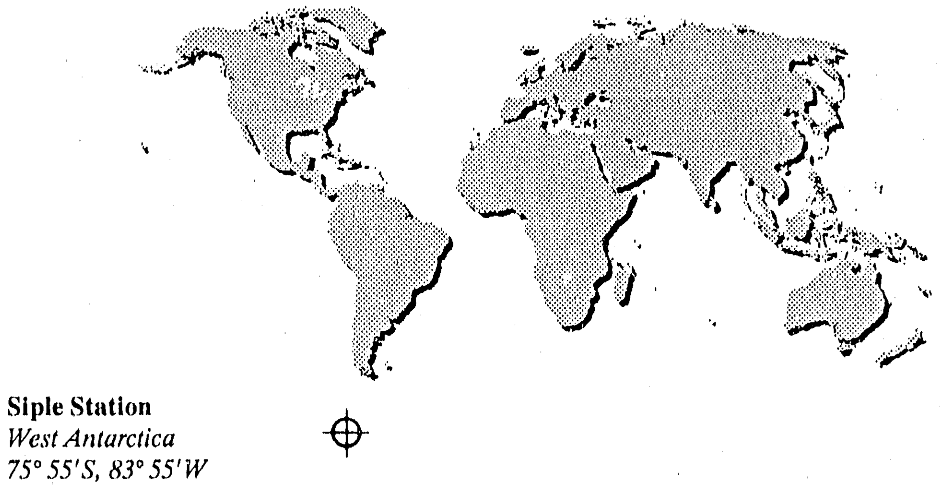
Method — Measurements were made on a 200-m ice core drilled in the Antarctic summer of 1983–84 at Siple Station in West Antarctica. The gases from ice samples were extracted by a dry-extraction system, in which bubbles are crushed mechanically to release the trapped gases, and then analyzed for CO_2 by infrared laser absorption spectroscopy or by gas chromatography. For further details, see Neftel et al. (1985) and Friedli et al. (1984).

Calibration Gases used — The analytical system is calibrated for each ice sample measurement with a standard mixture of CO_2 in nitrogen and oxygen.

Data availability — These data are available from CDIAC and the principal investigators and have been published in Neftel et al. (1985) and Friedli et al. (1986).



Atmospheric CO_2 concentrations derived from the Siple ice core.



Siple Station
West Antarctica
75° 55′S, 83° 55′W

Atmospheric CO_2 from Ice Cores

TRENDS

An atmospheric CO_2 record for the past 200 years has been obtained from the Siple ice core. At shallow depths atmospheric air still circulates through the open pores (Friedli et al. 1986). The enclosed air is younger than the surrounding ice, because the enclosure of air in bubbles occurs only between depths of 64 and 76m. Based on porosity measurements, the time lag between the mean age of the gas and the age of the ice was determined to be 95 years and the duration of the close-off process to be 22 years (Schwander and Stauffer 1984). Neftel et al. (1985) concluded that the atmospheric CO_2 concentration circa 1750 was 280 ± 5 ppmv and has increased by 22.5% since then to 345 ppmv in 1984, essentially because of human factors. Friedli et al. (1986) also reported graphically that the pre-industrial (pre-1800) CO_2 concentration was ~280 ppmv.

Siple Station

Atmospheric Concentrations of Carbon Dioxide from Ice Cores*

Depth (m)	Samples measured	Date of ice (yr A.D.)	Date air enclosed (yr A.D.)	CO_2 concentration in extracted air (ppmv)
68.2–68.6	8	1891	1962–1983	328 ± 3.5
72.4–72.7	11	1883	1954–1976	318 ± 3.0
76.2–76.6	11	1876	1947–1969	312 ± 3.0
82.0–83.0	28	1867	1938–1960	311 ± 3.0
92.0–93.0	25	1850	1921–1943	306 ± 3.0
102.0–103.0	26	1832	1903–1925	300 ± 3.0
111.0–112.0	26	1812	1883–1905	297 ± 3.0
128.0–129.0	47	1782	1842–1864	288 ± 3.0
147.0–147.2	10	1743	1814–1836	284 ± 3.0
162.0–162.3	9	1723	1794–1819	280 ± 3.0
177.0–177.3	10	1683	1754–1776	279 ± 3.0
187.0–187.3	10	1663	1734–1756	279 ± 3.0

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*Data published in Neftel et al. (1985).

Atmospheric Concentrations of Carbon Dioxide from Ice Cores*

Average depth (m)	Gas age (yr A.D.)	CO_2 Concentration (ppmv)	Average depth (m)	Gas age (yr A.D.)	CO_2 concentration (ppmv)
187.70	1744	276.8	116.82	1887	292.3
177.50	1764	276.7	110.20	1899	295.8
168.30	1791	279.7	108.80	1903	294.8
154.89	1816	283.8	107.20	1905	296.9
142.75	1839	283.1	105.25	1909	299.2
140.75	1843	287.4	101.80	1915	300.5
138.20	1847	286.8	98.80	1921	301.6
134.47	1854	288.2	95.17	1927	305.5
126.80	1869	289.3	90.77	1935	306.6
123.80	1874	289.5	86.80	1943	307.9
121.80	1878	290.3	81.22	1953	312.7

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*Data published in Friedli et al. (1986).

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Barnola, J.M., D. Raynaud, A. Neftel, and H. Oeschger. 1983. Comparison of CO_2 measurements by two laboratories on air bubbles in polar ice. *Nature* 303:410-13.

Barnola, J.M., D. Raynaud, Y.S. Korotkevich, and C. Lorius. 1987. Vostok ice core provides 160,000-year record of atmospheric CO_2. *Nature* 329:408–14.

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Mauna Loa

BACKGROUND

Principal investigators

Charles D. Keeling
Timothy P. Whorf
Scripps Institution of Oceanography
University of California
La Jolla, California 92093, U.S.A.

Air sample collection – Continuous. Air samples are collected from air intakes at the top of four 7-m towers and one 27-m tower. Four samples are collected every hour. Details are given in Keeling et al. (1982).

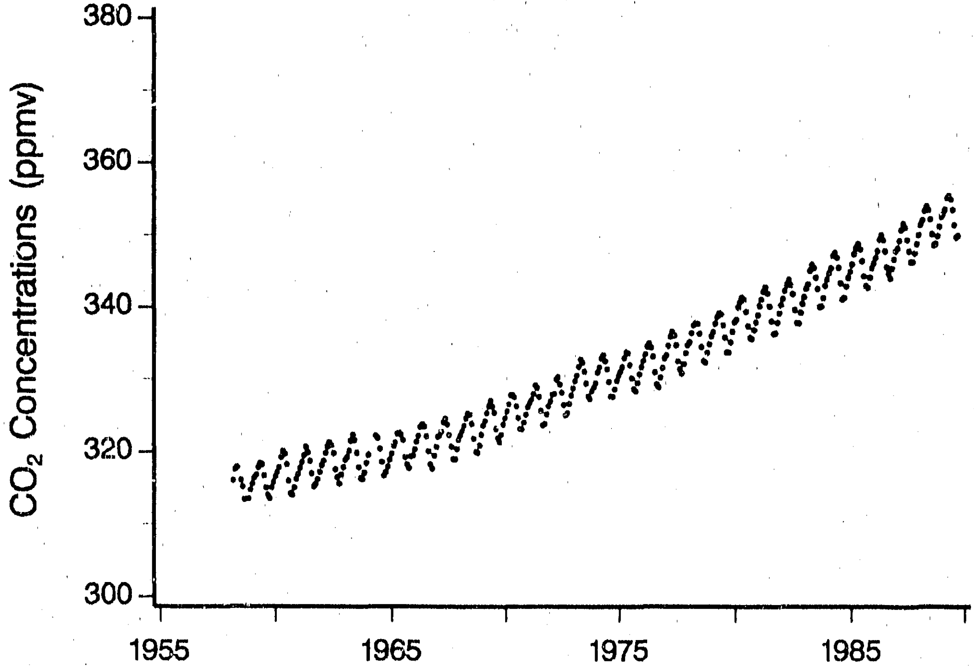
Measurement apparatus – Analyses of CO_2 concentrations are made by using an Applied Physics Corporation nondispersive infrared gas analyzer with a water vapor freeze trap.

Data selection procedures – Data are selected for periods of steady hourly data to within ~0.5 ppmv; at least six consecutive hours of steady data were required to form a daily average.

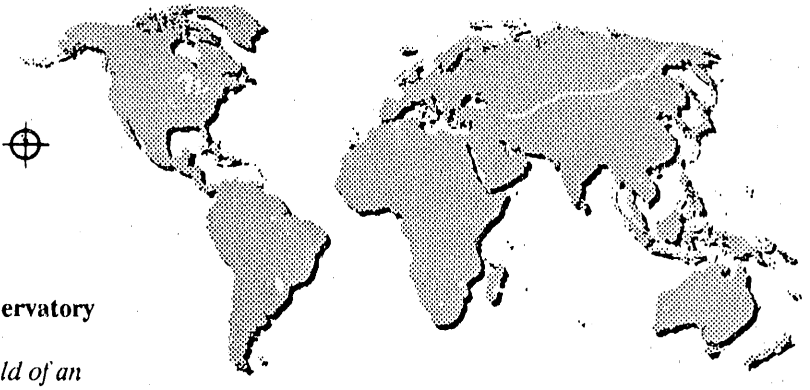
Calibration gases used – CO_2-in-N_2 until December 1983 and CO_2-in-air from December 1983 to the present.

Scale of data reported – 1987 WMO/Scripps mole fraction scale.

Data availability – These monthly and annual data, which are derived from daily "steady" data, are available from CDIAC. The monthly data through 1986, along with monthly data that have been adjusted to remove the seasonal effects, are available in machine-readable form from CDIAC (Keeling, 1986). Hourly, daily, monthly, and annual averages may be obtained from the principal investigator.



Monthly atmospheric CO_2 concentrations.



Mauna Loa Observatory
Hawaii, U.S.A.
Barren lava field of an active volcano
19° 32'N, 155° 35'W
3397 m above MSL

TREND

The Mauna Loa atmospheric CO_2 measurements constitute the longest continuous record of atmospheric CO_2 concentrations available in the world. The Mauna Loa site is considered one of the most favorable locations for measuring undisturbed air because possible local influences of vegetation or human activities on atmospheric CO_2 concentrations are considered minimal and any influences from volcanic vents may be excluded from the records. The methods and equipment used to obtain these measurements have been essentially unchanged over the 31-year record.

Because of the favorable site location, continuous monitoring, and careful selection and scrutiny of the data, the Mauna Loa record is considered to be a precise record and a reliable indicator of the regional trend in the concentrations of atmospheric CO_2 in the middle layers of the troposphere. The Mauna Loa record shows a 12 percent increase in the mean annual concentration in 31 years, from 315 parts per million by volume of dry air (ppm) in 1958 to 352 in 1989 (Keeling et al. 1989).

Mauna Loa

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1958			316.0	317.6	317.8		316.1	315.2	313.4	313.5		314.8	
1959	315.6	316.4	316.8	317.8	318.4	318.2	316.7	315.0	314.0	313.6	315.0	315.8	316.1
1960	316.5	317.1	317.8	319.2	320.1	319.7	318.3	316.0	314.2	314.1	315.1	316.2	317.0
1961	317.9	317.8	318.5	319.5	320.6	319.9	318.7	317.0	315.2	315.5	316.2	317.2	317.7
1962	318.1	318.7	319.8	320.7	321.3	320.9	319.8	317.6	316.5	315.6	316.9	317.9	318.6
1963	318.8	319.3	320.1	321.5	322.4	321.6	319.9	317.9	316.4	316.2	317.1	318.5	319.1
1964	319.6				322.2	321.9	320.4	318.6	316.7	317.2	317.9	318.9	
1965	319.7	320.8	321.2	322.5	322.6	322.4	321.6	319.2	318.2	317.8	319.4	319.5	320.4
1966	320.4	321.4	322.2	323.5	323.8	323.5	322.2	320.1	318.3	317.7	319.6	320.7	321.1
1967	322.1	322.2	322.8	324.1	324.6	323.8	322.3	320.7	319.0	319.0	320.4	321.7	322.0
1968	322.3	322.9	323.6	324.7	325.3	325.2	323.9	321.8	320.0	319.9	320.9	322.4	322.8
1969	323.6	324.2	325.3	326.3	327.0	326.2	325.4	323.2	321.9	321.3	322.3	323.7	324.2
1970	324.6	325.6	326.6	327.8	327.8	327.5	326.3	324.7	323.1	323.1	324.0	325.1	325.5
1971	326.1	326.6	327.2	327.9	329.2	328.8	327.5	325.7	323.6	323.8	325.1	326.3	326.5
1972	326.9	327.8	328.0	329.9	330.3	329.2	328.1	326.4	325.9	325.3	326.6	327.7	327.6
1973	328.7	329.7	330.5	331.7	332.7	332.2	331.0	329.4	327.6	327.3	328.3	328.8	329.8
1974	329.4	330.9	331.6	332.9	333.3	332.4	331.4	329.6	327.6	327.6	328.6	329.7	330.4
1975	330.5	331.1	331.6	332.9	333.6	333.5	331.9	330.1	328.6	328.3	329.4	330.6	331.0
1976	331.6	332.5	333.4	334.5	334.8	334.3	333.0	330.9	329.2	328.8	330.2	331.5	332.1
1977	332.8	333.2	334.5	335.8	336.5	336.0	334.7	332.4	331.3	330.7	332.1	333.5	333.6
1978	334.7	335.1	336.3	337.4	337.7	337.6	336.2	334.4	332.4	332.2	333.6	334.8	335.2
1979	335.9	336.4	337.6	338.5	339.1	338.9	337.4	335.7	333.6	333.7	335.1	336.5	336.5
1980	337.8	338.2	339.9	340.6	341.2	340.9	339.3	337.3	335.7	335.5	336.7	337.8	338.4
1981	338.8	340.1	340.9	342.0	342.7	341.8	340.0	337.9	336.2	336.3	337.8	339.1	339.5
1982	340.2	341.1	342.2	343.0	343.6	342.9	341.7	339.5	337.8	337.7	339.1	340.4	340.8
1983	341.3	342.5	343.1	344.9	345.8	345.3	344.0	342.4	339.9	340.0	341.2	342.9	342.8
1984	343.7	344.6	345.3	347.0	347.4	346.7	345.4	343.2	341.0	341.2	342.8	344.0	344.3
1985	344.8	345.8	347.2	348.1	348.7	347.9	346.3	344.2	342.9	342.6	344.0	345.3	345.7
1986	346.0	346.7	347.6	349.2	349.9	349.2	347.7	345.5	344.5	343.9	345.3	346.6	346.9
1987	347.7	348.1	349.1	350.6	351.5	351.0	349.2	347.7	346.2	346.2	347.4	348.7	348.6
1988	349.9	351.2	351.9	353.2	353.9	353.3	352.1	350.0	348.5	348.7	349.8	351.1	351.2
1989	352.5	352.8	353.4	355.1	355.4	354.9	353.4	351.3	349.6	349.9			

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*Atmospheric CO$_2$ in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

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American Samoa

BACKGROUND

Principal investigator

Charles D. Keeling
Scripps Institution of Oceanography
University of California
La Jolla, California 92093, U.S.A.

Air sample collection – Air samples are collected in 5-L evacuated glass flasks exposed in triplicate weekly.

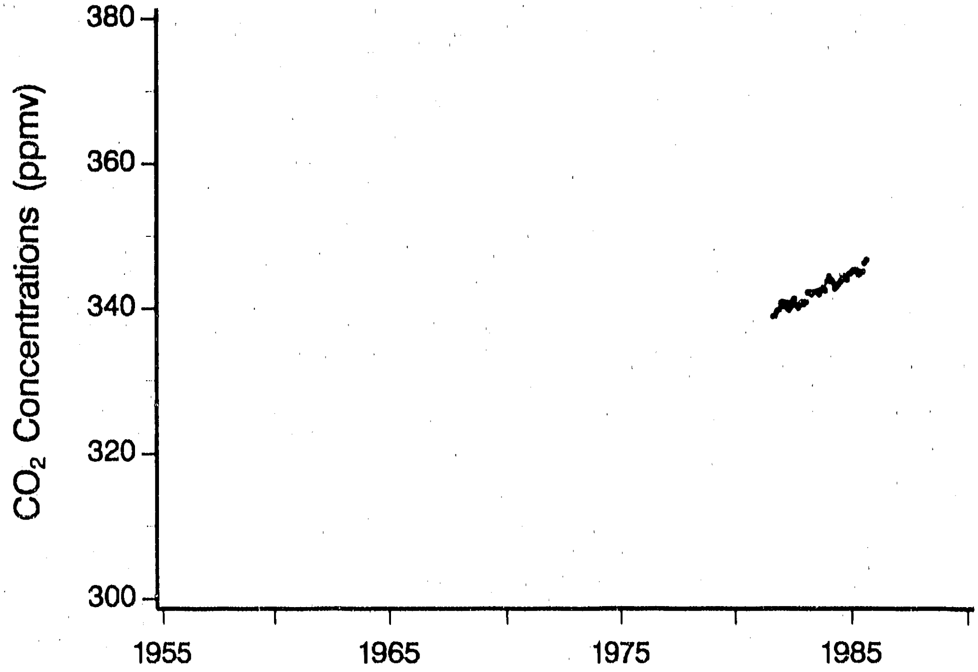
Measurement apparatus – Flask samples are measured for CO_2 concentration at Scripps Institution of Oceanography by using an Applied Physics Corporation nondispersive infrared gas analyzer with water vapor freeze trap.

Data selection procedures – Concentrations of replicate flask samples must agree within 0.40 ppmv to be accepted.

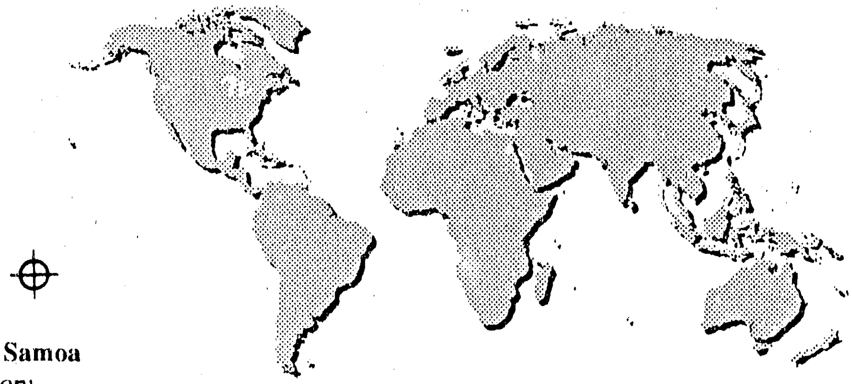
Calibration gases used – CO_2-in-N_2 until May 1983 and CO_2-in-air from May 1983 to the present.

Scale of data reported – 1985 WMO/Scripps mole fraction scale.

Data availability – These monthly and annual values, as well as the individual flask concentrations, may be obtained from the principal investigator. The monthly and annual values are available from CDIAC.



Monthly atmospheric CO_2 concentrations.



American Samoa
U.S. Territory
Rocky coastal promontory
14° 15'S, 170° 34'W
30 m above MSL

TREND

A monitoring project to observe the sea-level climate and atmospheric constituents of the tropical Southern Hemisphere was established by NOAA at Cape Matatula, American Samoa, in 1973. NOAA operates both a continuous monitoring program (Waterman et al. 1989) and a flask sampling (Conway et al. 1988) program at Cape Matatula. Scripps Institution of Oceanography (SIO) has also collected flask samples at American Samoa independently of NOAA since 1981.

Since 1981, the annual average concentration of CO_2, based on flask samples collected by SIO, has risen from 339.2 ppmv to 345.3 ppmv in 1985. This represents an annual growth rate of 1.2 ppmv per year at American Samoa. For comparison, Conway et al. (1988) reported an annual growth rate of 1.35 ppmv at American Samoa for 1981–1984 on the basis of flask data from the NOAA/CMDL flask sampling program.

American Samoa

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann†
1981									338.8	338.9	339.5	339.7	339.2
1982	340.6	340.8	340.1	340.7	339.7	340.0	340.9	341.2	340.3	340.0	340.4	340.8	340.5
1983	340.5	340.8	342.1	342.2	341.9	342.2	342.2	342.3	341.9	342.5	342.8	342.4	342.0
1984	343.6	344.3	343.9	343.5	342.7	343.0	343.3	343.7	344.4	344.0	343.9	344.6	343.7
1985	344.8	345.1	345.2	345.2	344.6	344.8	345.0	346.2	346.6				345.3

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*Average monthly concentration, accepted data. Atmospheric CO_2 concentrations in parts per million by volume (ppmv).

†Annual averages based on available monthly means.

le*

nt†

9.2

0.5

2.0

3.7

5.3

REFERENCES

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Point Barrow

BACKGROUND

Principal investigator

Charles D. Keeling
Scripps Institution of Oceanography
University of California
La Jolla, California 92093, U.S.A.

Air sample collection – Continuous measuring from July 1961 to September 1967, biweekly triplicate flask sampling using 2-L evacuated glass flasks from January 1974 to February 1982, and weekly flask sampling in pairs using 5-L evacuated glass flasks from March 1982 to September 1985.

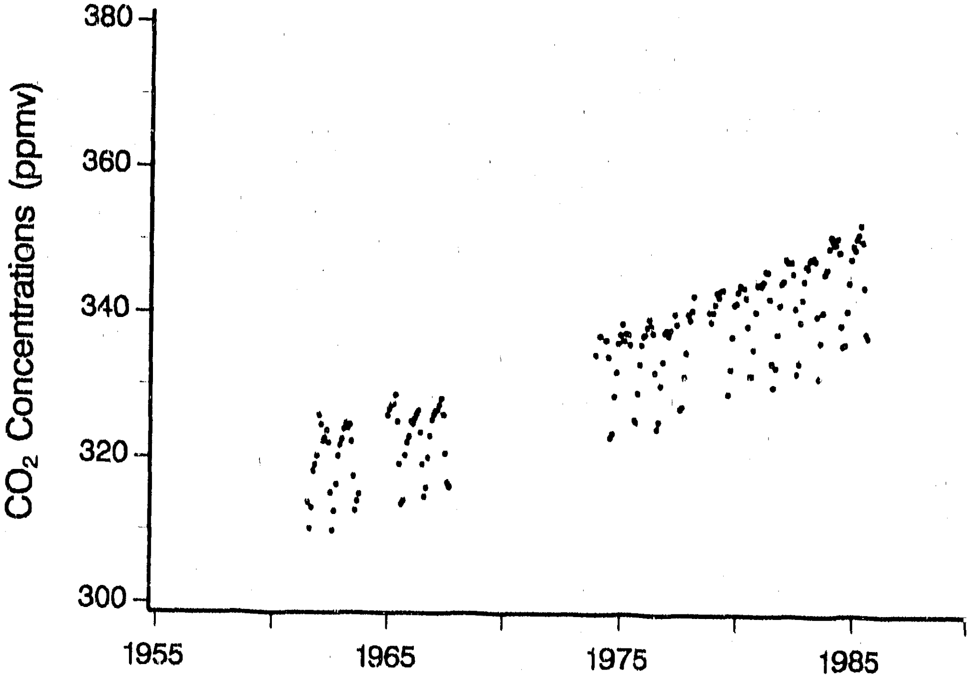
Measurement apparatus – For continuous measurements, an Analytic Systems Corporation nondispersive infrared gas analyzer with water vapor freeze trap was used. For flask samples measured at Scripps Institution of Oceanography, an Applied Physics Corporation nondispersive infrared gas analyzer was used.

Data selection procedures – Concentrations of replicate flask samples must agree within 0.40 ppmv to be accepted.

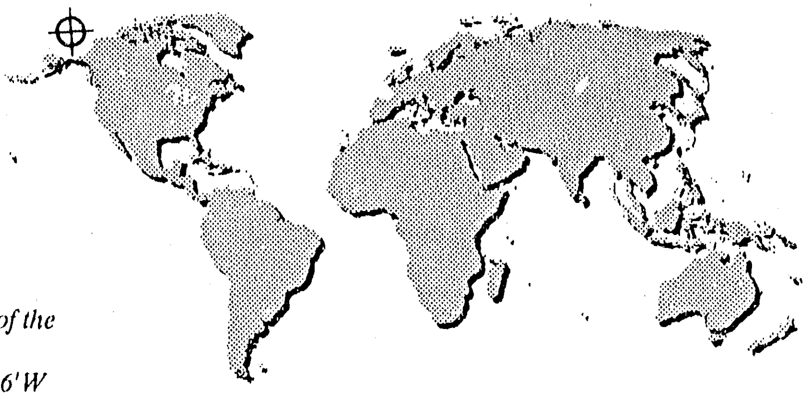
Calibration gases used – CO_2-in-N_2 until May 1983 and CO_2-in-air from May 1983 to the present.

Scale of data reported – 1985 WMO/Scripps mole fraction scale.

Data availability – These monthly and annual values, as well as the individual flask concentrations, may be obtained from the principal investigator. The monthly and annual concentrations from Point Barrow are available from CDIAC.



Monthly atmospheric CO_2 concentrations.



Point Barrow
Alaska, U.S.A.
On the coast of the
Arctic ocean
71° 19'N, 156° 36'W
11 m above MSL

TREND

Carbon dioxide was first measured at Barrow, Alaska, by Kelley and co-workers from the University of Washington during the 1960s (Kelley 1969). Their measurements with a continuously operating analyzer began in July 1961. From 1962 (which marks the first full year of monitoring atmospheric CO_2 concentrations at Point Barrow, Alaska) to 1985 (which represents the last full year of data available at the time this report was compiled) the annual CO_2 concentration rose from 319.7 to 346.7 ppmv. The Point Barrow record is considered to be very accurate and indicative of maritime air masses.

Point Barrow

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann†
1961							313.8	310.2	313.1	318.1	319.0	320.2	315.7
1962	325.8	324.5	322.2	322.7	323.7	322.0	315.1	309.9	312.6	316.3	320.2	321.7	319.7
1963	322.5	323.9	324.7	324.0	324.5	322.2	317.4	312.7	314.0	315.0			320.1
1964													
1965	325.8	326.7	327.2	327.3	328.6	324.9	319.1	313.6	314.1	320.3	322.1	322.9	322.7
1966	325.0	324.7	325.4	326.0	326.5	323.5	319.1	314.7	315.9	320.0	323.0	325.2	322.4
1967	325.9	326.4	326.5	327.2	328.1	325.9	320.6	316.6	316.0				323.7
1968													
1969													
1970													
1971													
1972													
1973													
1974	334.3		336.9			336.3	334.0	322.9	323.5	328.6	331.9	335.9	331.6
1975	337.1	338.6	336.3	337.3	337.2	335.8		325.4	325.1	329.1	333.1	335.8	333.7
1976	337.0	337.2	338.2	339.3	338.4	337.4	332.0	324.2	325.2	330.2	333.5	337.5	334.2
1977	337.8	337.1	337.8		340.0	338.6		326.9	327.2	331.4	334.7	340.0	335.1
1978	339.2	340.5	342.5								340.3	339.0	340.3
1979	340.3	341.4	343.0	342.4	343.3	343.4			329.0	332.4	336.9	341.3	339.3
1980	341.5	343.1	344.0		343.7	342.3	338.4	331.6	331.6	335.2	340.4	344.1	339.6
1981	344.2	344.0	344.5	346.0	345.9	342.2	333.3	330.0	332.7	337.3	341.3	344.3	340.5
1982	344.6	347.7	347.3	347.3	347.3	345.7	340.9	331.9	333.3	339.0	342.1	344.7	342.6
1983	346.7	346.5	347.5	347.8	347.9	347.5	339.9	331.3	336.2	340.4	345.7	346.3	343.6
1984	349.2	350.8	350.2	349.7	350.5	348.6	338.5	335.7	335.9	340.5	344.4	347.7	345.1
1985	349.5	349.0	350.5	351.1	352.4	350.1	343.8	337.4	336.9				346.7

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*Average monthly concentration, accepted data. Atmospheric CO_2 concentrations in parts per million by volume (ppmv).

†Annual averages based on available monthly means.

REFERENCES

Bacastow, R.B. 1979. Dip in the atmospheric CO_2 level during the mid-1960's. *Journal of Geophysical Research* 80:3109–14.

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South Pole

BACKGROUND

Principal investigator

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La Jolla, California 92093, U.S.A.

Air sample collection – Biweekly flask sampling, except for the continuous in situ measurements between 1960 and 1963 (Keeling et al. 1976a and 1976b; Bacastow and Keeling 1981). Five-liter evacuated glass flasks are exposed as triplets biweekly. From 1957 until October of 1963, 5-L glass flasks were exposed as singlets or pairs biweekly.

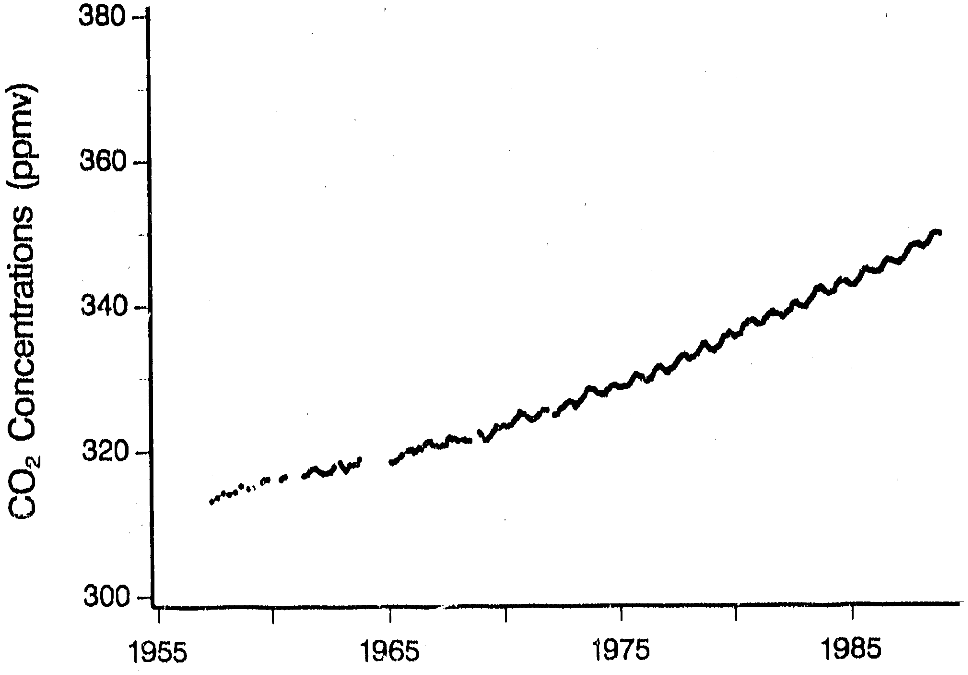
Measurement apparatus – Air samples obtained by flask sampling (as well as those obtained from continuous monitoring) are analyzed for CO_2 concentration at Scripps Institution of Oceanography by using an Applied Physics Corporation nondispersive infrared gas analyzer with a water vapor freeze trap.

Data selection procedures – Concentrations of replicate flask samples must agree within 0.40 ppmv to be accepted.

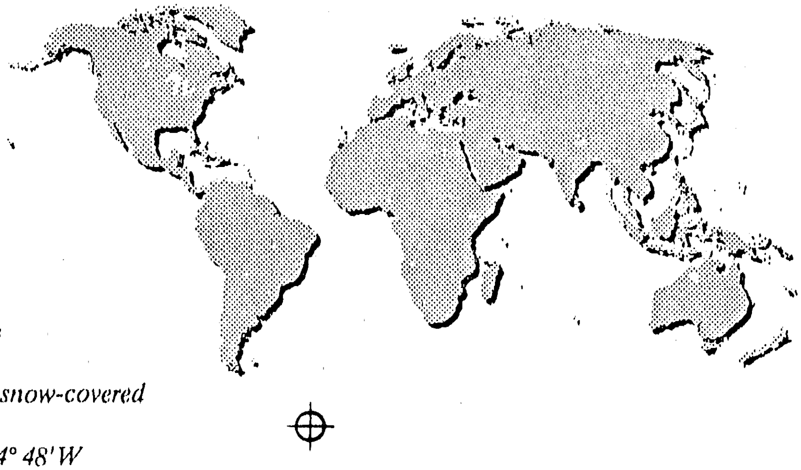
Calibration gases used – CO_2-in-N_2 until March 1983 and CO_2-in-air from March 1983 to the present.

Scale of data reported – 1985 WMO/Scripps mole fraction scale.

Data availability – These monthly and annual values, as well as the daily concentrations, may be obtained from the principal investigator. The monthly and annual data are available from CDIAC and have been published in Keeling et al. (1989).



Monthly atmospheric CO_2 concentrations.



South Pole
Antarctica
Ice- and snow-covered plateau
89° 59′S, 24° 48′W
2810 m above MSL

TREND

Precise measurements of atmospheric CO_2 at the South Pole have been obtained by Scripps Institution of Oceanography (SIO) since 1957. This record is based primarily on biweekly flask sampling. Since 1975, NOAA has also conducted continuous in situ measurements of atmospheric CO_2 at the South Pole (Gillette et al. 1987) as part of the CMDL program.

The SIO CO_2 record from the South Pole shows that annual averages of atmospheric CO_2 concentrations have risen from 313.7 ppmv in 1957 to 348.9 ppmv in 1988. This represents an annual increase of ~1.1 ppmv/year. Keeling et al. (1976a) reported that the seasonally adjusted concentration of atmospheric CO_2 from the South Pole rose 3.7% between 1957 and 1971. Gillette et al. (1987) reported a mean annual CO_2 increase of 1.32 ppmv for 6 years (1975–78, 1980–82) from the South Pole.

South Pole

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann†
1957						313.2			313.7			314.3	313.7
1958			314.1			314.4			315.2				314.5
1959	314.9	315.0	314.9					315.8	316.1		316.2		315.5
1960						316.2	316.5	316.6					316.4
1961					316.5	316.7	316.8	317.2	317.5	317.6	317.7	317.5	317.2
1962	317.3	317.1	316.9	317.0	317.0	317.1	317.1	317.5	317.9			318.5	317.3
1963	318.0	317.7	317.3	317.7	318.1	318.1	318.1	318.2	318.2	318.9			318.0
1964													
1965		318.5	318.4	318.5	318.7		319.2	319.5			320.0	320.1	319.1
1966	320.2	319.8	319.9	320.2	320.5	320.3		320.9	321.2	321.3	321.4	320.9	320.6
1967		320.8		320.7	320.8	320.8	320.9	321.7	321.9	321.6	321.7	321.6	321.3
1968	321.4			321.5	321.3	321.3	321.3					322.5	321.6
1969	322.2		321.5	321.5	321.8	322.0	322.5	322.8	323.4	323.2	323.2		322.4
1970	323.5	323.4	323.3	323.5	323.6	324.0	324.3	324.6	325.3	325.0	325.1		324.1
1971	324.6	324.4	324.2	324.3	324.5	324.7	325.0		325.6		325.6		324.8
1972			324.9	325.0	325.1	325.7	326.0	326.0	326.4	326.6	326.8	326.7	325.9
1973	326.6	326.0	326.2	326.7	326.9	327.3	327.6	328.2	328.5	328.5	328.4	328.4	327.4
1974	328.1	327.9	327.9	327.7	327.8	327.7	328.3	328.5	328.8	328.9	329.0	328.8	328.3
1975	328.7	328.7	328.7	328.8	328.8	328.9	329.2	329.7	330.1	330.4	330.3	330.1	329.4
1976	330.1	329.8	329.7	329.5	329.8	329.8	330.3	330.9	331.2	331.5	331.6	331.3	330.5
1977	331.1	330.8	330.7	331.2	331.2	331.5	331.9	332.3	332.7	332.9	333.1	333.0	331.9
1978	332.7	332.5	332.7	332.8		333.2	333.7	334.1	334.6	334.7	334.4	334.1	333.6
1979	333.8	333.9	333.7	334.0	334.2	334.4	335.0	335.6	335.7	335.8	336.2	335.9	334.8
1980	335.9	335.6		335.9	336.0	336.7	337.3	337.4	337.7	337.7	337.8	337.9	336.9
1981	337.6	337.3	337.3	337.4	337.5	338.0	338.2	338.6	338.7	339.0	338.7	338.7	338.1
1982		338.5	338.2	338.5	338.8	339.0	339.2	339.9	340.1	340.2	339.9	339.8	339.3
1983	339.7	339.7	339.7	340.1	340.5	340.8	341.2	341.7	342.2	342.1	342.4	342.2	341.0
1984	341.9		341.5	341.7	341.7	341.9	342.6	343.0	343.3	343.3	343.1	343.0	342.5
1985	342.8	342.6	342.6	342.6	343.0	343.3	343.8	344.4	344.7	344.8	344.6	344.5	343.6
1986	344.5	344.4	344.4	344.5	344.5	344.9	345.4	345.8	346.1	346.0	346.0	345.9	345.2
1987	345.8	345.7	345.6	346.0	346.1	346.5	347.1	347.5	347.9	348.0	348.1	348.2	346.9
1988	348.2	347.9	347.8	348.1	348.2	348.5	349.0	349.5	349.7	349.8	349.8	349.7	348.9
1989	349.8												

---

*Entries express averages of daily values (in ppm) adjusted to the 15th of each month. All numbers have been rounded by CDIAC to the nearest tenth.

†Annual averages based on available monthly means.

oxide*

Annt
313.7
314.5
315.5
316.4
317.2
317.3
318.0
319.1
320.6
321.3
321.6
322.4
324.1
324.8
325.9
327.4
328.3
329.4
330.5
331.9
333.6
334.8
336.9
338.1
339.3
341.0
342.5
343.6
345.2
346.9
348.9

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Amundsen Scott

BACKGROUND

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Air sample collection – Air samples are collected from a sample line 13.5 meters above the snow surface and dried before entering the analyzer. Details given in Gillette et al. (1987).

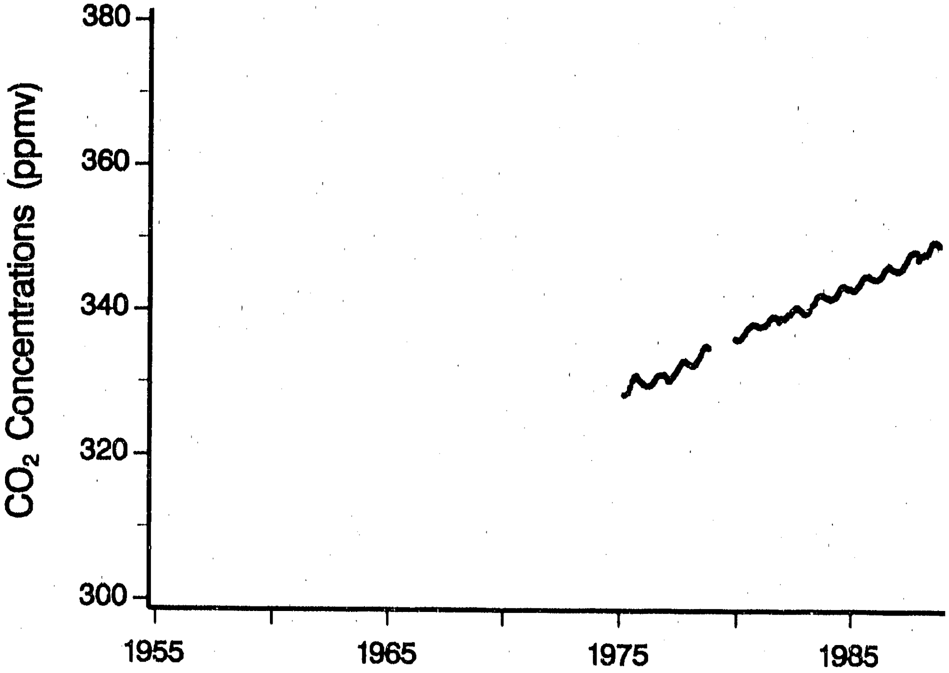
Measurement apparatus – URAS-2T semiautomatic nondispersive infrared gas analyzer manufactured by Hartmann and Braun.

Data selection procedures – Some data are rejected immediately for various reasons (e.g., lack of calibration data and instrument problems) using records kept by South Pole personnel. After the initial selection process, data are analyzed for short-term minute-to-minute and hour-to-hour variations. Algorithms have been written to remove these short-term variations. For further details see Gillette et al. (1987).

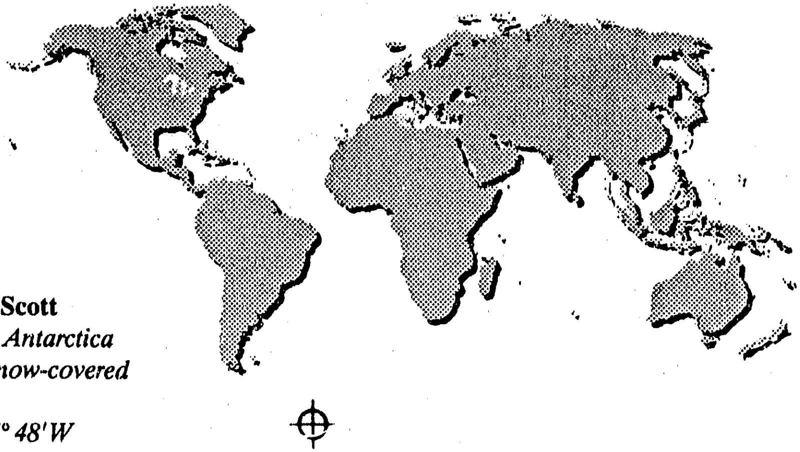
Calibration gases used – CO_2-in-air.

Scale of data reported – SIO X85 mole fraction scale.

Data availability – These monthly CO_2 concentrations from the South Pole are available from CDIAC. They are also available from the principal investigator at NOAA/CMDL and WMO.



Monthly atmospheric CO_2 concentrations.



Amundsen Scott
South Pole, Antarctica
Ice and snow-covered plateau
89° 59′S, 24° 48′W
2810 m above MSL

TREND

The South Pole Observatory (SPO) is one of four baseline atmospheric monitoring stations operated by the Climate Monitoring and Diagnostics Laboratory (CMDL) program of the National Oceanic and Atmospheric Administration (NOAA). The other three sites are located at Barrow, Alaska; Cape Matatula, American Samoa; and Mauna Loa Observatory, Hawaii. The remoteness of SPO makes it an ideal sampling location because it is removed from significant human-induced sources of CO_2.

Continuous measurements of atmospheric CO_2 concentrations have been made at SPO since 1957 by the Scripps Institution of Oceanography (SIO). The SIO program is based primarily on biweekly flask sampling, except for the continuous in situ measurements between 1960 and 1963. Since 1975, CMDL has also made continuous measurements of atmospheric CO_2 at the South Pole independently of SIO. Gillette et al. (1987) reported that, except for 1976, the continuous data from SPO for 1975–1982 showed good agreement with the SIO and CMDL flask data collected at the South Pole and with the results of the Australian Commonwealth and Scientific and Industrial Research Organization aircraft monitoring program.

Gillette et al. (1987) found the average growth rate of CO_2 at the South Pole for 1975–1982 to be 1.32 ± 0.66 ppm per year and the amplitude of the seasonal cycle to range from 1.59 ± 0.36 before 1979 to 1.02 ± 0.18 ppm after 1979. For comparison, Conway et al. (1988) reported a growth rate of 1.22 ppm per year for the flask sampling data from the South Pole for 1981–1984.

Amundsen Scott

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1975					328.4	328.7	329.4	330.3	330.9	331.1	330.7	330.3
1976	330.1	329.8	329.7	329.6	329.7	329.9	330.3	330.7	331.1	331.1	331.1	331.2
1977	330.9	330.4	330.3	330.7	331.1	331.4	331.8	332.3	332.8	333.1	333.1	332.8
1978	332.7	332.5	332.4	332.6	333.0	333.4	333.9	334.6	335.0	335.1	334.9	
1979												
1980	336.2	336.0	336.0	336.2	336.6	336.9	337.4	337.7	337.9	338.1	338.0	338.0
1981	337.8	337.8	337.9	337.9	338.1	338.3	338.8	339.0	339.2	339.2	339.0	338.6
1982	339.0	338.0	338.9	339.2	339.6	339.6	340.0	340.3	340.5	340.5	340.2	340.0
1983	339.7	339.6	339.7	340.1		340.9	341.2	341.9	342.1	342.2	342.2	342.0
1984	341.9	341.9	341.7	341.7	341.9	342.1	342.5	343.1	343.4	343.4	343.2	343.0
1985	343.1	342.9	342.8	343.0	343.3	343.6	344.1	344.5	344.8	344.8	344.8	344.6
1986	344.5	344.4	344.4	344.5	344.6	344.9	345.4	345.8	346.0	346.2	346.0	345.8
1987	345.7	345.5	345.5	345.7	346.0	346.4	346.9	347.5	347.9	348.0	348.2	348.1
1988†	347.1	347.5	347.6	347.8	347.9	348.1	348.6	349.3	349.5	349.6	349.4	349.1

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*Atmospheric CO_2 in parts per million by volume (ppmv). All numbers have been rounded to the nearest tenth.

†All 1988 data are preliminary and may change by several tenths of a ppmv based on re-calibrations of the reference gases used for measurements.

ide*

Dec

330.3
331.2
332.8

338.0
338.6
340.0
342.0
343.0
344.6
345.8
348.1
349.1

used

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Cape Matatula (American Samoa)

BACKGROUND

Principal investigators

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Air sample collection – Continuous monitoring of atmospheric CO_2 is accomplished by alternating a flowing sample of ambient air with two reference gases of known concentrations. Details given in Waterman et al. (1989).

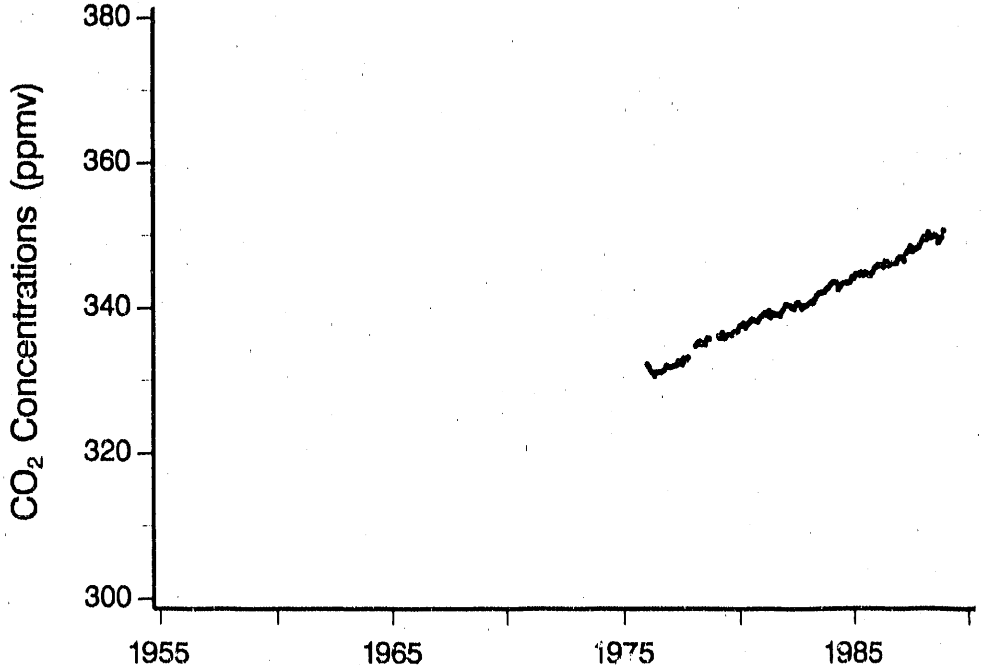
Measurement apparatus – URAS-2 semiautomatic nondispersive infrared gas analyzer manufactured by Hartmann and Braun.

Data selection procedures – See Waterman et al. (1989).

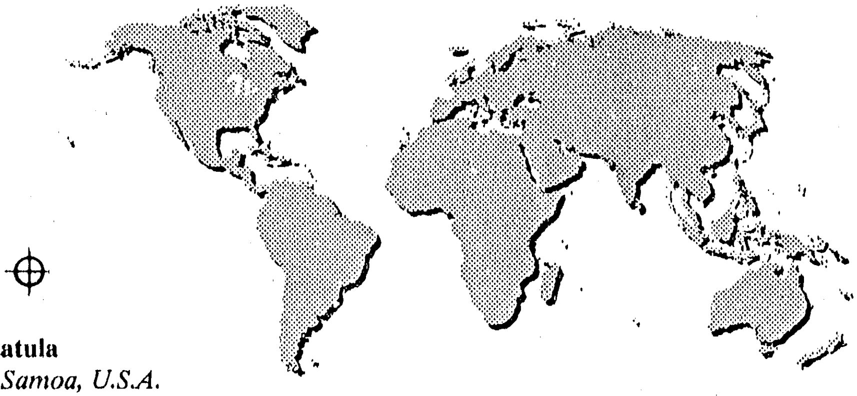
Calibration gases used – CO_2-in-air.

Scale of data reported – SIO X85 mole fraction scale.

Data availability – These monthly CO_2 concentrations from Cape Matatula are available from CDIAC. They are also available from the principal investigator at NOAA/CMDL and WMO.



Monthly atmospheric CO_2 concentrations.



Cape Matatula
American Samoa, U.S.A.
Island rocky promontory
14° 15'S, 170° 34'W
42 m above MSL

TREND

Continuous measurements of atmospheric CO_2 concentration in the Southern Hemisphere were initiated by C.D. Keeling of Scripps Institution of Oceanography (SIO) at Little America, Antarctica, in 1958. A monitoring project to observe the sea-level climate and atmospheric constituents of the tropical Southern Hemisphere was established by the National Oceanic and Atmospheric Administration (NOAA) at Cape Matatula, American Samoa, in 1973. Discrete samples of atmospheric air have been collected in glass flasks at regular intervals at Cape Matatula since that time and have been reported by Komhyr et al. (1985) and Conway et al. (1988). An observatory building was erected in 1975, and continuous CO_2 monitoring has been conducted since December 1975. The continuous CO_2 monitoring program at Cape Matatula, American Samoa, represents one of four baseline atmospheric monitoring stations operated by the Climate Monitoring and Diagnostics Laboratory (CMDL) program of NOAA. The other three sites are located at Barrow, Alaska; Mauna Loa Observatory, Hawaii; and South Pole Station, Antarctica.

Waterman et al. (1989) found that the average growth rate of CO_2 at Cape Matatula for 1976–1987 was 1.44 ppmv per year. For comparison, Conway et al. (1988) reported a growth rate of 1.35 ppmv per year for the flask sampling data from American Samoa for 1981–1984.

Cape Matatula (American Samoa)

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1976	332.2	331.9	331.3	331.1	330.7	331.2	331.1	331.2	313.3	331.5	332.0	331.9
1977	331.8	332.0	332.1	332.1	332.6	332.7	332.2	333.0	332.8	333.2		
1978		334.8	335.2	335.3	335.0	335.2	335.0	335.8	335.8			
1979		336.1	335.7	336.6	335.8	336.0	336.3	336.3	336.3	336.6	336.7	336.9
1980	337.4	337.6	337.9	337.3	337.8	338.0	338.4	338.3	338.2	338.1	338.5	338.8
1981	339.0	339.3	339.0	339.5	338.7	339.3	339.0	339.1	339.11	338.9	339.4	339.8
1982	340.4	340.4	340.3	340.2	340.0	339.9	340.6	340.7	340.36	339.9	340.3	340.2
1983	340.4	340.6	340.8	340.7	341.2	341.7	341.9	342.1	342.05	342.2	342.5	342.8
1984	343.1	343.4	343.5	343.4	342.5	342.9	343.2	343.3	343.39	343.4	343.5	344.1
1985	343.1	344.5	344.6	344.4	344.8	344.5	344.8	344.7	344.41	344.4	344.8	345.3
1986	345.5	345.8	345.8	345.8	345.6	346.3	346.3	345.8	346.01	346.1	346.1	346.1
1987	346.7	346.9	346.8	346.5	347.5	347.8	348.4	347.7	347.98	348.1	348.3	348.8
1988†	349.2	349.7	349.4	350.3	349.6	349.7	349.9	349.8	348.94	349.3	349.8	350.6

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*Atmospheric CO_2 in parts per million by volume (ppmv). All numbers have been rounded to the nearest tenth.

†All 1988 data are preliminary and may change by several tenths of a ppmv based on re-calibrations of the reference gases used for measurements.

lde*

ec

1.9

6.9

8.8

9.8

0.2

2.8

4.1

5.3

6.1

8.8

50.6

sed

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Waterman, L.S., D.W. Nelson, W.D. Komhyr, T.B. Harris, K.W. Thoning, and P.P. Tans. 1989. Atmospheric carbon dioxide measurements at Cape Matatula, American Samoa, 1976–1987. *Journal of Geophysical Research* 94(D12):14817-29.

Mauna Loa

BACKGROUND

Principal Investigators

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Air sample collection – Since November 1984, CMDL has been sampling exclusively from air intake lines on the "high tower" (23 m above ground). Details given in Komhyr et al. (1989).

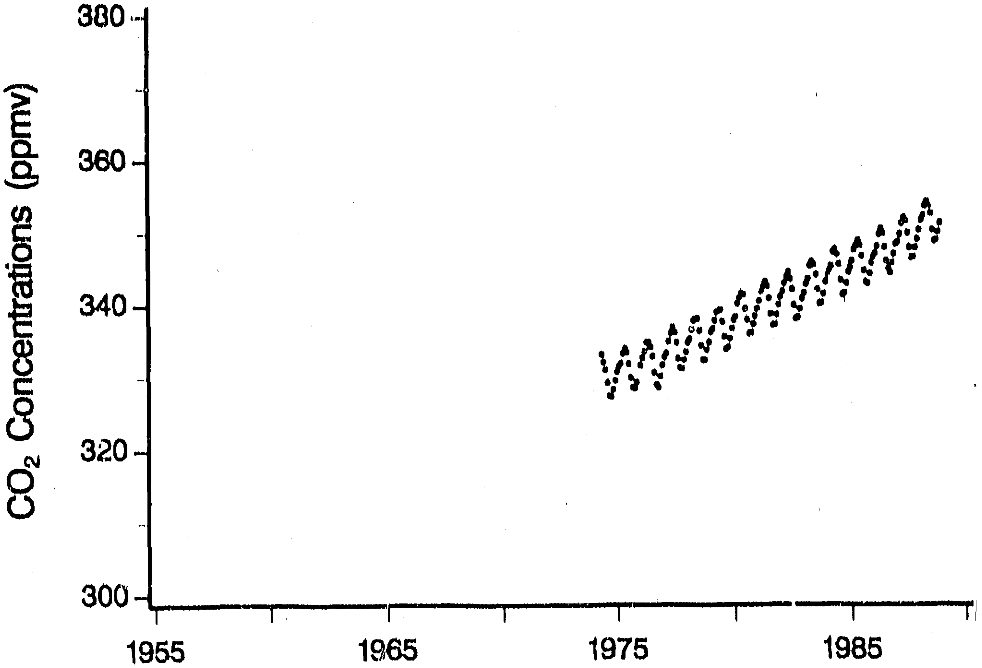
Measurement apparatus – URAS-2 semi-automatic nondispersive infrared gas analyzer.

Data selection procedures – A three-step selection process is used to select background hourly average CO_2 data from Mauna Loa: (1) a preliminary selection based on within-hour variability (2) an hour-to-hour concentration difference criteron that rejects data which change by more than 0.25 ppm from one hour to the next, and (3) a selection based on residuals from a spline fit. Details provided in Thoning (1989) and Thoning et al. (1989).

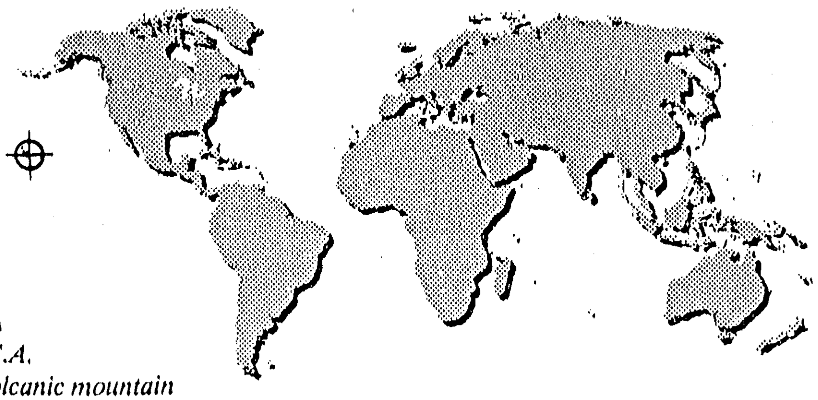
Calibration gases used – CO_2-in-air.

Scale of data reported – SIO X85 mole fraction scale.

Data availability – The monthly and annual CO_2 measurements from the NOAA/CMDL continuous monitoring program at Mauna Loa are also available from the principal investigator and WMO. These monthly and annual averages from Mauna Loa, as well as hourly data, are archived and available from CDIAC.



Monthly atmospheric CO_2 concentrations.



Mauna Loa
Hawaii, U.S.A.
Barren volcanic mountain slope
19° 5'N, 155° 6'W
3397 m above MSL

TREND

Continuous measurements of atmospheric CO_2 concentrations have been made at the Mauna Loa Observatory (MLO) since 1958 by Scripps Institution of Oceanography (SIO). Since 1974, the National Oceanic and Atmospheric Administration's Climate Monitoring and Diagnostics Laboratory (NOAA/CMDL) program has also made continuous measurements of atmospheric CO_2 at MLO independently of SIO. MLO is one of four baseline atmospheric monitoring stations operated by NOAA/CMDL. The other three sites are located at Point Barrow, Alaska; Cape Matatula, American Samoa; and South Pole Station, Antarctica. The SIO and CMDL records of atmospheric CO_2 measurements at MLO constitute some of the most important CO_2 records for studies of the global carbon cycle and CO_2-induced climate change.

Komhyr et al. (1989) reported that the average difference of corresponding monthly mean CO_2 values for the CMDL and SIO data sets was 0.15 ± 0.18 ppmv. Thoning et al. (1989) found that the average growth rate of CMDL continuous CO_2 data from MLO for 1974–1985 was 1.42 ± 0.02 ppmv per year and that the amplitude of the seasonal cycle was increasing at a rate of 0.05 ± 0.02 ppmv. For comparison, Conway et al. (1988) reported a growth rate of 1.21 ppmv per year for the flask sampling data from MLO for 1981–1984.

Mauna Loa

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1974					333.2	332.1	331.0	329.2	327.4	327.3	328.3	329.5	329.7
1975	330.7	331.4	331.8	333.5	333.9	333.4	331.8	329.9	328.6	328.5	329.3		331.1
1976	331.7	332.7	333.5	334.8	334.8	334.1	332.9	330.6	329.0	328.6	330.1	331.6	332.0
1977	332.7	333.2	334.9	336.0	336.8	336.1	334.8	332.5	331.3	331.2	332.4	333.5	333.8
1978	334.7	335.2	336.5	337.8	338.0	338.0	336.4	334.3	332.4	332.3	333.8	334.8	333.4
1979	336.2	336.7	337.8	339.0	339.0	339.2	337.6	335.5	333.8	334.0	335.3	336.7	336.7
1980	337.8	338.3	340.1	340.9	341.5	341.3	339.4	337.8	336.0	336.0	337.2	338.3	338.7
1981	339.4	340.5	341.7	342.5	343.0	342.5	340.8	338.6	337.0	337.1	338.5	339.9	340.1
1982	340.9	341.7	342.8	343.7	344.3	343.4	342.0	339.8	337.9	338.1	339.3	340.7	341.2
1983	341.5	342.7	343.4	345.2	345.8	345.4	344.0	342.0	340.0	340.2	341.4	343.0	342.8
1984	343.9	344.6	345.2	347.1	347.5	346.8	345.4	343.2	341.3	341.5	342.8	344.4	344.5
1985	345.0	345.9	347.5	348.0	348.7	348.1	346.6	344.6	343.0	342.9	344.2	345.6	345.8
1986	346.5	347.0	347.9	349.6	350.4	349.7	347.8	345.9	344.8	344.3	345.7	346.9	347.2
1987	348.2	348.5	349.6	351.1	351.9	351.5	349.8	347.7	346.4	346.5	347.7	348.9	349.0
1988†	350.2	351.5	352.1	353.5	354.0	353.5	352.5	350.2	348.7	348.8	349.9	351.1	351.3

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

†All 1988 data are preliminary and may change by several tenths of a ppmv based on re-calibrations of the reference gases used for measurements.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306. Geneva.

Point Barrow

BACKGROUND

Principal investigators

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James T. Peterson
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Air sample collection – See Komhyr and Harris (1977).

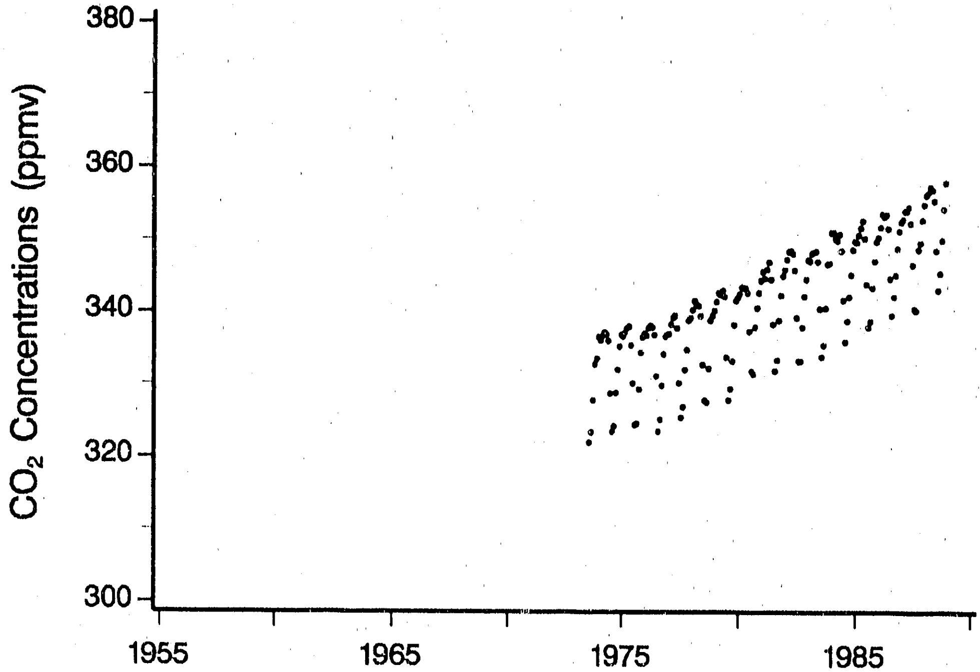
Measurement apparatus – URAS-2T semiautomatic nondispersive infrared gas analyzer manufactured by Hartmand and Braun.

Data selection procedures – Data are rejected based on instability of the CO_2 concentration within consecutive hours. When hour-to-hour change exceeds 0.25 ppm, values for both hours are deleted from the data set. Details about data selection are provided in Peterson et al. (1982, 1986), Thoning et al.(1987), and Thoning et al. (1989).

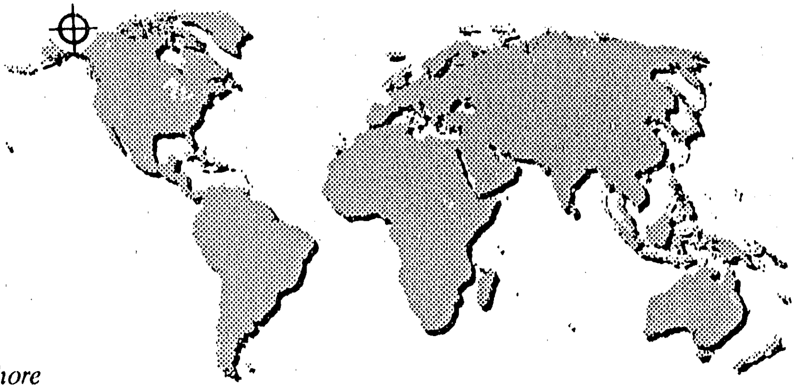
Calibration gases used – CO_2-in-air.

Scale of data reported – SIO X85 mole fraction scale.

Data availability – These monthly data from Point Barrow are available from CDIAC. They are also available from the principal investigator at NOAA/CMDL and WMO.



Monthly atmospheric CO_2 concentrations.



Point Barrow
Alaska, U.S.A.
Coastal seashore
71° 19'N, 156° 36'W
11 m above MSL

TREND

The Air Resources Laboratories of NOAA established a program to conduct continuous measurements of atmospheric CO_2 concentration at Point Barrow, Alaska, in 1973. The continuous CO_2 monitoring program at Point Barrow represents one of four baseline atmospheric monitoring stations operated by the Climate Monitoring and Diagnostics Laboratory (CMDL) program of the National Oceanic and Atmospheric Administration (NOAA). The other three sites are located at American Samoa; Mauna Loa Observatory, Hawaii; and South Pole Station, Antarctica.

Peterson et al. (1982) reported that concentrations of CO_2 at Point Barrow for 1973–1979 rose 4–5 ppmv and exhibited a seasonal cycle of 15.2 ppmv. Conway et al. (1988) reported a growth rate of 1.26 ppmv per year for the flask sampling data from Point Barrow for 1981–1984. Peterson et al. (1982) reported a slight decrease in absolute concentrations for 1976 in comparison with 1975. Atmospheric CO_2 concentrations at Point Barrow show an annual seasonal cycle with yearly minimum values recorded in late August and annual maximum values recorded in late April.

Point Barrow

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1973								322.0	323.4	327.8	332.7	333.5
1974	336.5	336.0	336.7	337.1	336.9	335.9	328.7	323.5	324.2	328.8	332.0	335.2
1975	336.8	336.6	337.1	337.7	337.9	335.4	330.1	324.9	324.6	329.3	334.3	336.5
1976	337.0	336.7	337.7	338.0	337.8	336.8	331.0	323.5	325.1	329.8	334.1	336.6
1977	336.8	336.9	338.2	339.5	339.4	337.7	330.1	325.4	326.8	332.0	334.7	338.8
1978	339.1	340.2	341.5	341.0	340.8	339.4	332.6	327.7	327.4	332.1	338.8	339.4
1979	340.1	341.3	342.5	342.4	342.9	342.0	333.6	327.7	329.3	333.1	338.1	341.5
1980	341.9	342.4	343.4	343.3	343.2	342.6	337.3	331.8	331.4	337.9	340.5	342.6
1981	344.3	345.5	344.6	345.8	346.8	344.4	338.2	331.8	333.3	338.8	342.2	344.9
1982	345.8	347.2	348.3	348.4	348.0	345.7	339.2	333.2	333.2	337.9	342.1	344.5
1983	347.1	347.0	348.0	348.2	348.3	347.0	340.4	333.8	335.4	340.5	346.5	346.7
1984	350.9	350.9	350.0	349.8	350.7	348.2	341.6	335.8	338.7	342.0	345.0	348.5
1985	349.7	349.5	350.5	351.5	352.5	350.1	343.8	337.8	338.7	343.3	346.9	349.7
1986	350.2	351.6	353.4	353.1	353.3	351.4	344.5	339.5	342.0	345.0	348.7	351.1
1987	352.4	352.7	353.9	353.9	354.4	352.2	346.5	340.4	340.2	348.6	349.5	352.6
1988†	354.8	356.1	356.4	357.2	356.8	355.3	348.4	343.0	345.3	349.8	354.2	357.8

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*Atmospheric CO_2 in parts per million by volume (ppmv). All numbers have been rounded to the nearest tenth.

†All 1988 data are preliminary and may change by several tenths of a ppmv based on re-calibrations of the reference gases used for measurements.

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Thoning, K.W., P.P. Tans, and W.D. Komhyr. 1989. Atmospheric carbon dioxide at Mauna Loa Observatory 2. Analysis of the NOAA GMCC data, 1974–1985. *Journal of Geophysical Research* 94(D6):8549–65.

Amsterdam Island

BACKGROUND

Principal investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

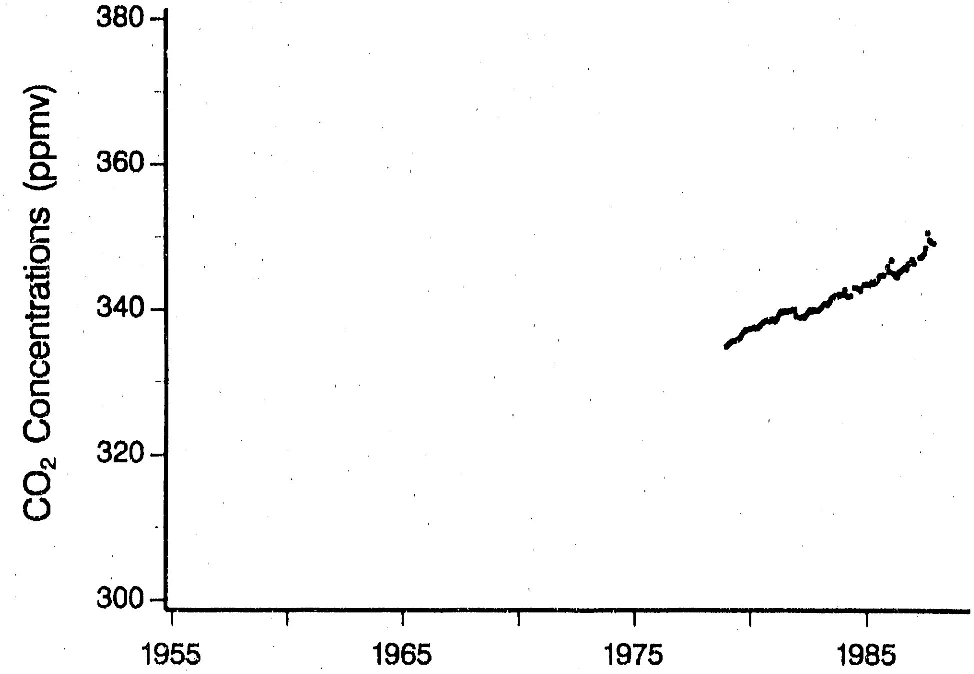
Measurement apparatus – UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985).

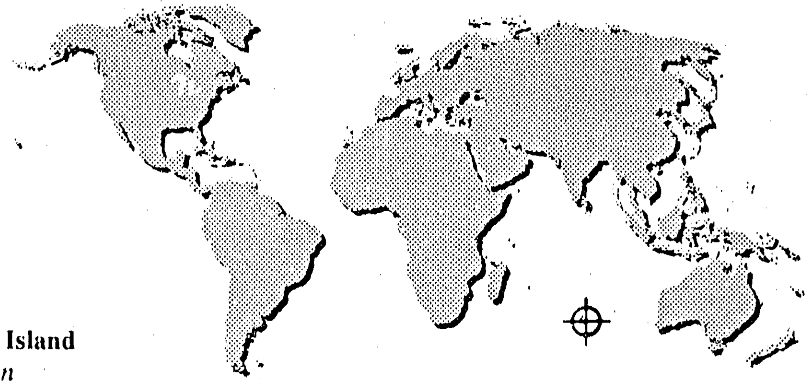
Calibration gases used – CO_2-in-air.

Scale of data reported – 1979–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values, with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Amsterdam Island
Indian Ocean
Island seashore
37° 52′S, 77° 32′E
150 m above MSL

TREND

The sampling site on Amsterdam Island is operated in cooperation with the French Centre des Faibles Radioactivities. Except during the summer (December–February), when this island is within the wind regime of the westerlies, the monthly mean concentrations from Amsterdam Island can be considered as representative of the background subantarctic atmosphere (Gaudry et al. 1983).

The NOAA flask data from Amsterdam Island have shown an increase in the annual value from 335.9 ppmv in 1979 to 348.2 ppmv in 1987. Conway et al. (1988) reported a 1.33-ppmv mean annual growth rate at Amsterdam Island for 1981–1984. Conway et al. (1988) found a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites. Ascencio-Parvy et al. (1983) found a 0.11 ppmv-per-month increase in atmospheric CO_2 concentrations at Amsterdam Island from October 1980 to November 1983. Both Conway et al. (1988) and Ascencio-Parvy et al. (1983) found considerable variability within each year and suggested that the growth rate minimum in 1982 and the growth rate maximum in 1983 may be due partly to the 1982/1983 El Niño event.

Atmospheric CO_2 concentrations at Amsterdam Island show a seasonal pattern, with the annual drawdown typically occurring in December-January and the annual buildup occurring in May–June. Conway et al. (1988) found the average peak-to-peak amplitude for Amsterdam Island to be 0.84 ppmv.

Amsterdam Island

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1979	334.8	335.1	335.3	335.5	335.6	335.7	335.8	336.0	336.4	336.8	337.1	337.1	335.9
1980	337.2	337.3	337.4	337.3	337.3	337.6	337.9	338.1	338.3	338.4	338.5	338.5	337.8
1981	338.6	338.3	338.6	339.2	339.6	339.5	339.7	339.6	339.7	339.7	339.9	339.9	339.4
1982	339.0		338.8	338.9	338.8	339.1	339.5	339.8	339.7	339.9	339.8	339.8	339.4
1983	339.9	340.2	340.5	340.7	340.6	340.9	341.4	341.6	341.8	341.7	342.0	341.9	341.1
1984	342.0	342.6	341.8	341.7	341.8		342.9	342.9	342.8	342.5		343.3	342.4
1985	343.4		343.3	343.7	343.5	343.7	344.0	344.5	344.6	344.6		345.8	344.1
1986	345.1	346.7	344.9	344.6	344.4	345.0	345.2	345.4	345.7	345.5	346.2		345.3
1987	346.8	346.3			347.1	347.2	347.6	348.4	350.5	349.5	349.2	349.1	348.2

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD -No. 306. Geneva.

Amundsen Scott (South Pole)

BACKGROUND

Principal Investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

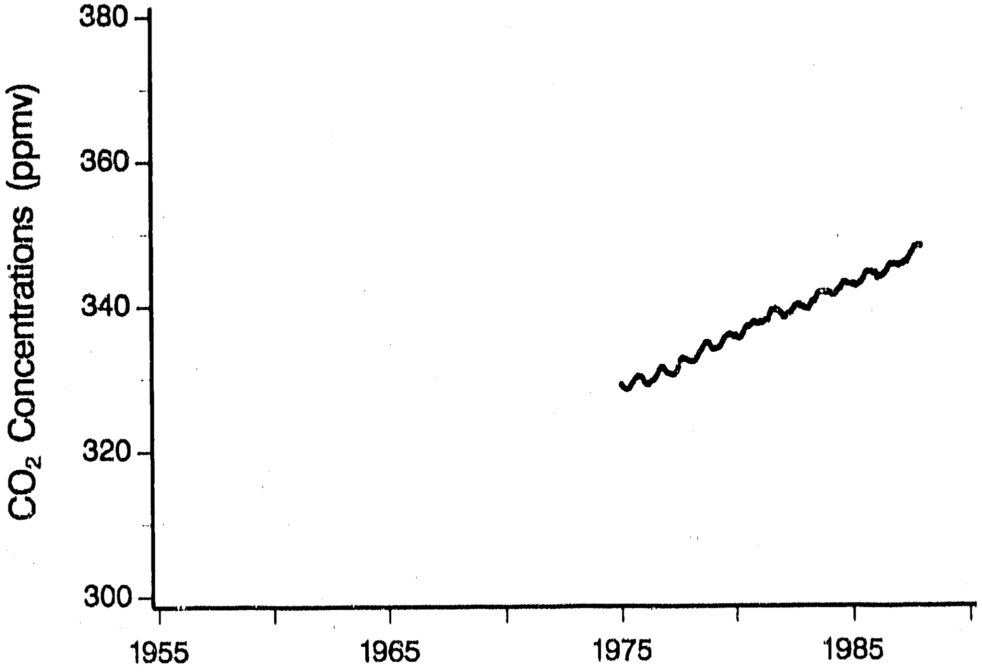
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder, using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

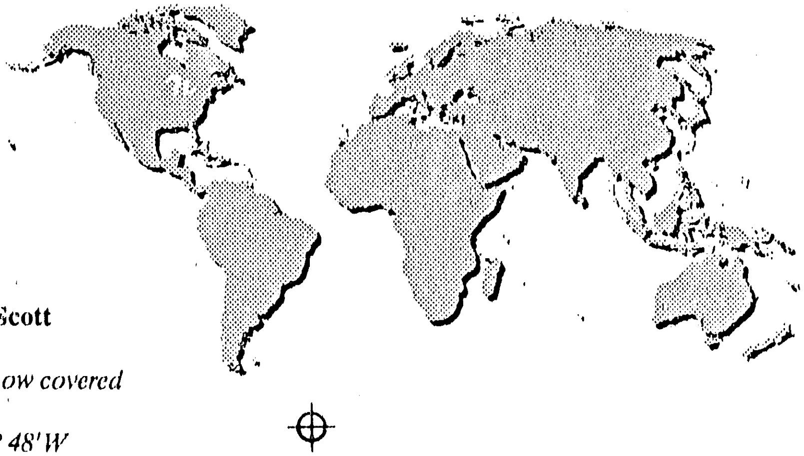
Calibration gases used – CO_2-in-air.

Scale of data reported – 1975–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values, with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Amundsen Scott
Antarctica
Ice and snow covered plateau
89° 59′S, 24° 48′W
2810 m above MSL

TREND

The sampling site at Amundsen Scott is operated in cooperation with the National Science Foundation.

The NOAA/CMDL flask data from Amundsen Scott show an increase in the annual value from 329.4 ppmv in 1975 to 346.8 ppmv in 1987. Conway et al. (1988) reported a 1.22-ppmv mean annual growth rate for both Amundsen Scott and all the NOAA/CMDL flask sampling sites, collectively, for 1981–1984.

Atmospheric CO_2 concentrations at Amundsen Scott show a seasonal pattern with the annual drawdown typically occurring in December–January and the annual buildup occurring in June–July. Conway et al. (1988) reported the peak-to-peak seasonal amplitude for Amundsen Scott to be 1.25 ppmv for 1981–1984.

Amundsen Scott (South Pole)

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1975	329.1	328.8	328.6	328.5	328.6	329.0	329.4	329.8	330.1	330.3	330.2	330.0	329.4
1976	329.5	329.2	329.1	329.4	329.6	329.8	330.1	330.6	331.2	331.5	331.5	331.1	330.2
1977	330.8	330.7	330.6	330.5	330.6	330.9	331.5	332.4	332.8	332.7	332.6	332.5	331.5
1978	332.4	332.3	332.3	332.6	333.0	333.5	333.9	334.3	334.8	334.9	334.8	334.3	333.6
1979	334.0	334.0	334.1	334.2	334.4	334.9	335.4	335.7	335.9	336.0	335.9	335.7	335.0
1980	335.9	335.6	335.5	335.7	336.2	336.8	337.1	337.1	337.3	337.6	337.7	337.5	336.7
1981	337.5	337.7	337.6	337.8	338.0	338.0	338.8	339.3	339.3	339.4	339.3	339.1	338.5
1982	338.9	338.4	338.4	338.7	338.9	339.0	339.4	339.8	340.0	340.1	339.8	339.8	339.3
1983	339.6	339.5	339.5	340.0	340.5	340.5	341.0	341.6	341.7	341.8	341.8	341.7	340.8
1984	341.8	341.7	341.5	341.4	341.6	342.0	342.2	342.7	343.1	343.1	342.9	342.9	342.3
1985	342.8	342.9	342.6	342.8	343.0	343.3	343.7	344.3	344.5	344.5	344.5	344.3	343.6
1986	344.4	343.7	344.0	343.9	344.1	344.4	344.8	345.3	345.6	345.5	345.6	345.5	344.7
1987	345.4	345.6	345.6	345.9	345.9	346.4	347.0	347.3	347.9	348.0	348.1	348.1	346.8

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

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REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

Conway, T.J. and P. Tans. 1990. Atmospheric CO_2 concentrations—The NOAA/GMCC flask sampling network. NDP-005/R1. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor, and K.W. Thoning. 1985a. Global atmospheric CO_2 distributions and variations from 1968–82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–96.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

Ascension Island

BACKGROUND

Principal investigators

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Air sample collection: – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

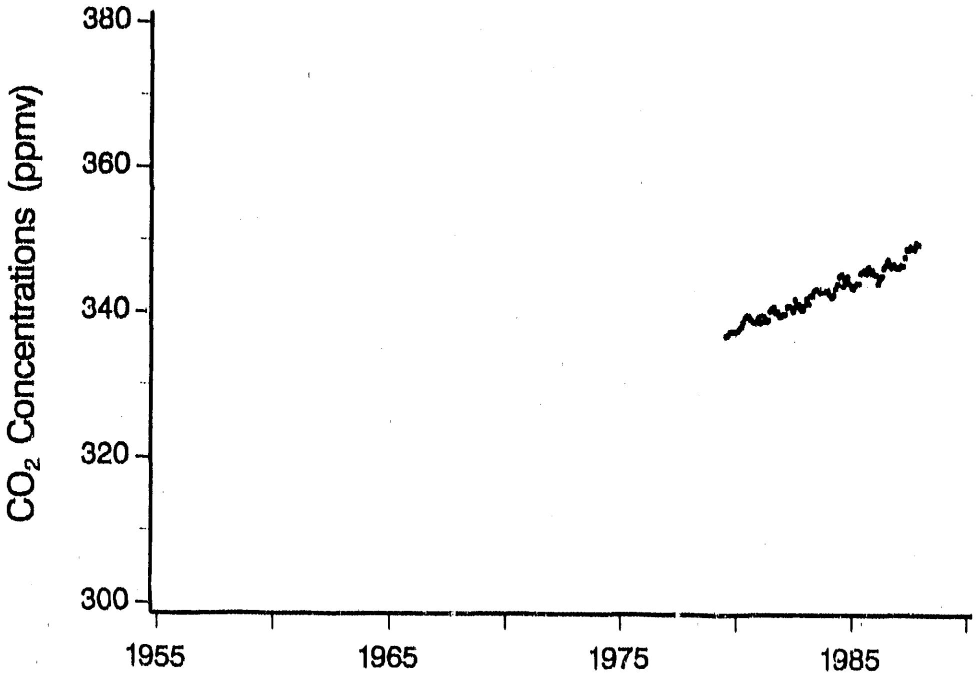
Measurement apparatus – UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

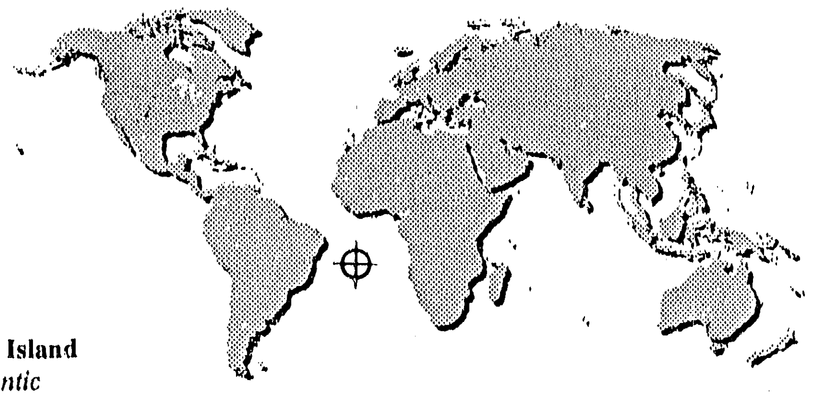
Calibration gases used – CO_2-in-air.

Scale of data reported – 1979–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values, with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Ascension Island
South Atlantic
Island seashore
7° 55'S, 14° 25'W
54 m above MSL

TREND

The sampling site on the Ascension Island is operated in cooperation with the United States Air Force and Pan American World Airways.

The NOAA/CMDL flask data from Ascension Island show an increase in the annual value from 338.8 ppmv in 1980 to 348.1 ppmv in 1987. Conway et al. (1988) reported a 1.30-ppmv mean annual growth rate at Ascension Island for 1981–1984 in comparison with a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Ascension Island show a seasonal pattern, with the annual drawdown typically occurring in December–January and the annual buildup occurring in May–June. Conway et al. (1988) found that the seasonality at Ascension Island does not appear to be affected by transport of northern air and reported the peak-to-trough seasonal amplitude for Ascension Island to be 2.00 ppmv for 1981–1984.

Ascension Island

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1979								337.0	337.1	337.5	337.6	337.6	
1980	337.6	337.7	338.0	338.3	338.9	339.5	339.8	339.7	339.3	339.0	338.8	338.8	338.8
1981	339.5	338.8	339.7	339.6	339.0	339.2	340.4	340.7	340.9	340.2	340.3	339.7	339.8
1982	339.7	340.0	340.0	341.0	341.0	341.0	340.4	342.0	341.1	341.4	340.7	340.6	340.7
1983	341.2	342.1	341.4	342.5	342.5	343.2	343.4	343.3	343.0	343.4	343.1	343.1	342.7
1984	343.2	342.7	342.3	342.6	343.5	344.1	345.2	345.4	343.9	344.6	345.1	344.2	343.9
1985	343.9	343.5	343.9	344.2	344.2	345.6	345.8	346.0	345.6	346.4	345.7	346.0	345.1
1986	345.5	345.4	344.2	344.8	345.2	346.3	346.7	347.4	346.8	346.4	346.8	346.5	346.0
1987	346.3	346.3	346.7	346.6	347.8	348.9	348.8	349.2	349.0	348.9	349.7	349.5	348.1

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

de*

nn

8.8
9.8
0.7
2.7
3.9
5.1
6.0
8.1

to

REFERENCES

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Conway, T.J. and P. Tans. 1990. Atmospheric CO_2 concentrations – The NOAA/GMCC flask sampling network. NDP-005/R1. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Komhyr, W.D., L.S. Waterman, and W.R. Taylor. 1983. Semiautomatic nondispersive infrared analyzer apparatus for CO_2 air sample analyses. *Journal of Geophysical Research* 88:1315--22.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

Cape Grim

BACKGROUND

Principal investigators:

Thomas J. Conway
Pieter Tans
Lee S. Waterman
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

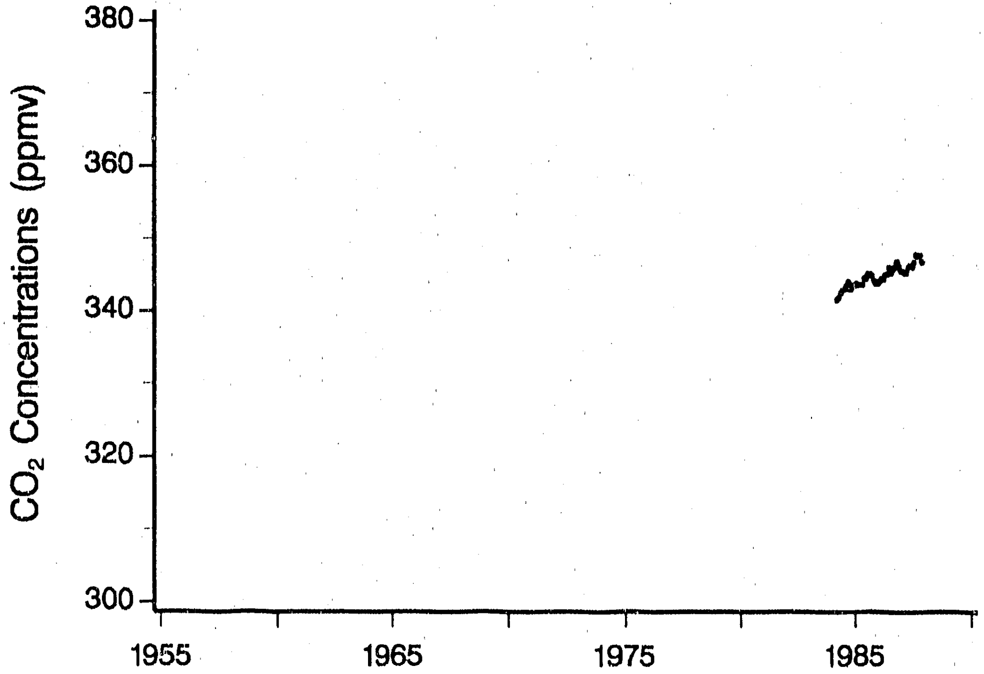
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

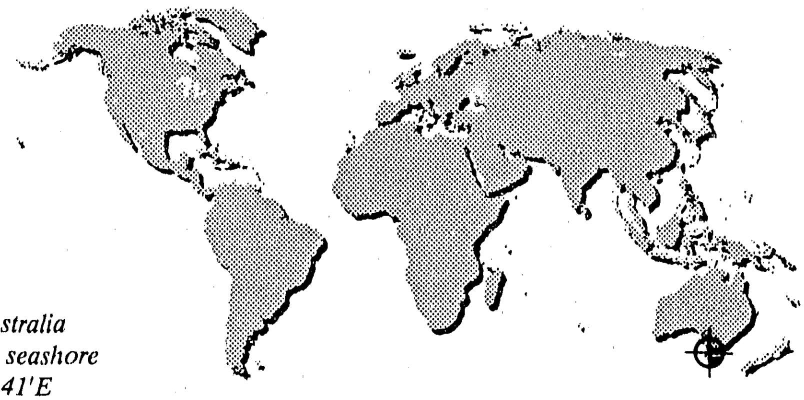
Calibration gases used – CO_2-in-air.

Scale of data reported – 1982–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values, with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Cape Grim
Tasmania, Australia
Promontory seashore
40° 41'S, 144° 41'E
94 m above MSL

TREND

The sampling site at Cape Grim, Tasmania, is operated in cooperation with Graeme Pearman and Paul Fraser of the Commonwealth Scientific and Industrial Research Organization's (CSIRO's) Division of Atmospheric Research. Cape Grim replaced Kaitorete Spit, New Zealand, after it was established that Cape Grim was a more suitable site for representative measurements at this latitude (Conway et al. 1988). From the outset of this cooperative program, samples have been taken in 0.5-L flasks. However, two sampling procedures have been used. One of the procedures is used at all the NOAA/CMDL flask sampling sites and is detailed in Komhyr et al. (1985a) and Conway et al. (1988). The second procedure differs in that the air samples are dried by passage through a glass column packed with anhydrous, granular magnesium perchlorate. This procedure is detailed in CSIRO (1989). Data derived from both procedures are given in the accompanying table.

From 1984–1987, annual average concentrations of CO_2 at Cape Grim, calculated on the basis of undried air samples, have risen from 342.9 to 346.3 ppmv. This represents an annual increase of 0.85 ppmv at Cape Grim in comparison with the increase of 1.22 ppmv per year reported by Conway et al. (1988) for all NOAA/CMDL flask sampling sites from 1981–1984.

Cape Grim

Atmospheric Concentrations of Carbon Dioxide*

Air samples collected undried with the portable batter-powered sampling unit

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1984				341.5	341.8	342.4	342.8	342.9	343.4	343.9	342.7	343.4	342.9
1985	343.4	343.7	343.5		343.5	344.4	344.3	345.0	345.0	344.8	344.1	343.7	344.1
1986	343.7	344.0	344.3	344.3	344.9	345.0	345.9	345.2	345.7	346.0	346.7	346.1	345.2
1987	345.5	345.4	345.2	345.2	346.0	346.2	346.0	346.6	347.7	347.5	347.6	346.7	346.3
Data from dried samples taken through the sampling stack													
1984				341.3	341.6	341.9	342.9		343.2	343.0	342.9	342.7	342.4
1985	342.5	342.5	342.7	342.8	342.8	343.2	343.9	344.4	344.4	344.3	344.1	344.0	343.5
1986	343.8	343.9	344.1	343.9	344.2	344.5	344.9	345.0	345.2	345.7	345.7	345.3	344.7
1987	345.0	344.9	345.1		345.8	346.0	346.5	347.2	347.7	347.8	348.0	347.8	346.5

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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Komhyr, W.D., T.B. Harris, and L.S. Waterman. 1985b. Calibration of nondispersive infrared CO_2 analyzers with CO_2-in-air reference gases. *Journal of Atmospheric and Oceanic Technology* 2:82–88.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva, Switzerland.

Cape Kumukahi

BACKGROUND

Principal investigators

Thomas J. Conway
Pieter Tans
Lee S. Waterman
National Oceanic and Atmospheric Administration
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325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

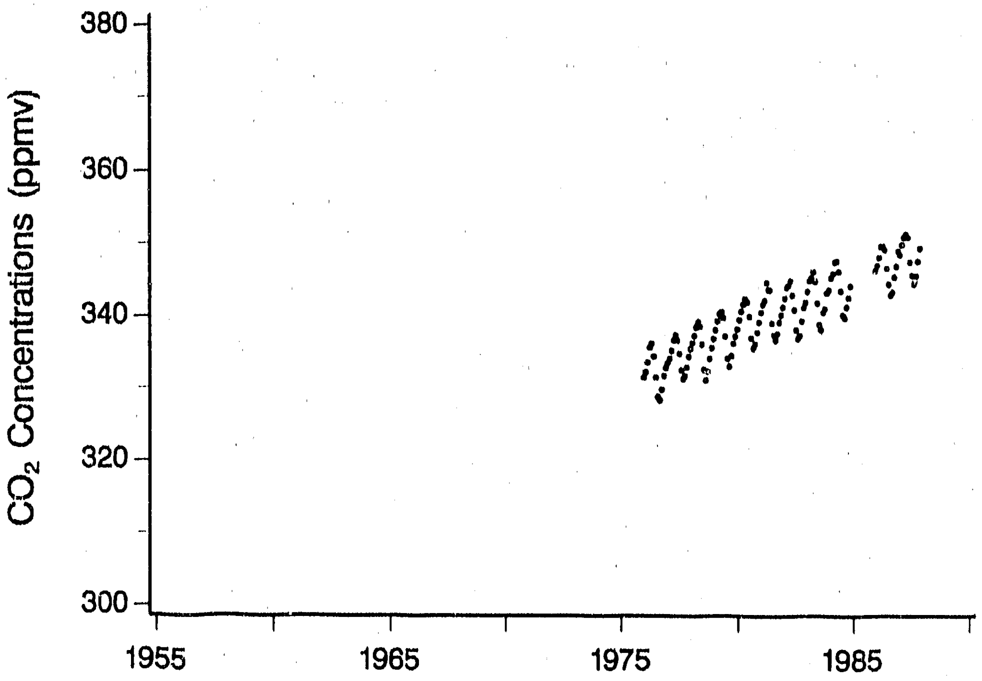
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

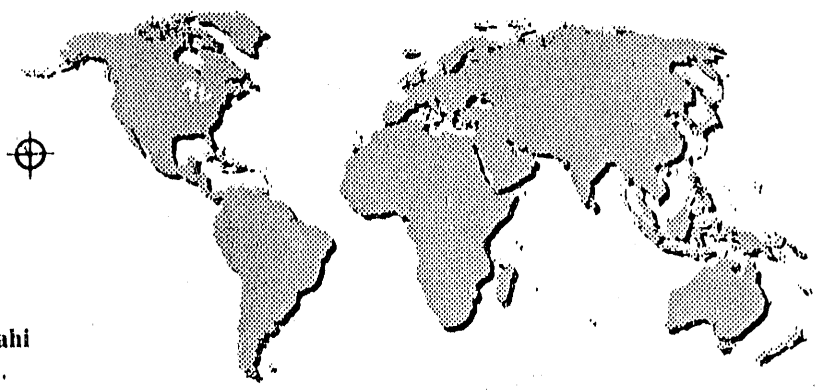
Calibration gases used – CO_2-in-air.

Scale of data reported – 1976–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values, with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Cape Kumukahi
Hawaii, U.S.A.
Island seashore
19° 31'N, 154° 49'W
3 m above MSL

TREND

The sampling site at Cape Kumukahi is operated in cooperation with the United States Air Force and Pan American World Airways.

The NOAA/CMDL flask data from Cape Kumukahi show an increase in the annual value from 332.3 ppmv in 1976 to 348.5 ppmv in 1987. Conway et al. (1988) reported a 1.15-ppmv mean annual growth rate at Cape Kumukahi for 1981–1984 in comparison with a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Cape Kumukahi show a seasonal pattern with the annual drawdown typically occurring in July and the annual buildup occurring in December–January. Conway et al. (1988) reported the peak-to-trough seasonal amplitude for Cape Kumukahi to be 8.87 ppmv for 1981–1984.

Cape Kumukahi

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1976	331.6	332.3	333.7	335.8	336.3	334.5	331.6	328.9	328.4	329.9	331.8	332.9	332.3
1977	333.6	334.2	335.3	336.8	337.5	336.8	334.9	332.6	331.4	331.8	333.0	334.5	334.4
1978	335.6	336.4	337.4	338.6	339.3	338.7	336.2	332.7	331.2	332.4	334.2	335.7	335.7
1979	337.0	338.2	339.4	340.4	340.7	339.9	337.3	334.2	333.1	334.6	336.3	337.3	337.4
1980	338.3	339.6	340.8	341.8	342.5	342.1	340.1	337.1	335.7	336.3	337.9	339.3	339.3
1981	340.7	341.8	342.3	344.8	343.8	343.8	339.2	337.5	336.8	337.7	339.3	340.3	340.7
1982	341.4	342.6	344.1	344.4	345.0	343.0	341.0	338.2	337.0	337.4	339.4	341.3	341.2
1983	342.0	343.5	345.0	345.4	346.2	344.9	341.9	338.9	338.2	340.6	341.1	343.3	342.6
1984	343.7	345.4	346.0	347.6	347.7	346.3	343.6	340.3	339.9	341.4	342.7	344.3	344.1
1985													
1986	346.4	347.1	348.2	349.7	349.7	349.3	346.7	344.5	343.0	343.4	345.5	347.0	346.7
1987	349.1	348.6	350.0	351.0	351.4	351.0	347.6	345.8	344.6	345.7	347.7	349.5	348.5

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

de*
nn
2.3
4.4
5.7
7.4
9.3
0.7
1.2
2.6
4.1
6.7
8.5
to

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306. Geneva.

Cape Matatula (American Samoa)

BACKGROUND

Principal Investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

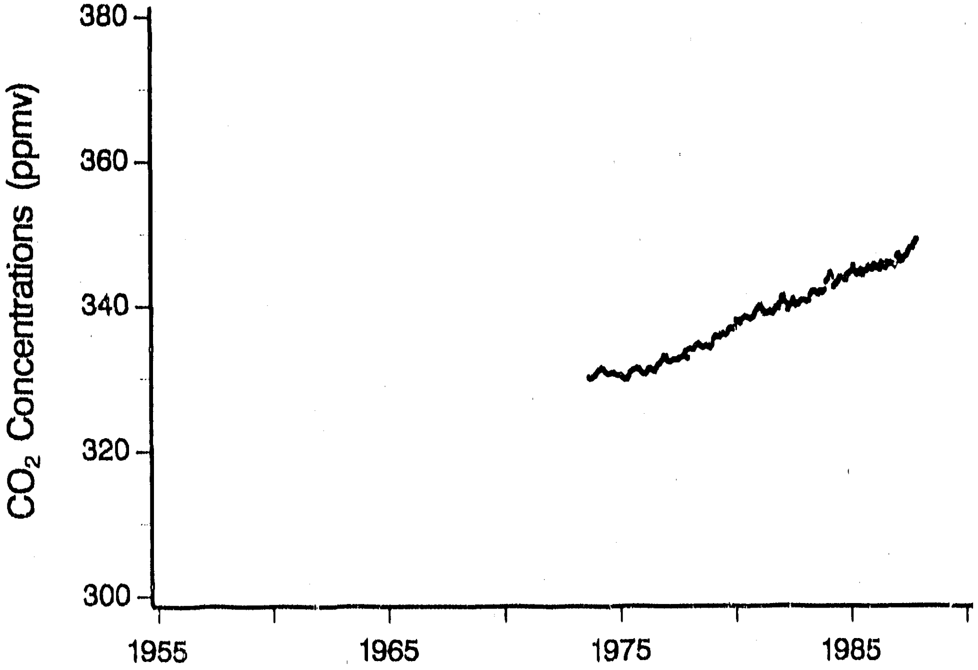
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

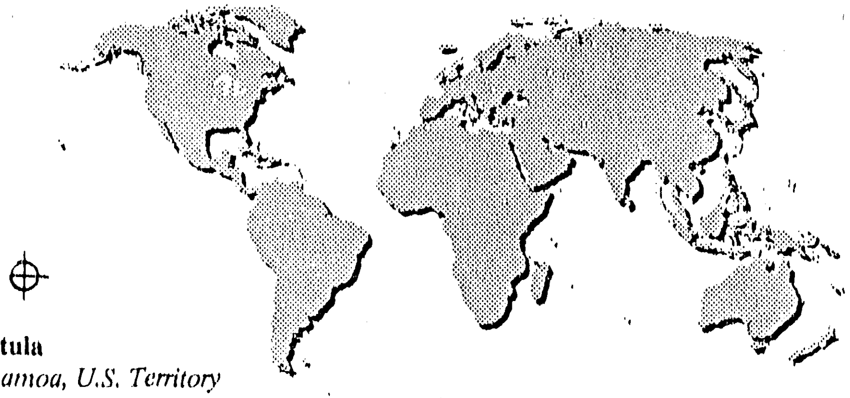
Calibration gases used – CO_2-in-air.

Scale of data reported – 1973–1983, SIO X83 mole fraction scale; 1984–1987 SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values, with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Cape Matatula
American Samoa, U.S. Territory
South Pacific
Island rocky promontory
14° 15'S, 170° 34'W
42 m above MSL

TREND

The NOAA/CMDL flask data from American Samoa show an increase in the annual value from 330.9 ppmv in 1974 to 347.1 ppmv in 1987. Conway et al. (1988) reported a 1.35-ppmv mean annual growth rate at American Samoa for 1981–1984 in comparison with a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites. Conway et al. (1988) reported the peak-to-trough seasonal amplitude for American Samoa to be 1.40 ppmv for 1981–1984.

Cape Matatula (American Samoa)

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1973									330.1	330.0	330.1	330.3	
1974	330.6	331.0	331.2	331.4	331.2	330.9	330.7	330.7	330.8	330.8	330.6	330.5	330.9
1975	330.4	330.4	330.1	329.9	329.9	330.3	330.9	331.1	331.2	331.4	331.3	331.0	330.7
1976	330.7	330.6	330.8	331.3	331.4	331.1	331.0	331.5	331.9	332.1	332.5	333.1	331.5
1977	333.0	332.4	332.3	332.5	332.6	332.6	332.6	332.8	332.9	332.9	333.1	333.7	332.8
1978	334.0	334.0	334.0	334.3	334.6	334.7	334.5	334.3	334.3	334.5	334.4	334.2	334.3
1979	334.6	335.4	335.8	335.7	335.7	336.0	336.1	336.0	336.2	336.7	336.9	336.8	336.0
1980	337.0	338.0	338.0	337.6	338.1	338.3	338.5	338.4	338.3	338.2	338.4	338.9	338.1
1981	339.4	339.7	340.0	339.4	338.9	338.9	339.1	339.2	338.9	339.2	339.7	339.6	339.3
1982	340.2	341.1	341.2	340.4	339.4	339.9	340.2	340.8	340.0	340.1	340.3	340.6	340.4
1983	340.7	340.7	340.6	340.7	341.5	341.9	342.0	341.8	341.6	342.0	341.8	342.1	341.5
1984	343.3	343.6	344.4	343.9	342.6	342.9	343.2	343.8	343.8	343.6	343.5	344.2	343.5
1985	344.4	344.6	345.4	344.7	344.3	344.4	344.9	344.2	344.8	344.8	345.3	345.0	344.7
1986	345.4	345.6	345.5	345.1	345.0	345.9	345.6	345.2	345.9	345.6	345.8	345.7	345.5
1987	345.5	346.8	347.0	346.1	346.2	346.6	346.9	347.4	347.9	347.9	348.5	349.0	347.1

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor, and K.W. Thoning. 1985a. Global atmospheric CO_2 distributions and variations from 1968–82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–96.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306. Geneva.

Cape Meares

BACKGROUND

Principal investigators

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Pieter Tans
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National Oceanic and Atmospheric Administration
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

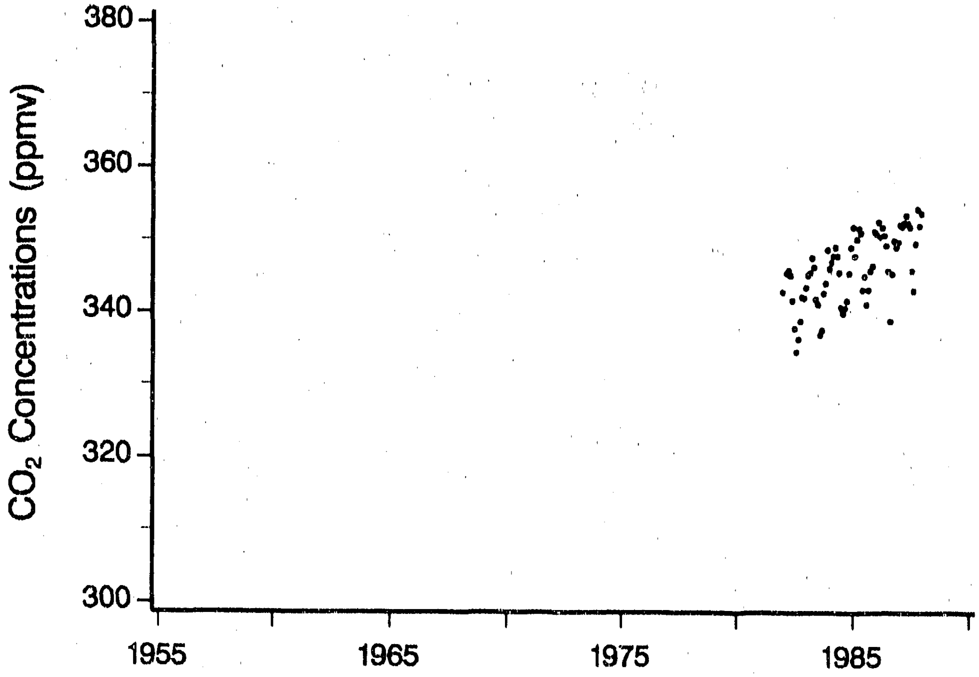
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

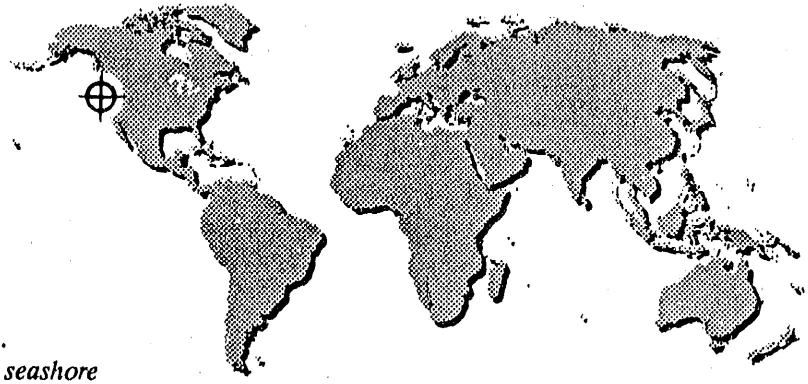
Calibration gases used – CO_2-in-air.

Scale of data reported – 1982–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values, with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Cape Meares
Oregon, U.S.A.
Promontory seashore
45° 29′N, 120° 00′W
30 m above MSL

TREND

The sampling site at Cape Meares is operated in cooperation with the Oregon Graduate Institute of Science and Technology. The NOAA/CMDL flask data from Cape Meares show an increase in the annual value from 341.0 ppmv in 1982 to 350.9 ppmv in 1987. This represents an increase of ~ 1.7 ppmv per year in comparison with a global growth rate of 1.22 ppmv per year reported by Conway et al. (1988) for all NOAA/CMDL flask sampling sites for 1981–1984.

Atmospheric CO_2 concentrations at Cape Meares show a seasonal pattern, with the annual minimum recorded during August and the annual maximum recorded during January–April.

Cape Meares

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1982	342.7		345.3	345.7	345.0	341.5	337.7	334.5	336.2	338.7	342.0	341.9	341.0
1983	343.3	345.0	345.3	347.4	346.1	341.7	341.0	336.8	337.4	342.5	343.9	348.5	343.2
1984	345.9	346.8	347.7	348.9	347.7	345.4	340.6	339.8	340.5	341.5	345.3	348.9	344.9
1985	351.7	347.7	350.0	351.5	350.9		344.9	341.0	343.0	345.6	346.3	351.1	347.9
1986	350.8	352.4	350.4	351.6	350.5	349.1	345.6	338.7	345.2	349.8	348.9	349.6	349.5
1987	352.0	351.8	352.3	353.3	352.2	351.7	345.7	342.9	349.4	354.2	351.9	353.6	350.9

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

Christmas Island

BACKGROUND

Principal investigators

Thomas J. Conway
Pieter Tans
Lee S. Waterman
National Oceanic and Atmospheric Administration
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325 Broadway
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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

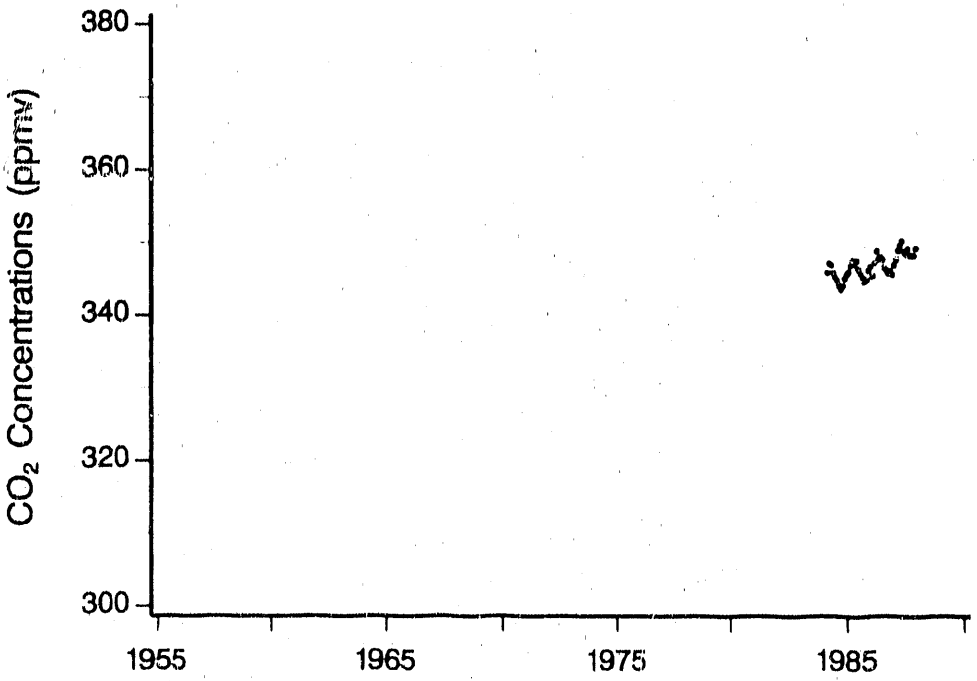
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder, using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

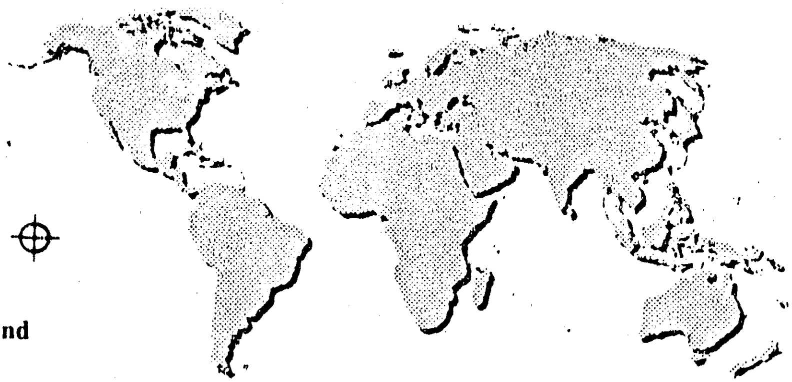
Calibration gases used – CO_2-in-air.

Scale of data reported – 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values, with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Christmas Island
Kiribati
Island seashore
2° 00′ N, 157° 18′ W
3 m above MSL

TREND

The sampling site on Christmas Island is operated in cooperation with the Scripps Institution of Oceanography.

The NOAA/CMDL flask data from Christmas Island show an increase in the annual value from 345.1 ppmv in 1984 to 348.4 ppmv in 1987. From 1984–1987, the annual average CO_2 concentration at Christmas Island showed a 0.83 ppmv per year increase. Conway et al. (1988) found a global growth rate of 1.22 ppmv per year for all NOAA/CMDL flask sampling sites from 1981–1984.

Based on the few years of data available, atmospheric CO_2 concentrations at Christmas Island show variable seasonal patterns. From 1985–1987, annual minimum values were measured in October, February, and January, respectively. For the same time period, the annual high was recorded during either April or May of each year.

Christmas Island

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1984			345.6	346.9	346.7	345.6	345.0	344.6	343.9	343.4	343.9	344.9	345.1
1985	345.4	345.8	346.7	347.4	346.9	347.3	346.2	345.6	345.1	344.5	344.7	346.0	346.0
1986	346.5	345.2	347.0	348.6	347.5	347.8	347.4	346.3	346.0	345.5	345.9	345.4	346.6
1987	346.7	347.4	348.7	349.4	350.0	348.6	348.3	349.0	348.1	348.1	348.1	349.1	348.4

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

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REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306, Geneva.

Cold Bay

BACKGROUND

Principal investigators

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Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

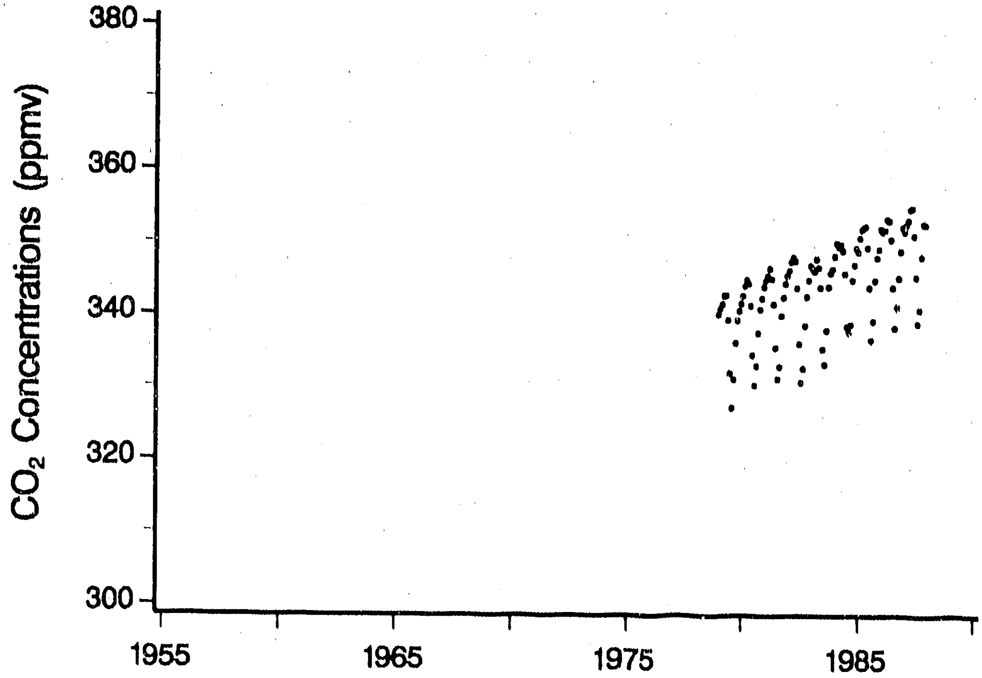
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

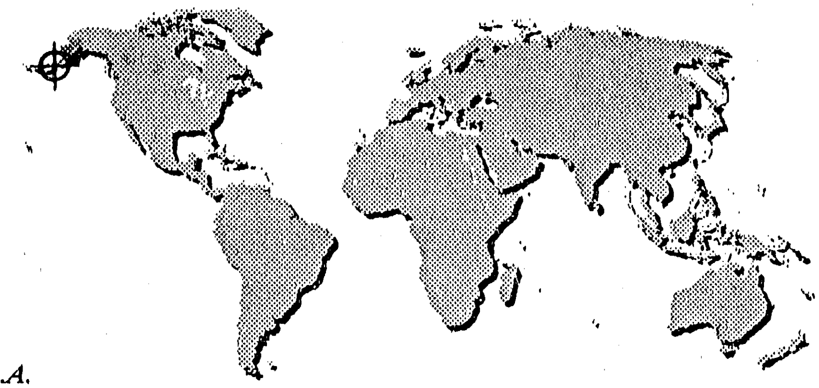
Calibration gases used – CO_2-in-air.

Scale of data reported – 1979–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Cold Bay
Alaska, U.S.A.
Treeless peninsula
55° 12'N, 162° 43'W
11 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The sampling site at Cold Bay, Alaska, is operated in cooperation with the National Weather Service. The NOAA/CMDL flask data from Cold Bay show an increase in the annual value from 337.7 ppmv in 1979 to 349.6 ppmv in 1987. Conway et al. (1988) reported a 1.44-ppmv mean annual growth rate at Cold Bay for 1981–1984 in comparison with a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Cold Bay show a seasonal pattern, with the annual drawdown typically in June and the annual buildup occurring in November. Conway et al. (1988) found the average peak-to-trough amplitude for Cold Bay to be 14.27 ppmv from 1981–1984.

Cold Bay

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1979	340.1	340.9	341.5	342.7	342.7	339.3	332.0	327.2	331.1	336.1	339.2	340.5	337.7
1980	341.5	342.6	344.0	344.8	344.3	341.3	334.5	330.3	333.0	337.5	340.8	342.3	339.7
1981	343.9	344.8	345.4	346.4	345.2	341.5	335.5	331.2	332.9	339.9	342.4	344.3	341.1
1982	345.4	346.1	347.3	347.9	347.4	343.7	336.0	330.7	332.6	338.5	342.5	344.8	341.9
1983	346.8	346.4	346.0	347.7	346.5	343.8	335.3	333.2	337.9	343.9	345.8	346.3	343.3
1984	348.1	349.9	349.4	349.7	348.9	345.7	338.4	337.7	338.7	344.8	346.9	349.2	345.6
1985	348.7	350.6	351.8	352.0	352.2	349.3	343.8	336.6	339.2	344.8	347.9	349.1	347.2
1986	351.9	351.5	351.7	353.2	353.0	350.4	343.8	338.2	341.1	345.1	348.8	352.1	348.8
1987	351.5	352.5	353.1	354.6	354.8	351.0	345.3	338.9	340.8	348.1	352.6	352.5	349.6

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

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REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

Halley Bay

BACKGROUND

Principal investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

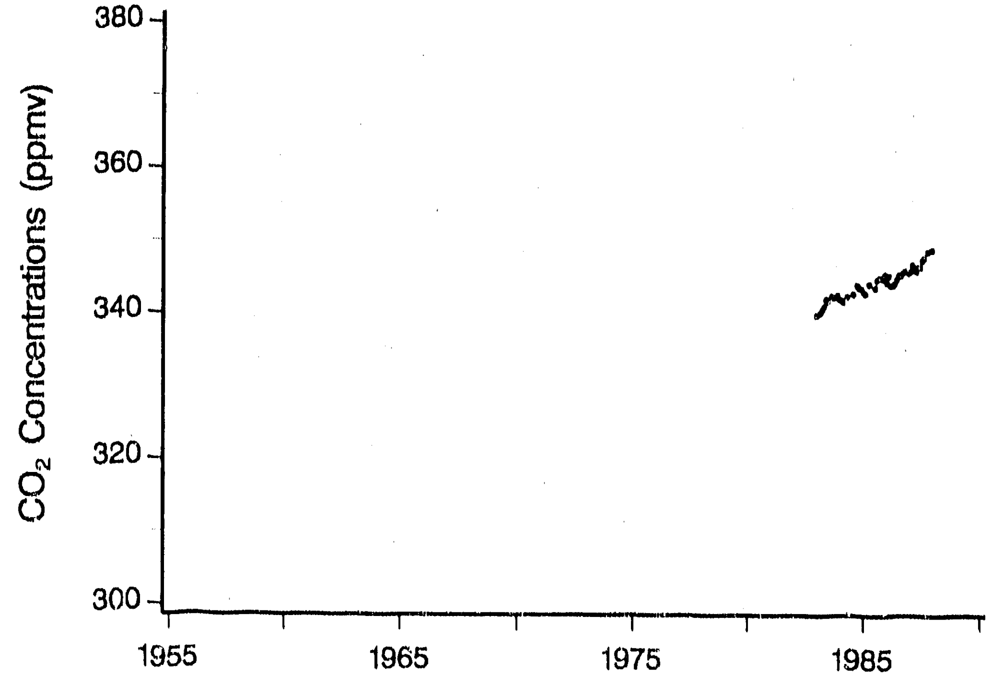
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

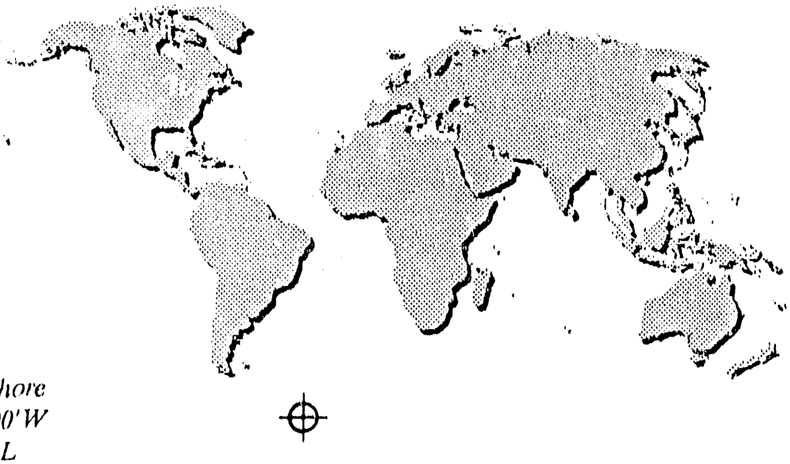
Calibration gases used – CO_2-in-air.

Scale of data reported – 1983 (SIO X83 mole fraction scale) 1984–1987 (SIO X85 mole fraction scale).

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Halley Bay
Antarctica
Barren seashore
75° 40′S, 27° 00′W
3 m above MSL

Cold Bay

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1979	340.1	340.9	341.5	342.7	342.7	339.3	332.0	327.2	331.1	336.1	339.2	340.5	337.7
1980	341.5	342.6	344.0	344.8	344.3	341.3	334.5	330.3	333.0	337.5	340.8	342.3	339.7
1981	343.9	344.8	345.4	346.4	345.2	341.5	335.5	331.2	332.9	339.9	342.4	344.3	341.1
1982	345.4	346.1	347.3	347.9	347.4	343.7	336.0	330.7	332.6	338.5	342.5	344.8	341.9
1983	346.8	346.4	346.0	347.7	346.5	343.8	335.3	333.2	337.9	343.9	345.8	346.3	343.3
1984	348.1	349.9	349.4	349.7	348.9	345.7	338.4	337.7	338.7	344.8	346.9	349.2	345.6
1985	348.7	350.6	351.8	352.0	352.2	349.3	343.8	336.6	339.2	344.8	347.9	349.1	347.2
1986	351.9	351.5	351.7	353.2	353.0	350.4	343.8	338.2	341.1	345.1	348.8	352.1	348.8
1987	351.5	352.5	353.1	354.6	354.8	351.0	345.3	338.9	340.8	348.1	352.6	352.5	349.6

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

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Halley Bay

BACKGROUND

Principal investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

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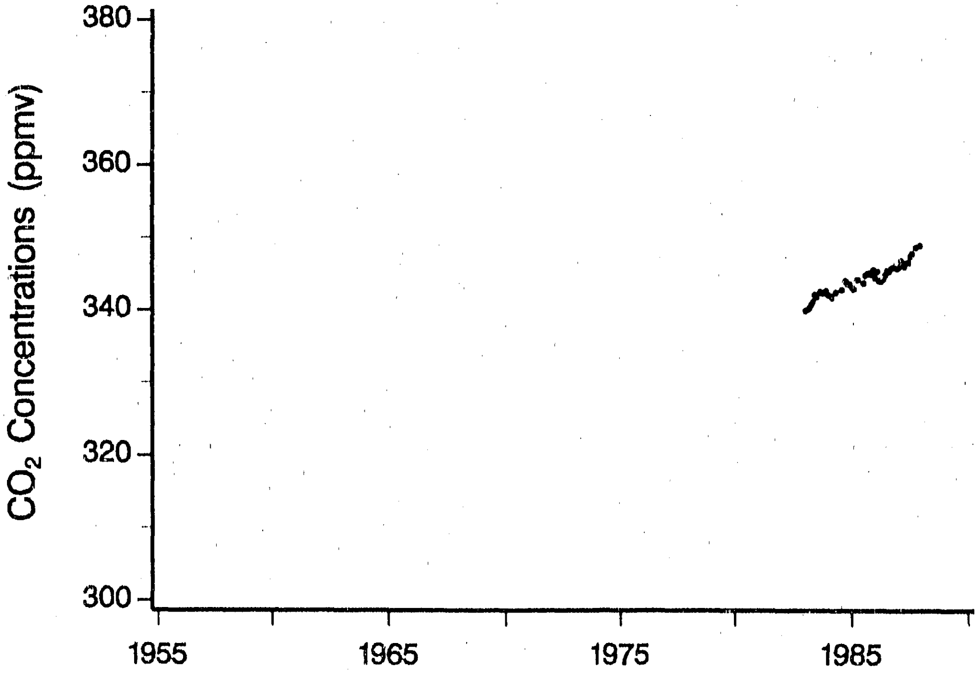
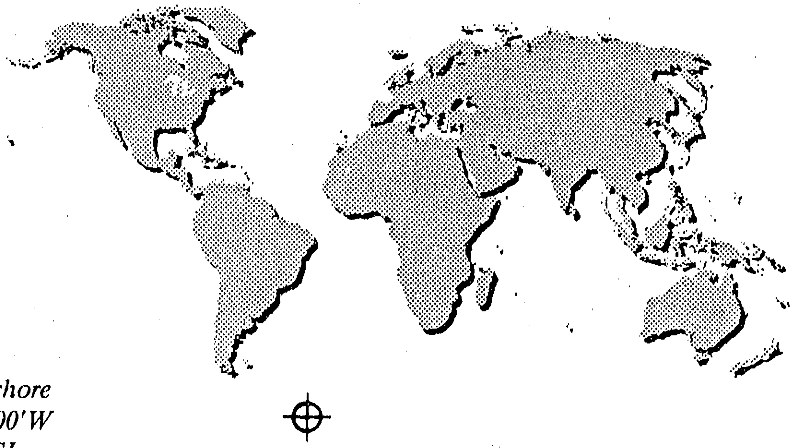
Calibration gases used – CO_2-in-air.

Scale of data reported – 1983 (SIO X83 mole fraction scale) 1984–1987 (SIO X85 mole fraction scale).

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Halley Bay
Antarctica
Barren seashore
75° 40′S, 27° 00′W
3 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The sampling site at Halley Bay is operated in cooperation with the British Antarctic Survey. The NOAA/CMDL flask data from Halley Bay show an increase in the annual value from 341.3 ppmv in 1983 to 345.0 ppmv in 1986. By simply dividing the difference between the 1983 and 1986 annual averages by 4, this represents a growth rate of 0.93 ppmv per year at Halley Bay. For comparison, Conway et al. (1988) reported a global growth rate of 1.22 ppmv per year for all NOAA/CMDL flask sampling sites for 1981–1984.

Atmospheric CO_2 concentrations at Halley Bay show a seasonal pattern, with the annual minimum measurements recorded during January–April and the annual maximum during October–December. Conway et al. (1988) found the average peak-to-trough amplitude for Halley Bay to be 1.25 ppmv.

Halley Bay

Atmospheric Concentrations of Carbon Dioxide

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983	339.8	339.9	340.1	340.5	341.0	342.0	341.7		342.4	342.2	342.3	342.5	341.3
1984	342.0	341.9	341.6		342.3			342.7		343.9	343.5	343.5	342.7
1985	343.0	342.8		344.1			343.6	344.7	344.9	345.0	344.8	345.4	344.3
1986	344.3	345.2	343.9	343.9	344.2	344.7	345.3	345.2	345.6	345.8	345.7	345.6	345.0
1987	345.8	346.7		345.9	346.4	346.4	347.3	347.7		348.5		348.8	

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

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REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD No. 306, Geneva.

Kaitorete Spit

BACKGROUND

Principal investigators

Thomas J. Conway
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National Oceanic and Atmospheric Administration
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

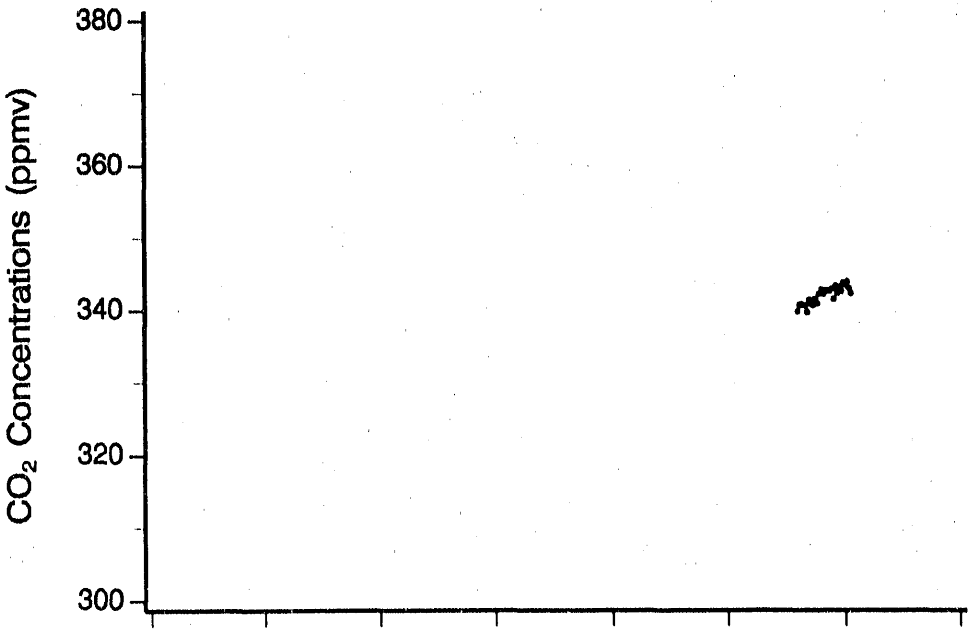
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

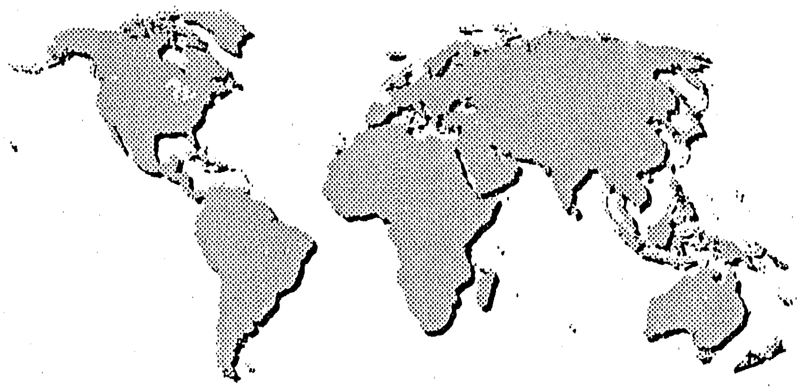
Calibration gases used – CO_2-in-air.

Scale of data reported – 1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Kaitorete Spit
New Zealand
Treeless spit
43° 50'S, 172° 38'W
3 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The sampling site at Kaitorete Spit was operated in cooperation with the National Center for Atmospheric Research. Sampling at Kaitorete Spit was discontinued in 1985 after it was established that the Cape Grim site was a more suitable site for representative measurements at that latitude.

The NOAA/CMDL flask data from Kaitorete Spit show an increase in the annual value from 340.7 ppmv in 1983 to 342.6 ppmv in 1984. Conway et al. (1988) reported a global growth rate of 1.22 ppmv per year for all NOAA/CMDL flask sampling sites from 1981–1984.

Kaitorete Spit

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983	339.7	340.6	340.7	340.6	340.5	339.6	341.3	340.7	340.6	341.4	340.8	342.1	340.7
1984	342.7	342.1	342.6	342.6	342.5	342.8	341.4	343.2	342.2	343.0	342.5	343.6	342.6
1985	343.4	343.8	342.9	342.2									

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masaric, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306. Geneva.

Key Biscayne

BACKGROUND

Principal investigators

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National Oceanic and Atmospheric
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325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

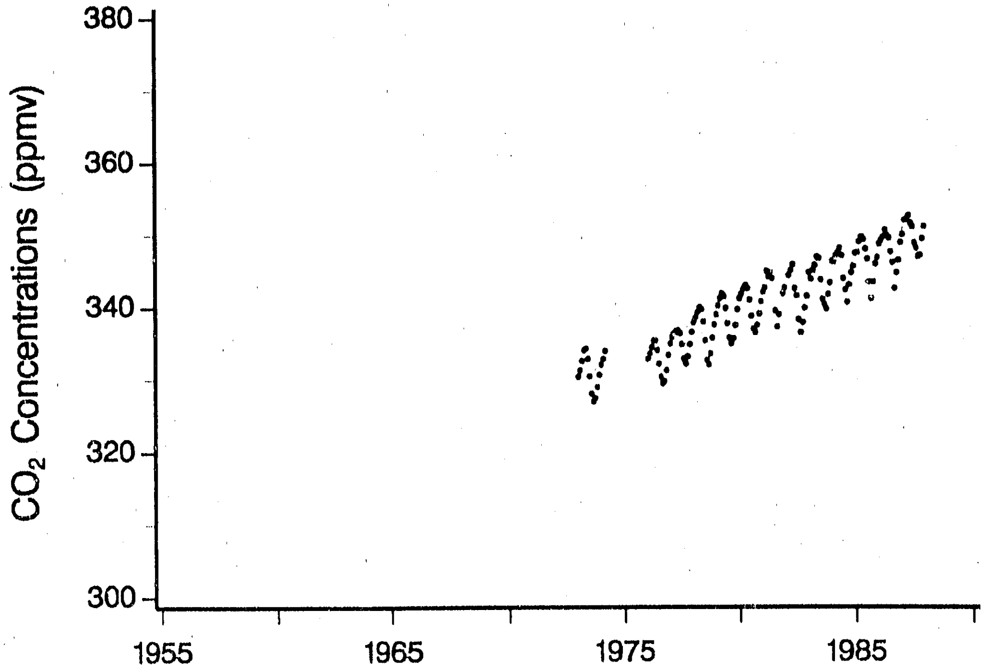
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

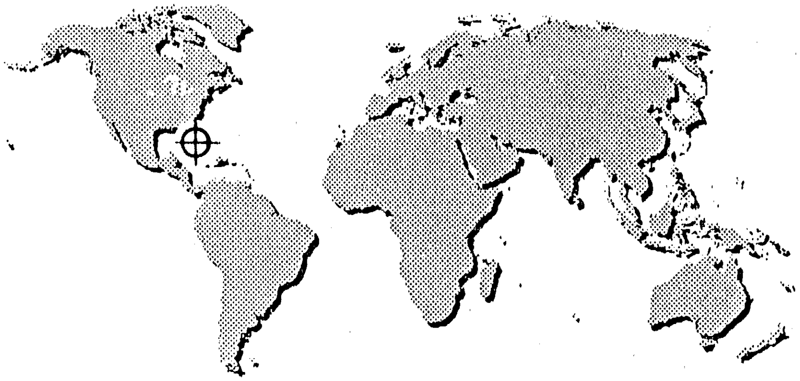
Calibration gases used – CO_2-in-air.

Scale of data reported – 1979–1983 (SIO X83 mole fraction scale) 1984–1987 (SIO X85 mole fraction scale).

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Key Biscayne
Florida, U.S.A.
Coastal island seashore
25° 40'N, 80° 10'W
3 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The sampling site at Key Biscayne, Florida, is operated in cooperation with the Sea-Air-Interaction Laboratory.

The NOAA/CMDL flask data from Key Biscayne show an increase in the annual value from 330.7 ppmv in 1973 to 350.2 ppmv in 1987. Conway et al. (1988) reported a 1.11-ppmv mean annual growth rate at Key Biscayne for 1981–1984 in comparison with a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Key Biscayne show a seasonal pattern, with the annual drawdown occurring in July and the annual buildup occurring in December. Conway et al. (1988) found the peak-to-trough amplitude for the seasonal cycle at Key Biscayne to be 7.28 ppmv for the 1981–1984.

Key Biscayne

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1973	330.4	331.3	332.6	334.1	334.3	332.9	330.5	328.1	327.0	327.5	329.0	330.7	330.7
1974	332.1	332.9	334.0										
1975													
1976	332.9	333.6	334.5	335.4	335.4	334.1	332.2	330.4	329.5	329.8	331.3	333.4	332.7
1977	335.0	335.9	336.4	336.7	336.8	336.4	334.9	332.9	332.2	333.2	334.9	336.6	335.2
1978	337.9	338.6	339.3	340.0	339.7	338.0	335.4	332.7	332.1	333.6	335.8	337.6	336.7
1979	339.0	340.2	341.2	341.9	341.5	339.9	337.8	335.8	335.0	335.7	337.5	339.7	338.8
1980	341.2	341.8	342.5	343.0	342.6	341.0	338.8	337.0	336.5	337.5	339.1	340.8	340.1
1981	342.1	342.7	345.0	344.2	344.8	344.0		339.5	337.3	339.0		341.9	342.1
1982	342.7		344.4	345.1	345.9	342.6	341.6	338.3	336.5	337.9	339.9	341.5	341.5
1983	344.8	343.9	345.1	345.8	347.0	346.8	343.8	341.1	340.4	339.8	341.8	343.4	343.6
1984	346.4	346.3	347.2	347.6	348.2	347.2	344.0	342.4	340.7	343.1	344.8	345.7	345.3
1985	347.5	347.6	349.1	349.8	349.4	348.1	346.7	343.5	341.2	343.5	346.0	346.9	346.6
1986	348.8	349.3	349.8	350.7	350.0	349.6	347.7	346.2	342.6	344.8	346.5	349.0	347.6
1987	350.1	352.1	352.2	352.7	351.7	351.2	348.9	348.2	347.0	347.2	349.5	351.2	350.2

---

*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

Conway, T.J. and P. Tans. 1990. Atmospheric CO_2 concentrations—The NOAA/GMCC flask sampling network. NDP-005/R1. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

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Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor, and K.W. Thoning. 1985a. Global atmospheric CO_2 distributions and variations from 1968-82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–5596.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306. Geneva.

Mahé Island (Seychelles)

BACKGROUND

Principal investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

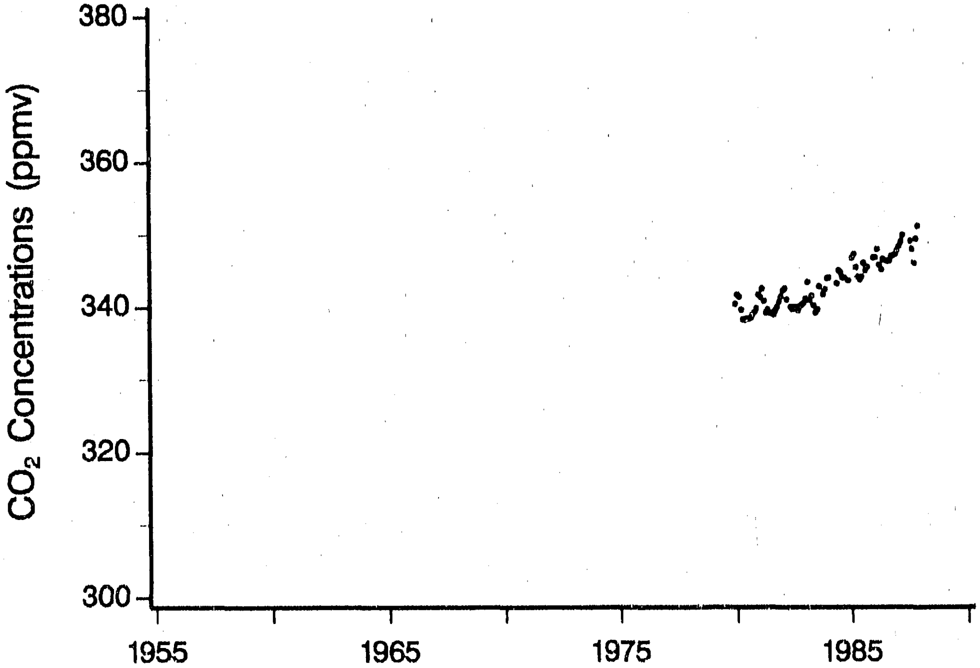
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

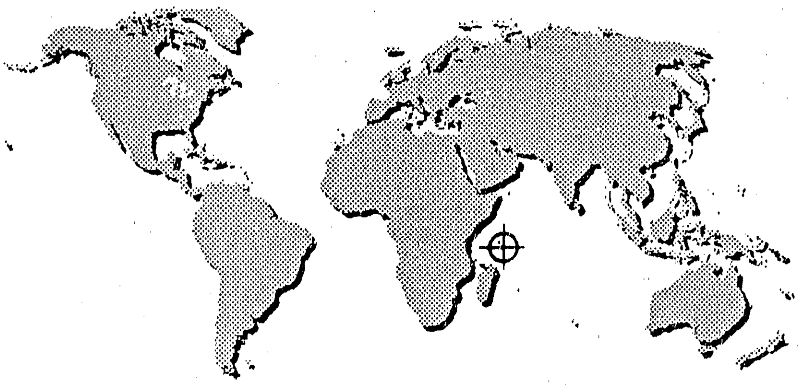
Calibration gases used – CO_2-in-air.

Scale of data reported – 1980–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Mahé Island
Seychelles
Island seashore
4° 40′S, 55° 10′E
3 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The Seychelles sampling site on Mahé Island is operated in cooperation with the Physical Science Laboratory at New Mexico State University.

The NOAA/CMDL flask data from the Seychelles show an increase in the annual value from 339.3 ppmv in 1980 to 346.3 ppmv in 1986. Conway et al. (1988) reported a 1.21-ppmv mean annual growth rate at Seychelles for 1981–1984 compared to a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Seychelles show a seasonal pattern with the annual drawdown typically occurring in May and the annual buildup occurring in November–January. Conway et al. (1988) reported the peak-to-peak seasonal amplitude for Seychelles to be 2.85 ppmv for 1981–1984.

Mahé Island (Seychelles)

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1980	340.3	341.6	341.3	339.5	338.2	338.1	338.3	338.3	338.4	338.8	339.2	339.7	339.3
1981	341.6	341.3	342.4	340.7	339.1	339.5	339.1		338.8	339.4	339.9	340.6	340.2
1982	341.3	342.1	342.4	340.9		339.9	339.6	339.9	339.9	339.4	340.0	340.2	340.5
1983	340.4	341.0	343.3	340.8	341.4	340.1	339.1	339.5	342.7		341.6	342.3	341.1
1984	343.8	343.9				343.1	344.9	344.6	343.9	343.9		343.5	344.0
1985		346.6	347.1	345.3	344.0	343.6	344.0	345.9	344.9	345.3			345.2
1986	346.6	346.7	347.8	345.6	345.0	346.4	346.2	346.1	346.2	346.8	346.9	347.1	346.3
1987	347.7	348.2	348.8	349.7				348.9	347.8	345.9	349.2	351.0	

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Tayler, and K.W. Thoning. 1985a. Global atmospheric CO_2 distributions and variations from 1968-82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–5596.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306. Geneva.

Mariana Islands

BACKGROUND

Principal investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

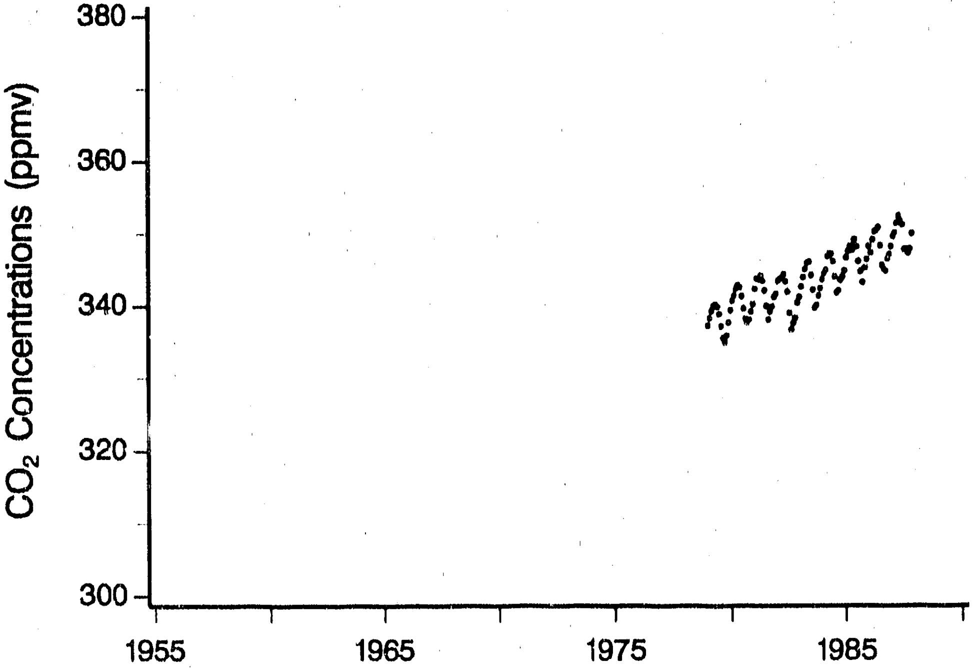
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

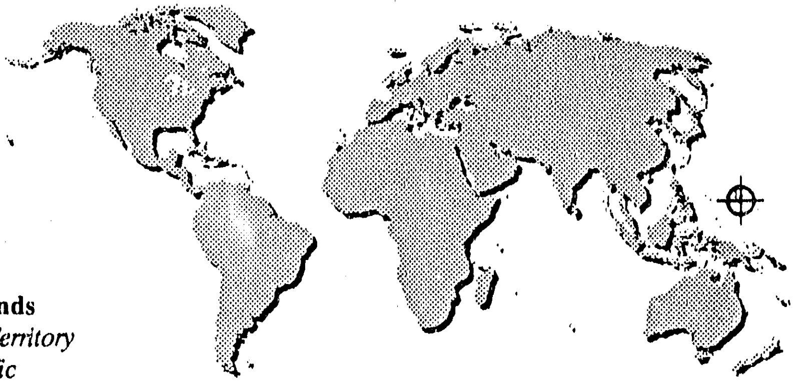
Calibration gases used – CO_2-in-air.

Scale of data reported – 1979–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Mariana Islands
Guam, U.S. Territory
South Pacific
Island seashore
13° 26′N, 144° 47′E
2 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The sampling site on the Mariana Islands is operated in cooperation with the University of Guam. The NOAA/CMDL flask data from Guam show an increase in the annual value from 337.7 ppm in 1979 to 349.4 ppm in 1987. Conway et al. (1988) reported a 1.01-ppm mean annual growth rate at Guam for 1981–1984 compared to a global growth rate of 1.22 ppm per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Guam show a seasonal pattern with the annual drawdown typically occurring in July–August and the annual buildup occurring in January. Conway et al. (1988) found the average peak-to-peak amplitude for Guam from 1981–1984 to be 6.46 ppm.

Mariana Islands

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1979	337.1	338.1	339.1	339.8	340.0	339.7	338.7	337.0	335.4	334.8	335.7	337.5	337.7
1980	339.2	340.5	341.2	342.1	342.6	342.3	341.1	339.4	338.0	337.5	337.9	339.0	340.1
1981	340.0	342.1	343.5	343.4	343.9	343.2	341.9	339.8	337.9	339.0	339.7	341.0	341.3
1982	341.4	343.2	343.4	343.6	344.1	343.1	341.7	338.8	336.5	337.4	338.1	340.2	341.0
1983	341.0	342.4	343.7	344.8	345.7	345.8	344.0	342.0	339.5	339.9	341.2	342.2	342.7
1984	343.4	344.2	344.7	346.6	347.0	346.9	345.9	343.8	341.6	341.9	343.3	343.8	344.4
1985	344.6	346.4	347.3	348.0	347.4	348.9	347.9	345.9	344.5	343.0	345.0	346.2	346.3
1986	348.0	347.1	348.9	350.0	350.2	350.6	348.1	345.4	344.9	344.6	346.3	346.9	348.1
1987	348.0	349.4	349.9	351.2	352.2	351.5	351.0	347.6	347.7	347.1	347.7	349.8	349.4

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

Conway, T.J. and P. Tans. 1990. Atmospheric CO_2 concentrations – The NOAA/GMCC flask sampling network. NDP-005/R.. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

Mauna Loa

BACKGROUND

Principal Investigators:

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Lee S. Waterman
National Oceanic and Atmospheric Administration
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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

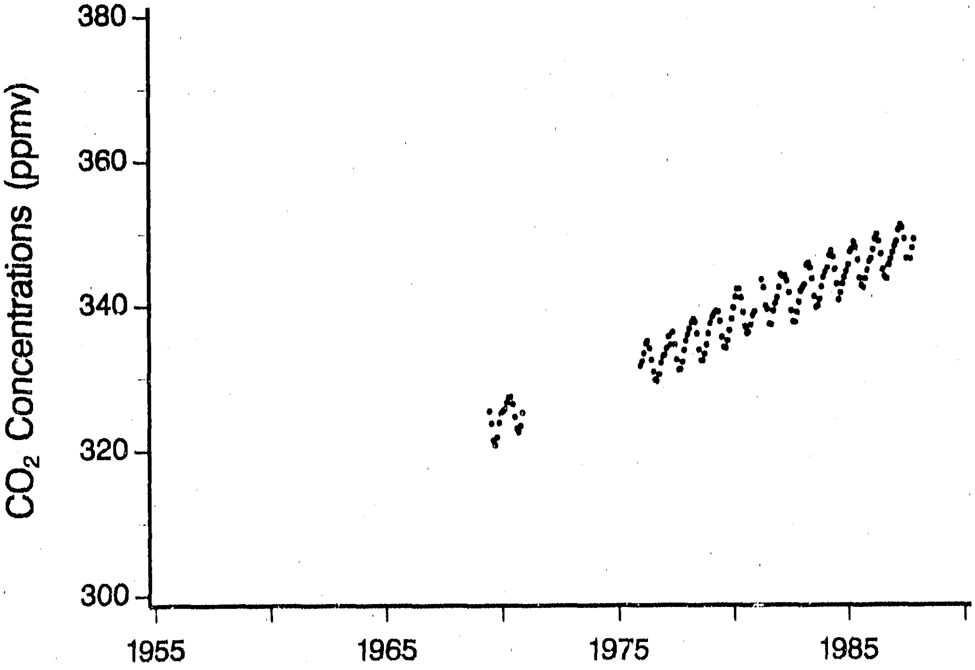
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

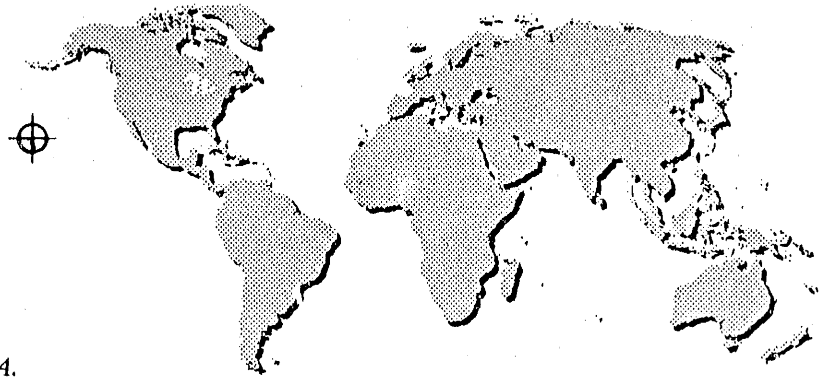
Calibration gases used – CO_2-in-air.

Scale of data reported – 1969–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Mauna Loa
Hawaii, U.S.A.
Barren volcanic slope
19° 32′N, 155° 35′W
3397 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The NOAA/CMDL flask data from Mauna Loa show an increase in the annual value from 325.2 ppmv in 1970 to 348.3 ppmv in 1987. Conway et al. (1988) reported a 1.21-ppmv mean annual growth rate at Mauna Loa for 1981–1984 compared to a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Mauna Loa show a seasonal pattern with the annual drawdown occurring in July and the annual buildup occurring in January. Conway et al. (1988) reported the peak-to-peak seasonal amplitude for Mauna Loa to be 6.67 ppmv for 1981–1984.

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1969							325.4	323.7	321.4	320.7	321.8	323.8	
1970	325.1	325.4	325.7	326.6	327.3	327.4	326.4	324.6	323.0	322.5	323.4	325.2	325.2
1971													
1972													
1973													
1974													
1975													
1976	331.6	332.2	333.3	334.7	335.0	334.0	332.4	330.8	329.7	329.5	330.4	332.0	332.1
1977	332.9	333.1	334.0	335.6	336.5	336.2	334.5	332.4	331.0	331.1	332.1	333.7	333.6
1978	335.0	335.9	336.7	337.6	338.0	337.6	336.0	333.8	332.3	332.3	333.2	334.5	335.2
1979	336.0	337.4	338.3	338.8	339.1	339.0	337.7	335.5	334.1	334.0	335.0	336.4	336.8
1980	338.0	339.5	341.0	342.1	342.1	340.9	338.9	337.0	336.0	336.2	337.2	338.5	339.0
1981	339.0				343.4	342.3	339.8	339.3	337.3	337.2	339.1	340.1	339.7
1982	340.9	342.3	344.1	343.8	343.9	343.2	341.6	339.1	337.6	337.5	338.9	340.3	341.1
1983	341.8	342.3	342.7	345.4	345.7	345.0	343.5	341.1	339.6	339.8	340.7	342.4	342.5
1984	343.7	344.4	345.0	346.7	347.3	346.5	344.8	342.8	340.6	341.6	342.8	343.7	344.2
1985	344.5	345.4	347.2	347.6	348.5	347.8	346.1	343.6	342.6	342.3	343.5	344.7	345.3
1986	345.9	346.3	347.5	349.0	349.6	348.7	346.9	344.8	343.8	343.5	345.4	346.2	346.4
1987	347.1	348.0	348.6	350.2	350.9	350.5	349.0	346.3	346.3	346.3	347.8	349.0	348.3

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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Komhyr, W.D., L.S. Waterman, and W.R. Taylor. 1983. Semiautomatic nondispersive infrared analyzer apparatus for CO_2 air sample analyses. *Journal of Geophysical Research* 88:1315–22.

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Komhyr, W.D., T.B. Harris, and L.S. Waterman. 1985b. Calibration of nondispersive infrared CO_2 analyzers with CO_2-in-air reference gases. *Journal of Atmospheric and Oceanic Technology* 2:82-88.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306, Geneva.

Mould Bay

BACKGROUND

Principal investigators

Thomas J. Conway
Pieter Tans
Lee S. Waterman
National Oceanic and Atmospheric Administration
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325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

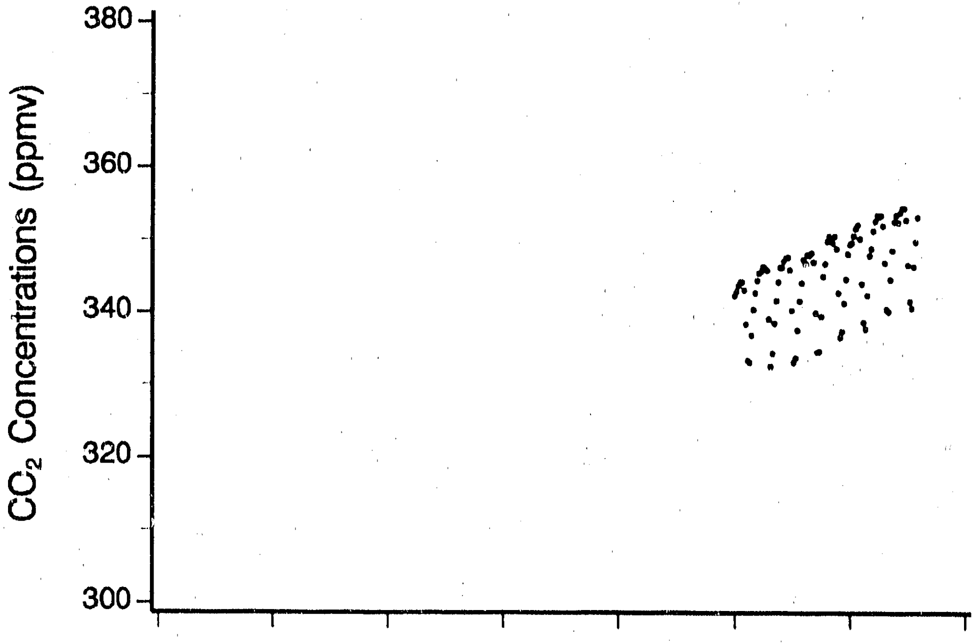
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

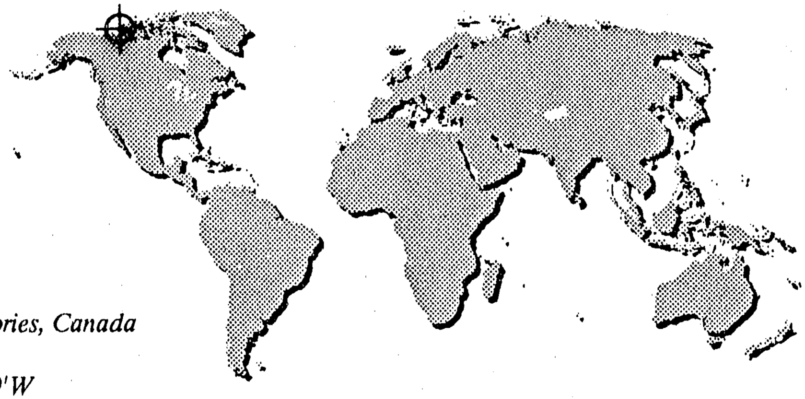
Calibration gases used – CO_2-in-air.

Scale of data reported – 1980–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Mould Bay
Northwest Territories, Canada
Island tundra
76° 14′N, 119° 20′W
15 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The sampling site at Mould Bay is operated in cooperation with the Atmospheric Environment Service of Environment Canada.

The NOAA/CMDL flask data from Mould Bay show an increase in the annual value from 340.3 ppmv in 1980 to 349.8 ppmv in 1987. Conway et al. (1988) reported identical 1.22-ppmv annual growth rates at Mould Bay alone and for all the NOAA/CMDL flask sampling sites for the period 1981–1984.

Atmospheric CO_2 concentrations at Mould Bay show a seasonal pattern with the annual drawdown occurring in July and the annual buildup occurring in November–December. Conway et al. (1988) reported the peak-to-peak seasonal amplitude for Mould Bay to be 15.15 ppmv for 1981–1984.

Mould Bay

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1980	342.1	342.7	343.5	344.0	[illegible]	342.9	338.2	333.2	333.0	336.7	340.2	342.5	340.3
1981	344.2	345.2	345.4	346.1	345.9	345.6	338.9	332.4	334.2	338.3	341.4	344.0	341.8
1982	346.0	346.0	346.9	347.3	347.4	345.7	340.1	333.0	333.6	337.4	341.4	343.9	342.4
1983	347.1	346.6	347.8	347.7	348.0	346.8	339.8	334.4	334.5	339.3	344.8	346.5	343.6
1984	349.6	350.3	350.0	349.4	350.3	348.6	342.5	336.4	337.2	341.1	344.4	347.9	345.6
1985	349.2	349.4	350.4	351.4	351.9	350.0	343.8	338.5	337.6	342.2	347.7	348.6	346.7
1986	351.1	352.4	353.2	353.0	353.2	351.8	346.7	340.3	340.0	344.4	348.4	352.4	348.6
1987	353.3	352.3	353.6	354.2	354.2	352.6	346.4	341.4	340.5	346.2	349.6	353.0	349.8

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

Conway, T.J. and P. Tans. 1990. Atmospheric CO_2 concentrations—The NOAA/GMCC flask sampling network. NDP-005/R1. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Komhyr, W.D., L.S. Waterman, and W.R. Taylor. 1983. Semiautomatic nondispersive infrared analyzer apparatus for CO_2 air sample analyses. *Journal of Geophysical Research* 88:1315–22.

Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor, and K.W. Thoning. 1985a. Global atmospheric CO_2 distributions and variations from 1968-82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–5596.

Komhyr, W.D., T.B. Harris, and L.S. Waterman. 1985b. Calibration of nondispersive infrared CO_2 analyzers with CO_2-in-air reference gases. *Journal of Atmospheric and Oceanic Technology* 2:82-88.

Thoning, K.W., P. Tans, T.J. Conway, and L.S. Waterman. 1987. *NOAA/GMCC calibrations of CO_2-in-air reference gases: 1979–85.* NOAA Technical Memorandum ERL ARL-150. Environmental Research Laboratory, Boulder, Colorado.

World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

Niwot Ridge

BACKGROUND

Principal investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

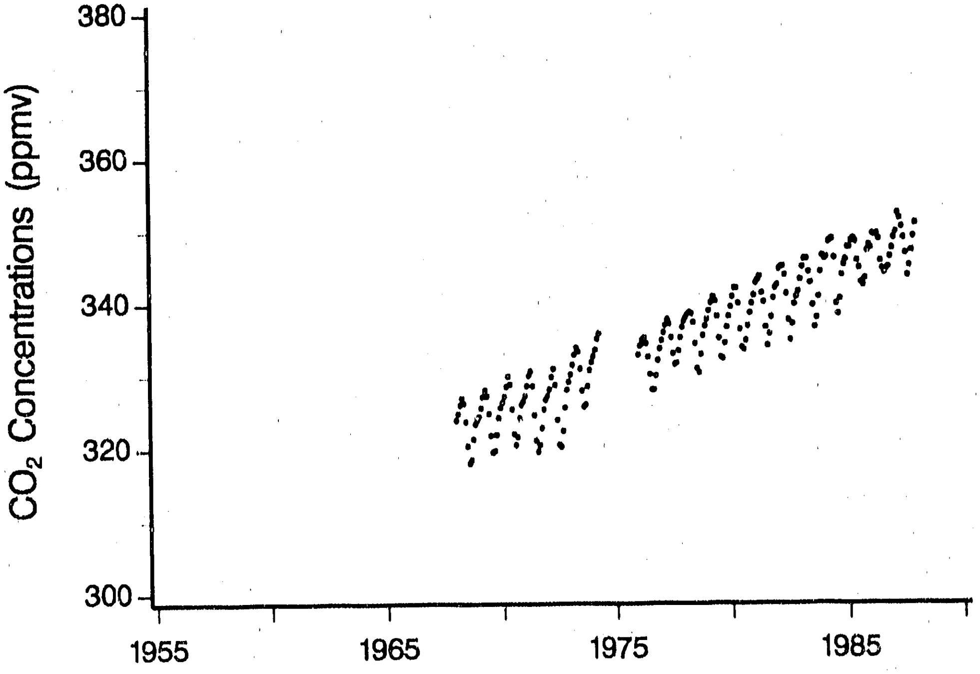
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

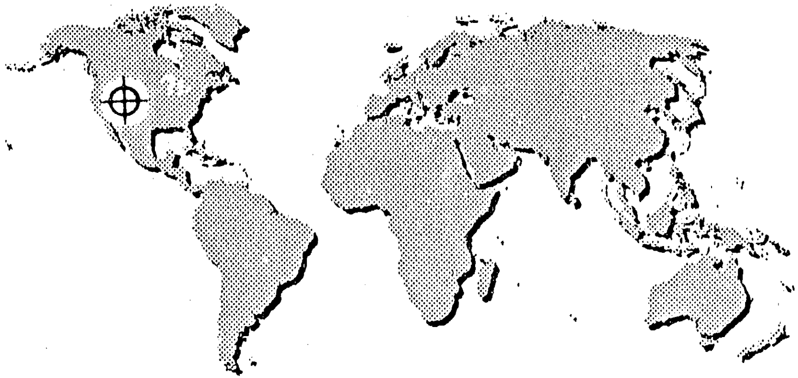
Calibration gases used – CO_2-in-air.

Scale of data reported – 1968–1983 (SIO X83 mole fraction scale), 1984–1987 (SIO X85 mole fraction scale).

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Niwot Ridge
Colorado, U.S.A.
Alpine mountain
40° 03′N, 105° 38′W
3749 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The sampling site at Niwot Ridge is operated in cooperation with the University of Colorado.

The NOAA/CMDL flask data from Niwot Ridge show an increase in the annual value from 323.1 ppmv in 1968 to 348.6 ppmv in 1987. Conway et al. (1988) reported a 1.57-ppmv mean annual growth rate at Niwot Ridge for 1981–1984 compared to a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Niwot Ridge show a seasonal pattern with the annual drawdown occurring in June and the annual buildup occurring in November–December. Conway et al. (1988) reported the peak-to-peak seasonal amplitude for Niwot Ridge to be 10.49 ppmv for 1981–1984.

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1968	323.9	324.8	326.0	326.9	326.2	323.7	320.4	318.0	318.5	321.3	323.4	323.9	323.1
1969	324.4	325.6	327.1	328.0	327.2	324.8	321.8	319.5	319.7	321.9	324.2	325.6	324.1
1970	326.3	327.1	328.5	329.9	328.8	325.4	322.0	320.5	321.6	324.2	326.0	326.5	325.6
1971	327.2	328.6	330.0	330.6	328.6	324.6	321.1	319.6	320.5	322.8	325.4	326.7	325.4
1972	327.2	328.1	329.8	330.9	328.7	323.9	320.5	320.2	322.4	325.6	328.0	329.1	326.2
1973	330.1	331.4	332.8	333.8	333.2	330.9	327.9	325.7	326.0	328.5	330.7	331.8	330.2
1974	332.6	333.5	335.0	335.7									
1975													
1976	332.8	334.0	334.8	335.1	334.3	332.5	330.1	328.0	328.0	329.9	332.0	333.6	332.1
1977	334.7	335.8	336.8	337.6	337.0	335.1	332.9	331.4	331.6	333.3	335.1	336.5	334.8
1978	337.4	337.9	338.3	338.6	338.4	337.2	334.3	330.9	330.3	332.8	335.4	336.7	335.7
1979	337.6	338.8	339.9	340.7	340.1	338.0	335.0	332.4	332.2	334.3	336.5	338.0	336.9
1980	339.3	340.7	341.9	341.9	339.8	336.2	333.8	333.5	334.7	336.7	338.5	339.8	338.0
1981	340.9	342.6	343.0	343.5	341.2	340.0	336.5	334.0	335.6	337.9	340.5	341.9	339.8
1982	342.3	344.5	344.8	344.9	343.7	341.1	337.5	334.8	337.0	339.7	340.7	341.4	341.0
1983	343.1	344.8	345.9	345.9	344.1	342.6	339.5	336.5	337.8	340.7	344.1	346.3	342.6
1984	345.9	346.1	348.2	348.4	348.6	346.0	339.7	338.3	340.4	343.7	345.1	345.8	344.7
1985	347.5	347.5	348.4	348.7	348.3	345.7	344.7	342.7	342.3	343.2	347.0	347.8	346.2
1986	347.4	349.3	349.2	349.3	348.6	345.6	344.5	344.0	344.5	344.8	346.2	347.4	346.5
1987	348.8	349.6	352.2	351.5	350.3	348.8	346.7	343.6	345.0	347.1	349.0	350.8	348.6

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

Ocean Station "M"

BACKGROUND

Principal investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

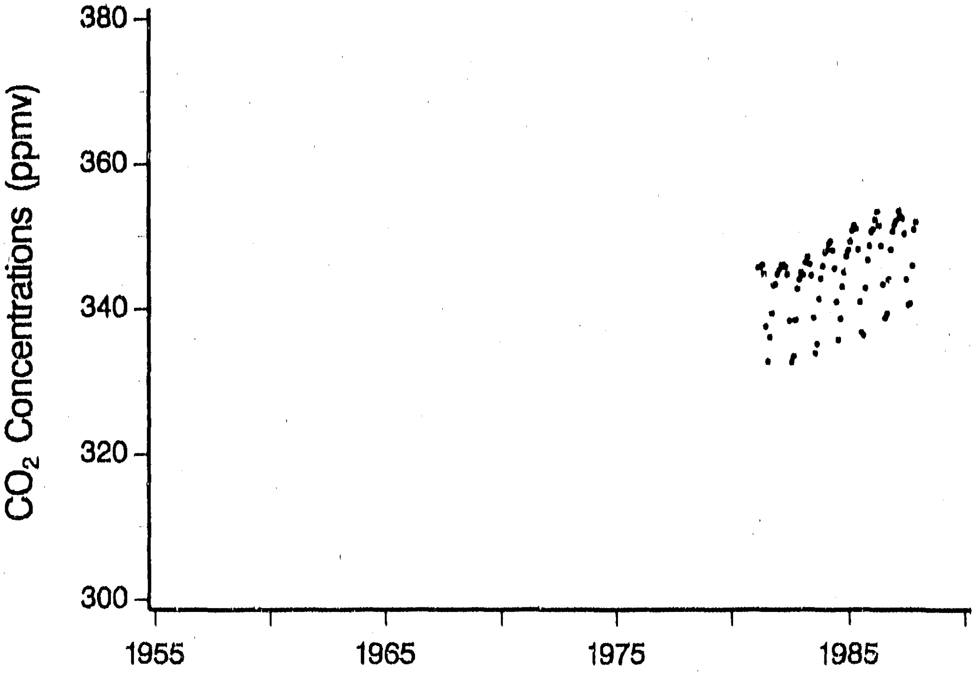
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

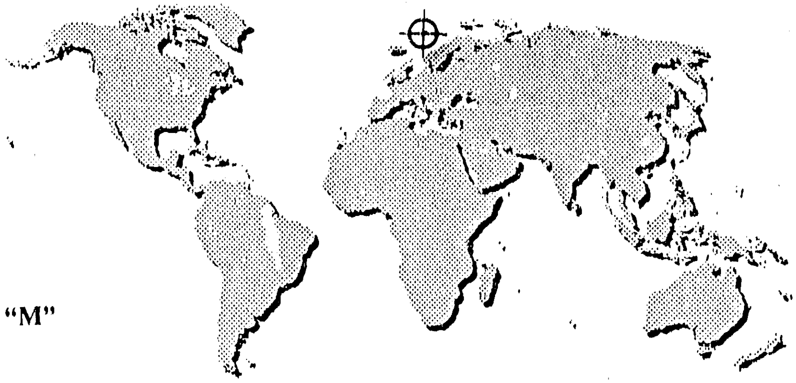
Calibration gases used – CO_2-in-air.

Scale of data reported – 1981–1983, SIO X83 mole fraction scale; 1984–1987 SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Ocean Station "M"
North Atlantic
Open ocean
66° 00'N, 2° 00'E
6 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The Ocean Station "M" sampling site is operated in cooperation with the Norway Meteorological Institute.

The NOAA/CMDL flask data from Ocean Station "M" show an increase in the annual value from 341.6 ppmv in 1981 to 348.9 ppmv in 1987. Conway et al. (1988) reported a 0.92-ppmv mean annual growth rate at Ocean Station "M" for 1981–1984 in comparison with a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Ocean Station "M" show a seasonal pattern with the annual drawdown occurring in November and the annual buildup occurring in June. Conway et al. (1988) reported the peak-to-trough seasonal amplitude for Ocean Station "M" to be 14.43 ppmv for 1981–1984.

Ocean Station "M"

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1981			345.6	345.6	346.0	344.8	337.5	332.7	336.0	339.3	343.2	343.3	341.6
1982	344.7	345.3	346.0	346.0	345.7	344.7	338.3	332.6	333.4	338.4	342.7	344.0	341.8
1983	345.0	344.6	346.3	347.1	346.1	344.5	338.7	333.8	335.1	341.3	344.1	345.8	342.7
1984	347.7	347.9	348.9	349.2	348.0	345.5	340.9	335.7	338.6	343.0	345.0	347.2	344.8
1985	348.0	349.2	350.7	351.4	351.0	348.1	340.9	336.7	336.3	342.8	346.6	348.6	345.9
1986	350.5	350.9	352.2	353.3	351.4	348.6	343.3	338.7	339.3	344.0	348.1	350.6	347.6
1987	351.5	352.1	353.4	352.7	352.4	350.3	344.0	340.5	340.7	345.9	350.9	351.9	348.9

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor, and K.W. Thoning. 1985a. Global atmospheric CO_2 distributions and variations from 1968-82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–5596.

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World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306. Geneva.

Palmer Station (Anver Island)

BACKGROUND

Principal investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

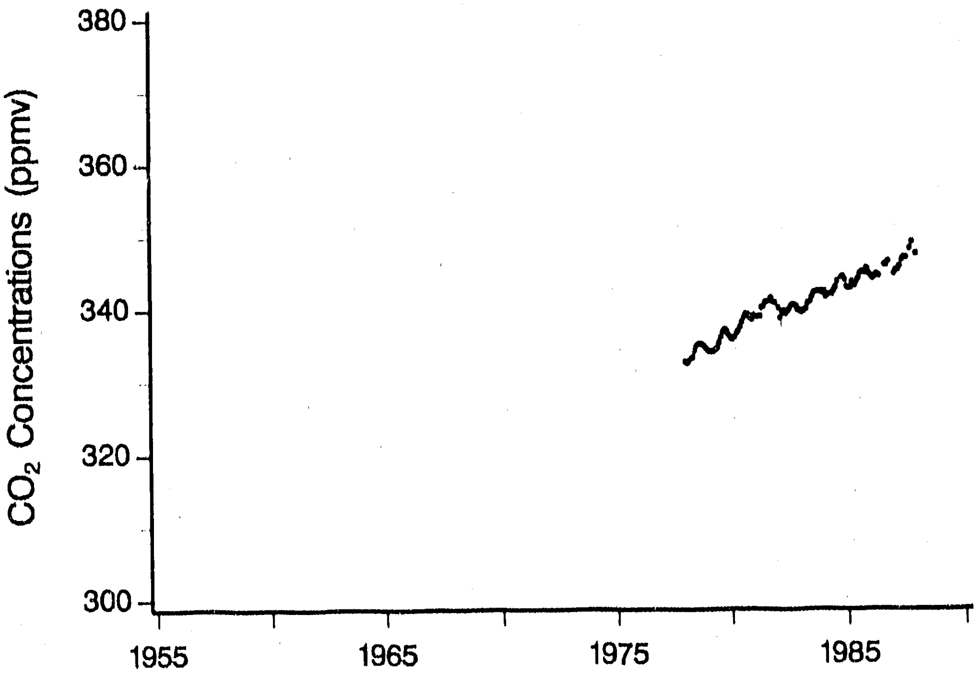
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

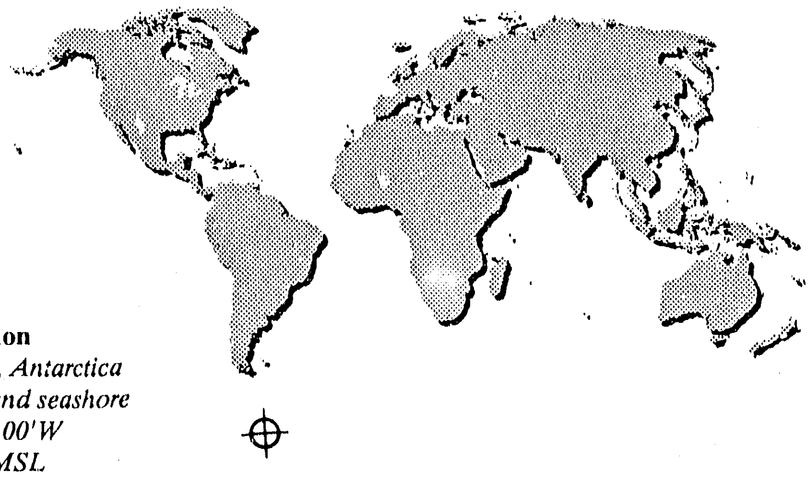
Calibration gases used – CO_2-in-air.

Scale of data reported – 1978–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Palmer Station
Anver Island, Antarctica
Barren island seashore
64° 55′S, 64° 00′W
33 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The sampling site at Palmer Station on Anver Island is operated in cooperation with the Washington State University Laboratory for Atmospheric Research.

The NOAA/CMDL flask data from Palmer Station show an increase in the annual value from 333.9 ppmv in 1978 to 343.9 ppmv in 1985. Conway et al. (1988) reported a 0.86-ppmv mean annual growth rate at Palmer Station for 1981–1984 compared to a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Palmer Station show a seasonal pattern with the annual drawdown typically occurring in December–January and the annual buildup occurring in May–July. Conway et al. (1988) reported the peak-to-peak seasonal amplitude for Palmer Station to be 1.30 ppmv for 1981–1984.

Palmer Station (Anver Island)

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1978	332.6	332.4	332.7	333.0	333.2	334.1	334.8	335.0	335.1	335.0	334.8	334.5	333.9
1979	334.2	334.0	334.0	334.0	334.2	334.5	335.2	336.0	336.7	337.0	336.8	336.2	335.2
1980	335.8	335.7	335.9	336.4	336.8	337.3	338.0	338.7	339.1	339.0	338.6	338.4	337.5
1981	338.9	338.7		338.8	340.0	340.2	340.7	340.8	340.9	341.3	340.8	340.7	340.2
1982		340.0	338.6	339.3	339.6	339.2	339.5	339.9	340.3	340.4	340.3	339.7	339.7
1983	339.7	339.4	339.6	339.8	340.6	340.8	341.4	342.0	342.1	342.2	342.2	342.0	341.0
1984	342.2	341.4	341.7	341.8	341.8	342.2	342.7	343.5		343.9	344.2	343.8	342.7
1985	342.8	342.7	342.7	343.5	343.0	343.5	344.0	344.7	344.9	344.8	345.3	344.6	343.9
1986	344.4	344.0	344.2	344.5	344.3			345.8	345.8	346.3			344.4
1987	344.6	345.1	345.2	345.7	346.5	346.9	346.9		348.1	349.0		347.4	346.5

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

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Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

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Point Barrow

BACKGROUND

Principal investigators

Thomas J. Conway
Pieter Tans
Lee S. Waterman
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Environmental Research Laboratories
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Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure. Samples are generally collected once per week on a schedule determined largely by the sample collector.

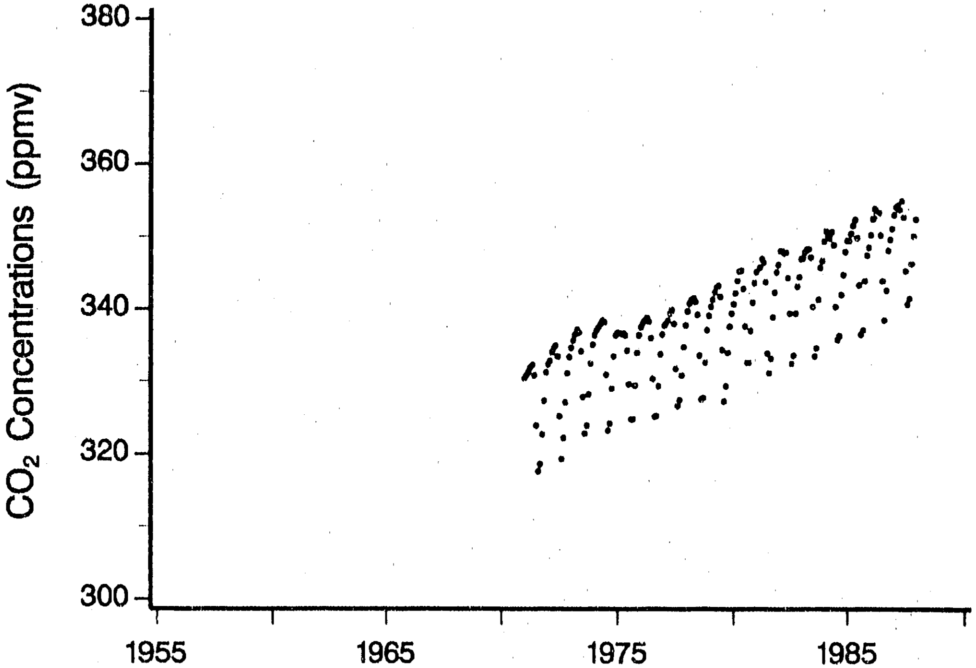
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

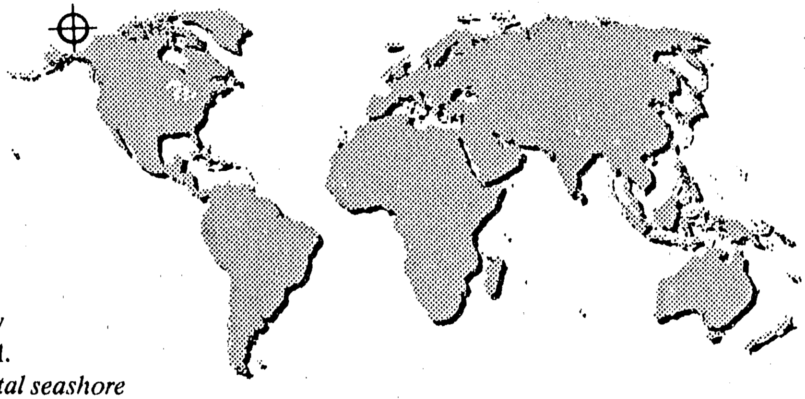
Calibration gases used – CO_2-in-air.

Scale of data reported – 1971–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Point Barrow
Alaska, U.S.A.
Arctic coastal seashore
71° 19'N, 156° 36'W
11 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The NOAA/CMDL flask data from Point Barrow show an increase in the annual value from 327.3 ppmv in 1971 to 349.7 ppmv in 1987. Conway et al. (1988) reported a 1.26-ppmv mean annual growth rate at Point Barrow for 1981–1984 compared to a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at Point Barrow show a seasonal pattern with the annual drawdown occurring in June and the annual buildup occurring in November. Conway et al. (1988) found the average peak-to-peak amplitude for Point Barrow to be 15.65 ppmv for the years 1981–1984.

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1971	330.3	330.7	331.2	331.8	332.1	330.7	323.8	317.5	318.5	322.6	327.2	331.1	327.3
1972	333.2	333.7	333.9	334.5	334.8	333.3	325.1	319.2	322.1	327.0	331.0	333.2	330.1
1973	334.5	335.5	336.3	337.0	336.6	334.0	327.7	322.7	323.8	328.1	332.3	334.9	331.9
1974	336.2	336.9	337.3	337.7	338.2	338.0	330.8	323.1	324.1	328.9	333.3	335.7	333.3
1975	336.6	336.5	336.4	336.5	336.2	334.1	329.5	324.7	324.7	329.3	333.8	336.2	332.8
1976	337.3	337.9	338.3	338.6	338.1	335.8	330.2	325.0	325.1	329.2	333.6	336.3	333.8
1977	337.5	337.8	338.2	339.2	339.7	337.8	331.6	326.5	327.3	330.7	334.6	337.6	334.8
1978	339.5	340.6	341.1	341.3	340.8	339.0	333.4	327.4	327.6	332.4	336.9	338.9	336.5
1979	340.1	341.1	342.1	342.8	343.0	341.5	334.2	327.1	329.2	333.8	337.4	339.2	337.6
1980	340.5	342.0	343.7	345.0	345.1	342.6	337.4	332.4	332.4	336.8	340.7	343.4	340.2
1981	344.9		345.5	346.7	346.2	343.5	333.7	331.0	333.0	338.7	342.1	344.9	340.9
1982	345.9	347.8	347.8	347.5	347.6	344.1	339.2	332.3	333.4	339.2	342.9	344.2	342.7
1983	346.7	346.8	347.6	348.0	348.0	346.9	340.1	333.3	334.4	341.1	345.5	346.4	343.7
1984	349.1	350.5	349.8	349.5	350.4	348.6	340.1	335.6	336.1	341.8	344.5	347.7	345.3
1985	349.2	349.2	350.2	351.3	352.1	349.6	343.1	336.3	336.9	343.7	347.2	348.3	346.4
1986	350.0	352.2	353.6	352.8	353.1	350.0	343.7	338.3	342.4	347.9	349.4	350.9	348.6
1987	352.8	353.9	354.1	353.5	354.7	352.5	345.1	340.5	341.3	346.1	349.9	352.6	349.7

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

Conway, T.J. and P. Tans. 1990. Atmospheric CO_2 concentrations—The NOAA/GMCC flask sampling network. NDP-005/R1. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Komhyr, W.D., L.S. Waterman, and W.R. Taylor. 1983. Semiautomatic nondispersive infrared analyzer apparatus for CO_2 air sample analyses. *Journal of Geophysical Research* 88:1315–22.

Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor, and K.W. Thoning. 1985a. Global atmospheric CO_2 distributions and variations from 1968-82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–5596.

Komhyr, W.D., T.B. Harris, and L.S. Waterman. 1985b. Calibration of nondispersive infrared CO_2 analyzers with CO_2-in-air reference gases. *Journal of Atmospheric and Oceanic Technology* 2:82-88.

Thoning, K.W., P. Tans, T.J. Conway, and L.S. Waterman. 1987. *NOAA/GMCC calibrations of CO_2-in-air reference gases: 1979–85.* NOAA Technical Memorandum ERL ARL-150. Environmental Research Laboratory, Boulder, Colorado.

World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

St. Croix

BACKGROUND

Principal investigators

Thomas J. Conway
Pieter Tans
Lee S. Waterman
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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

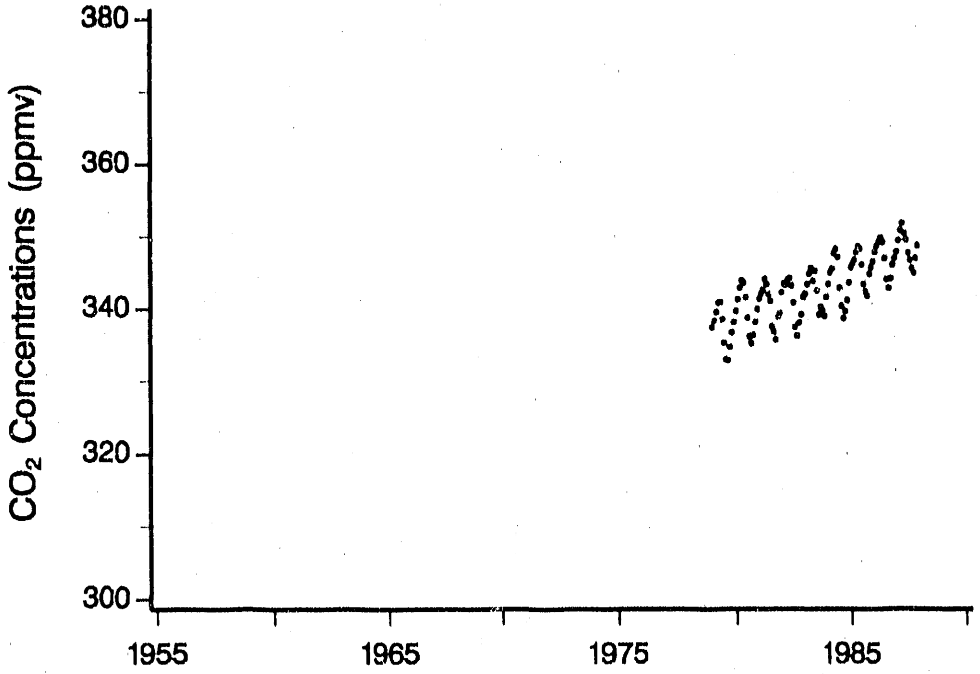
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

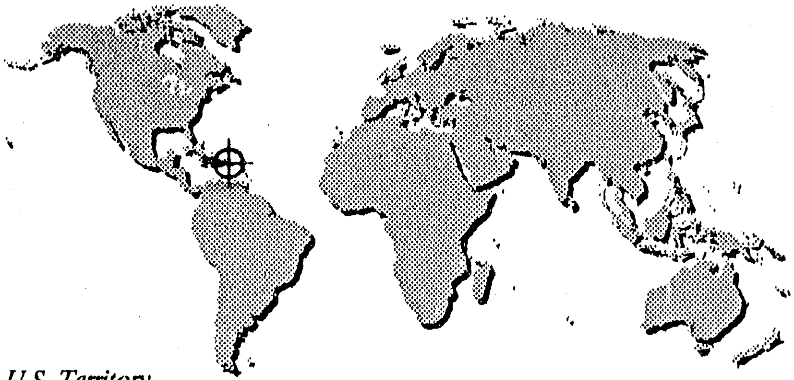
Calibration gases used – CO_2-in-air.

Scale of data reported – 1979–1983, SIO X83 mole fraction scale; 1984–1987 SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The CDIAC archive contains a complete listing of individual flask values, with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



St. Croix
Virgin Islands, U.S. Territory
Island seashore
17° 45′N, 64° 45′W
3 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The sampling site at St. Croix is operated in cooperation with Fairleigh Dickinson University. The NOAA/CMDL flask data from St. Croix, Virgin Islands, show an increase in the annual value from 337.1 ppmv in 1979 to 348.1 ppmv in 1987. The 1987 annual average was based on 147 flask samples. Conway et al. (1988) reported a 0.96-ppmv mean annual growth rate at St. Croix, Virgin Islands, for 1981–1984. Conway et al. (1988) found a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Atmospheric CO_2 concentrations at St. Croix, Virgin Islands, show a seasonal pattern with the annual drawdown typically occurring in July and the annual buildup occurring in December–January. Conway et al. (1988) found the average peak-to-peak amplitude at St. Croix, Virgin Islands, during 1981–1984 to be 8.73 ppmv. Unlike the data from a majority of stations in the NOAA/CMDL flask sampling network during 1981–1984, the data from St. Croix did not show a growth rate minimum in 1982 and a growth rate maximum in 1983. Instead, the data from St. Croix exhibited large oscillations in growth rate throughout the data record.

St. Croix

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1979	337.3	338.2	339.4	340.7	340.8	338.4	335.2	332.9	332.8	334.6	336.6	338.0	337.1
1980	339.5	341.1	342.7	343.7	343.4	341.4	338.6	336.0	335.1	336.2	338.0	339.8	339.6
1981	341.2	341.9	342.4	343.9	343.2	341.8	340.9	337.4	336.7	335.6	338.7	339.2	340.2
1982	342.1	343.3	343.1	343.8	344.0	343.0	340.7	337.3	336.1	337.9	339.0	341.4	341.0
1983	341.9	343.2	344.6	345.4	343.6	345.0	342.3	339.0	340.1	339.6	338.8	341.4	342.1
1984	343.2	344.8	345.3	347.4	348.0	346.9	342.7	340.2	338.5	339.5	341.0	343.4	343.4
1985	345.5	346.0	346.5	347.6	348.4	348.1	345.9	343.2	342.2	341.6	344.6	345.5	345.4
1986	346.3	347.6	348.4	349.0	349.6	349.0	346.8	343.9	342.7	344.0	345.9	346.8	346.9
1987	347.7	349.2	350.6	351.6	350.2	349.3	347.5	346.5	345.4	344.8	346.8	348.5	348.1

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

Conway, T.J. and P. Tans. 1990. Atmospheric CO_2 concentrations—The NOAA/GMCC flask sampling network. NDP-005/R1. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Komhyr, W.D., L.S. Waterman, and W.R. Taylor. 1983. Semiautomatic nondispersive infrared analyzer apparatus for CO_2 air sample analyses. *Journal of Geophysical Research* 88:1315–22.

Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor, and K.W. Thoning. 1985a. Global atmospheric CO_2 distributions and variations from 1968-82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–5596.

Komhyr, W.D., T.B. Harris, and L.S. Waterman. 1985b. Calibration of nondispersive infrared CO_2 analyzers with CO_2-in-air reference gases. *Journal of Atmospheric and Oceanic Technology* 2:82-88.

Thoning, K.W., P. Tans, T.J. Conway, and L.S. Waterman. 1987. *NOAA/GMCC calibrations of CO_2-in-air reference gases: 1979–85*. NOAA Technical Memorandum ERL ARL-150. Environmental Research Laboratory, Boulder, Colorado.

World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306. Geneva.

Terceira Islands (Azores)

BACKGROUND

Principal Investigators

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Air sample collection – With the use of a portable sampling apparatus, two Pyrex glass flasks (0.5-L) previously filled with a dry gas of known concentration and connected in series are flushed for 5 min with ambient air and pressurized to 1.2–1.5 times ambient atmospheric pressure.

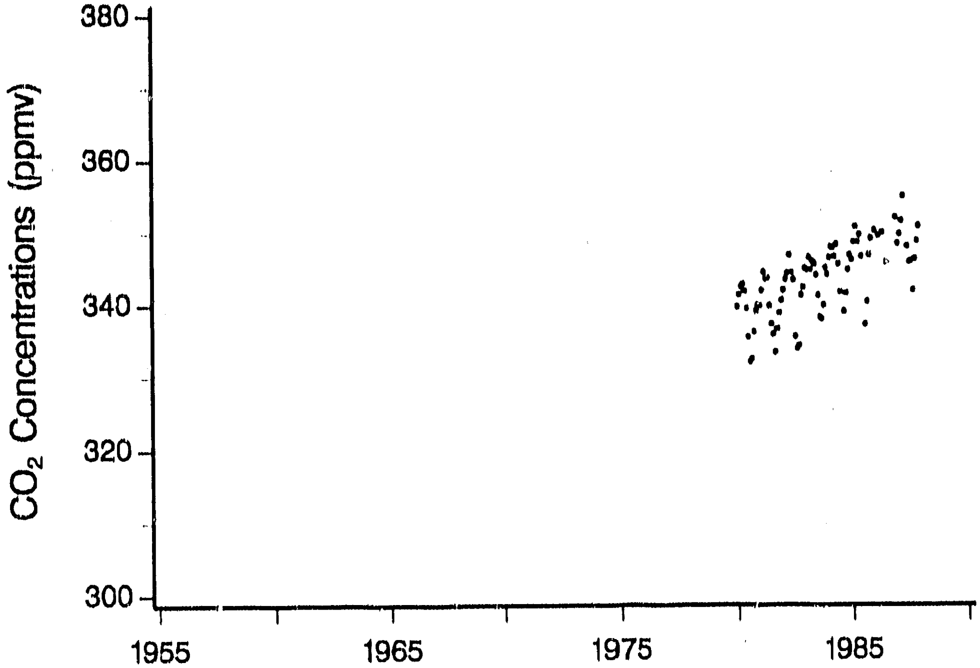
Measurement apparatus – The flask samples are analyzed for CO_2 concentrations at the CMDL laboratory in Boulder by using a UNOR-2 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – See Conway et al. (1988) and Komhyr et al. (1985a).

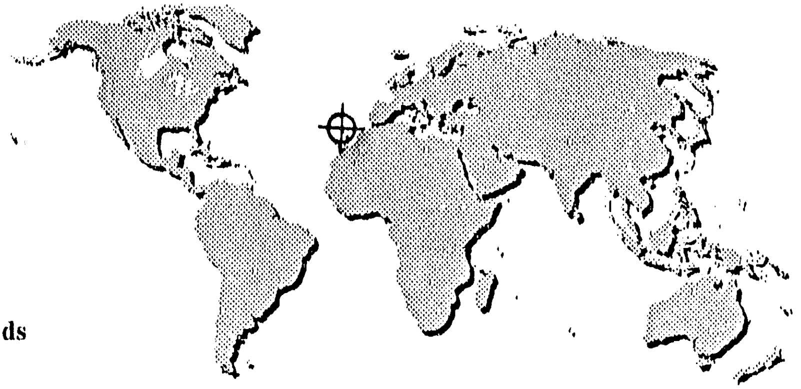
Calibration gases used – CO_2-in-air.

Scale of data reported – 1979–1983, SIO X83 mole fraction scale; 1984–1987, SIO X85 mole fraction scale.

Data availability – The NOAA/CMDL flask data have been archived with WMO and CDIAC. The data archived with WMO are pair averages. The data available from CDIAC (Conway and Tans, 1990) contain a complete listing of individual flask values with flags indicating the results of NOAA/CMDL's data selection schemes.



Monthly atmospheric CO_2 concentrations.



Terceira Islands
Azores
Island seashore
38° 45'N, 27° 05'W
30 m above MSL

TREND

These data are from the NOAA/CMDL flask sampling program. The Terceira Islands sampling site is operated in cooperation with the 7th Weather Wing of the United States Air Force. The NOAA/CMDL flask data from the Azores show an increase in the annual value from 338.4 ppmv in 1980 to 348.2 ppmv in 1987. The 1987 annual average was based on 55 flask samples. Conway et al. (1988) reported a 1.65-ppmv mean annual growth rate at the Azores sampling site for 1981–1984 compared to a global growth rate of 1.22 ppmv per year over the same time frame for all NOAA/CMDL flask sampling sites.

Conway et al. (1988) found the average peak-to-peak amplitude at the Terceira Islands sampling site during 1981–1984 to be 10.15 ppmv. Unlike the majority of stations in the NOAA/CMDL flask sampling network during 1981–1984, the data from the Azores did not show a growth rate minimum in 1982 and a growth rate maximum in 1983. Instead, the data from the Terceira Islands sampling site exhibited large oscillations in growth rate throughout the data record.

Terceira Island (Azores)

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1980	339.5	341.2	342.3	342.6	341.7	339.3	335.4	332.0	332.4	336.1	339.0	339.8	338.4
1981	339.7	341.8	344.3	343.4	343.5	339.7	337.2	335.8	333.3	336.5	338.7	340.4	339.5
1982	341.8	343.3	344.1	346.6	344.2	343.2	335.4	333.8	334.2	341.1	342.2	344.8	341.2
1983	344.6	346.3	344.6	345.8	345.4	343.9	341.1	338.1	337.9	339.8	344.9	344.0	343.0
1984	346.3	347.8	347.6	346.4	348.1	345.4	341.6		338.9	341.4	344.6	346.6	345.0
1985	346.0	348.4	350.5	348.4	349.4	346.4		337.1	340.2	346.6	348.9		346.2
1986	350.0		349.3		349.7		345.6					351.8	
1987	348.2	349.5	351.3	354.7		347.8	345.7	345.8	341.8	346.1	348.6	350.6	348.2

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

Conway, T.J. and P. Tans. 1990. Atmospheric CO_2 concentrations—The NOAA/GMCC flask sampling network. NDP-005/R1. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Komhyr, W.D., L.S. Waterman, and W.R. Taylor. 1983. Semiautomatic nondispersive infrared analyzer apparatus for CO_2 air sample analyses. *Journal of Geophysical Research* 88:1315–22.

Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor, and K.W. Thoning. 1985a. Global atmospheric CO_2 distributions and variations from 1968–82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–5596.

Komhyr, W.D., T.B. Harris, and L.S. Waterman. 1985b. Calibration of nondispersive infrared CO_2 analyzers with CO_2-in-air reference gases. *Journal of Atmospheric and Oceanic Technology* 2:82–88.

Thoning, K.W., P. Tans, T.J. Conway, and L.S. Waterman. 1987. *NOAA/GMCC calibrations of CO_2-in-air reference gases: 1979–85*. NOAA Technical Memorandum ERL ARL-150. Environmental Research Laboratory, Boulder, Colorado.

World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD No. 306. Geneva.

Izaña

BACKGROUND

Principal investigators

Alberto Linés Escardó
Beatriz Navascués
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F.R.G.

Air sample collection – Air samples are collected continuously through an 18-m-high air intake. Greater details about the measurement methodology and calibrations are given in Navascués et al. (1988).

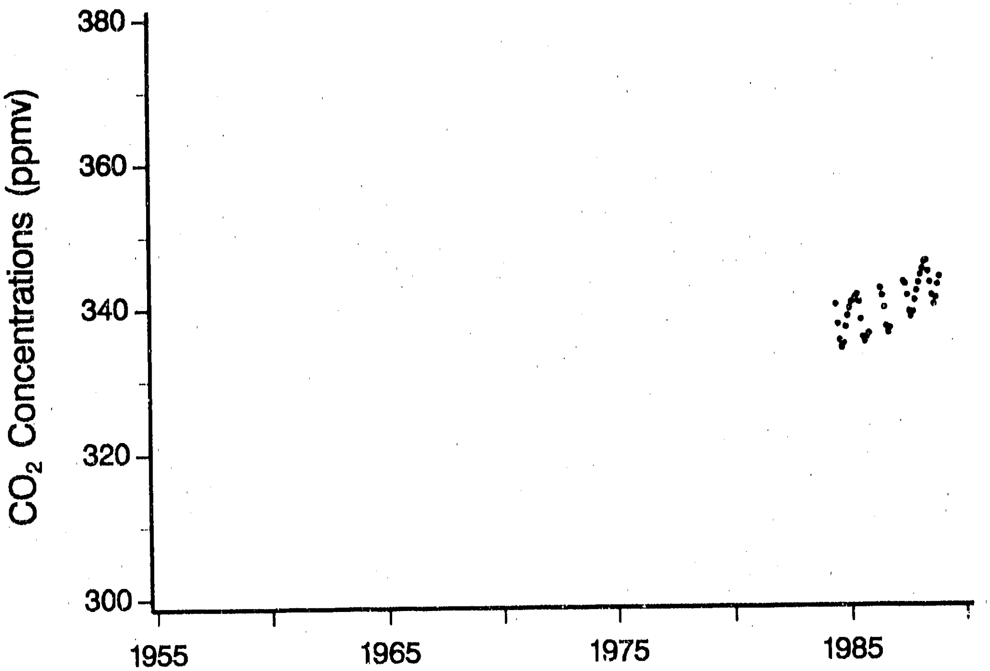
Measurement apparatus – Siemens ULTRAMAT 3 semiautomatic nondispersive infared gas analyzer.

Data selection procedures – Data are accepted when, during 0.5 h, the standard deviation of individual measurements taken every 10 s does not exceed 0.075 ppm.

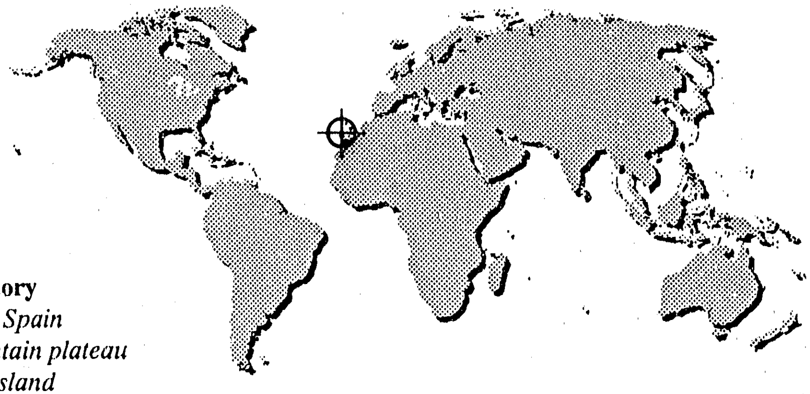
Calibration gases used – CO_2-in-N_2 and CO_2-in-air.

Scale of data reported – CO_2 concentrations are given relative to an internal scale based on three primary CO_2-in-N_2 tanks and a set of CO_2-in-synthetic tanks.

Data availability – In addition to being available from the principal investigators, these monthly and annual data are provided to and have been reported by the WMO (1987). These same data are also available from CDIAC.



Monthly atmospheric CO_2 concentrations.



Izaña Observatory
Canary Islands, Spain
Top of a mountain plateau on a volcanic island
28° 18'N, 16° 29'W
2367 m above MSL

TREND

The Izaña Baseline Station at Tenerife, Canary Islands, has been making meteorological observations since 1916. In 1983 the governments of Spain and the Federal Republic of Germany signed an agreement to set up a baseline station on the Canary Islands. Since June 1984, the Izaña station has served as the Spanish contribution to the WMO BAPMoN network.

The climate of the Canary Islands is affected by three major factors: circulation forced by trade winds, Saharan air invasions, and oceanic disturbances (Navascués et al. 1988). All of these factors influence the measurements of atmospheric CO_2 recorded at Izaña. Changes of air mass are strongly reflected in the concentration records of CO_2, CH_4, and O_3. Saharan air invasions normally occur in August, when there is a high-pressure system to the northeast of the Islands. These invasions carry dry, dust-laden air that has been depleted of CO_2; Schmitt et al. (1988) also reported that the transport of Sahara dust results in an increase of optical thickness and an ozone depletion.

The mean annual atmospheric CO_2 concentration at the Izaña Baseline Station has risen from 336.6 ppmv in 1984 to 343.3 ppmv in 1988. Atmospheric CO_2 concentrations from Izaña exhibit both diurnal and seasonal patterns. Annual maximum values occur in May, and annual minimum values occur in September.

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1984						340.0	337.3	335.0	334.0	334.7	336.9	338.4	336.6
1985	339.4	340.3	340.4	341.0	341.3	340.3	337.9	335.5	334.8	335.4	336.0		338.4
1986					342.1	341.1	339.5	336.9	336.0	336.7			338.1
1987					343.0	342.7	341.2	339.0	338.2	338.9	340.5	341.8	340.7
1988	342.9	344.0	344.8	345.8	345.9	344.4	342.9	341.2	339.9	340.8	342.7	343.8	343.3

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Navascués, B., C.J. Rus, A.S. Pastor, and F.R. Elizaga. 1988. *Estacion base de Izaña Tenerife 1984–1988.* Ministerio de Transportes, Instituto Nacional de Meteorologia, Madrid.

Schmitt, R., and I. Levin. 1985. *Baseline station Tenerife: Technical realization of the CO_2 monitoring system and first results of atmospheric measurements.* Proceedings of 2nd WMO-Expert Meeting on Atmospheric Carbon Dioxide Measurement Techniques, Lake Arrowhead, California, November 4–8.

Schmitt, R., B. Schreiber, and I. Levin. 1988. Effects of long-range transport on atmospheric trace constituents at the baseline station Tenerife (Canary Islands). *Journal of Atmospheric Chemistry* 7:335–51.

World Meteorological Organization. 1987. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the year 1985.* WMO/TD-No. 198. Geneva.

Mt. Cimone

BACKGROUND

Principal investigator

Luigi Ciattaglia
Aeronautica Militare
Italian Meteorological Service
Vigna di Valle Observatory
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Rome, Italy

Air sample collection – Continuous. Since December 1988, flask samples have also been collected.

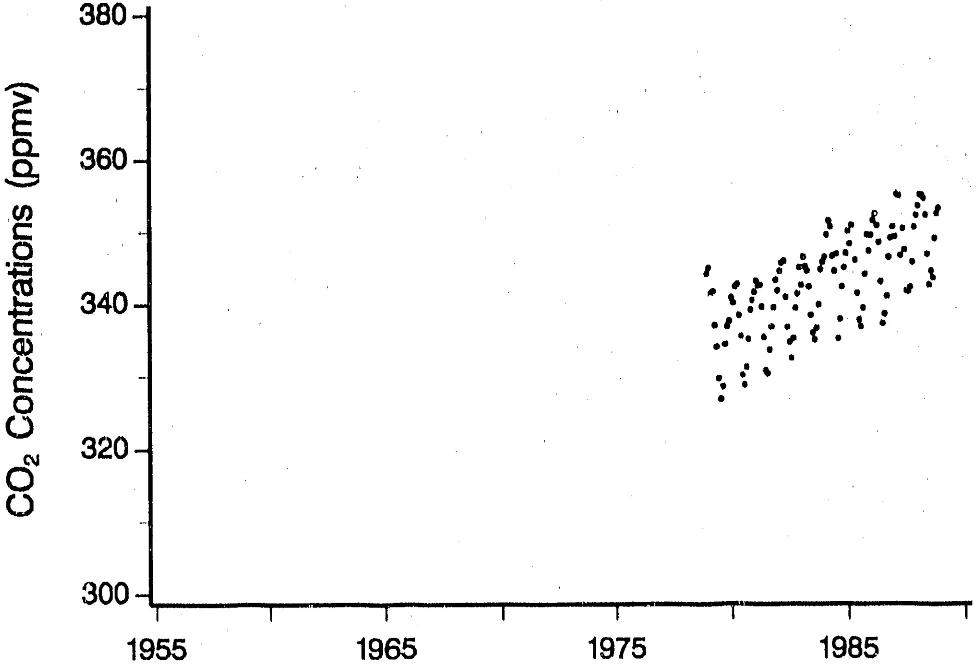
Measurement apparatus – From 1979 until December 1988, a Hartmann-Braun URAS 2T NDIR gas analyzer was used for CO_2 determinations. Since December 1988, a Siemens Ultramat 5E gas analyzer has been used for CO_2 determinations.

Data selection procedures – Hourly CO_2 values are routinely plotted together with wind data. Anomalous values and values affected by instrument failures or local sources are rejected. According to Ciattaglia et al. (1987), only 11.2% of the recorded data is removed.

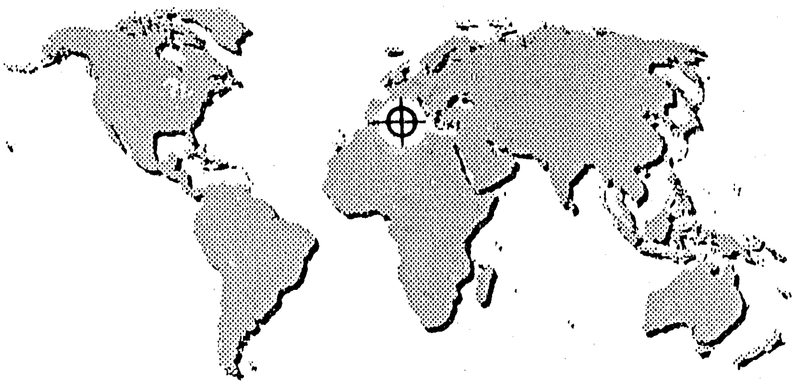
Calibration gases used – CO_2-in-N_2. Mixtures provided by the Scripps Institution of Oceanography.

Scale of data reported – 1985 WMO/Scripps mole fraction scale.

Data availability – These monthly and annual values, as well as the hourly and daily concentrations from Mt. Cimone, may be obtained from the principal investigator. The monthly and annual concentrations presented are available from CDIAC and are also archived at the WMO and NCDC.



Monthly atmospheric CO_2 concentrations.



Mt. Cimone
Italy
Mountain top
44° 11'N, 10° 42'E
2165 m above MSL

TREND

Mt. Cimone observatory, a station of the Italian Meteorological Service, has been participating in the WMO-BAPMoN program since 1978. The atmospheric CO_2 record from Mt. Cimone represents the longest continuous record available for the Mediterranean area. From 1979 to 1988, the annual mean atmospheric CO_2 concentration at Mt. Cimone rose from 336.38 ppmv to 350.17 ppmv. This represents an increase of approximately ~1.4 ppmv per year. Ciattaglia reported a trend of 1.7 ppmv per year for the period March 1979–June 1985. Ciattaglia et al. (1987) also found the seasonal oscillation for this same time period to have an amplitude of 13 ppmv. This seasonal amplitude is attributable to photosynthetic depletion from vegetation below the timberline at Mt. Cimone and to the relationship between CO_2 concentrations and wind direction. Ciattaglia et al. (1987) found a relationship between the behavior of selected CO_2 data with prevailing winds [i.e., SW (180°–290°) and NE (0°–90°) winds] and episodes of Sahara dust transport. During winter, NE winds continue the high CO_2 concentrations measured on site, while SW winds are characterized by lower concentrations. During summer, the situation is reversed. During the cold season, Saharan transports are characterized by low CO_2 and by small record variability. When these episodes occur during hot periods, CO_2 concentrations show values above average.

Mt. Cimone

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1979	344.1	344.8	341.3	341.7	337.0	334.0	329.7	326.8	328.6	334.3	336.8	337.5	336.4
1980	340.7	340.0	342.3	342.6	338.3	335.5	330.1	328.8	331.2	335.1	339.1	340.4	337.0
1981	341.5	343.1	342.4	342.5	339.5	335.3	330.8	330.3	333.6	336.8	339.4	343.2	338.2
1982	341.7	344.4	345.5	345.8	340.8	336.7	334.7	332.4	335.2	339.3	341.3	344.9	340.2
1983	342.5	346.3	345.0	344.4	342.3	338.3	335.9	335.0	336.6	339.8	344.6	345.6	341.4
1984	346.3	349.4	351.3	350.5	346.4	344.4	346.7	335.1	337.8	342.3	344.9	346.8	345.2
1985	349.9	348.2	350.7			345.9	341.4	337.7	336.8	339.3	344.0	349.4	347.2
1986	349.4	351.4	352.3	350.7	348.4	343.0	337.2	338.5	340.9	346.3	349.0	350.5	346.5
1987	349.2	355.0	354.8	346.5	350.3	347.4	341.7	341.6	342.2	345.7	350.5	352.1	348.1
1988	353.5	355.0	355.0	354.5	352.2	346.8	342.6	344.5	343.6	349.0	352.4	353.2	350.2

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

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Cape Grim

BACKGROUND

Principal investigators

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Graeme I. Pearman
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Mordialloc, Victoria 3195, Australia

Air sample collection – Air samples for continuous monitoring are collected from an air intake at the 70-m level of a 74-m microwave communications tower. Flask samples are collected periodically in 0.5-L glass flasks from the same air intake.

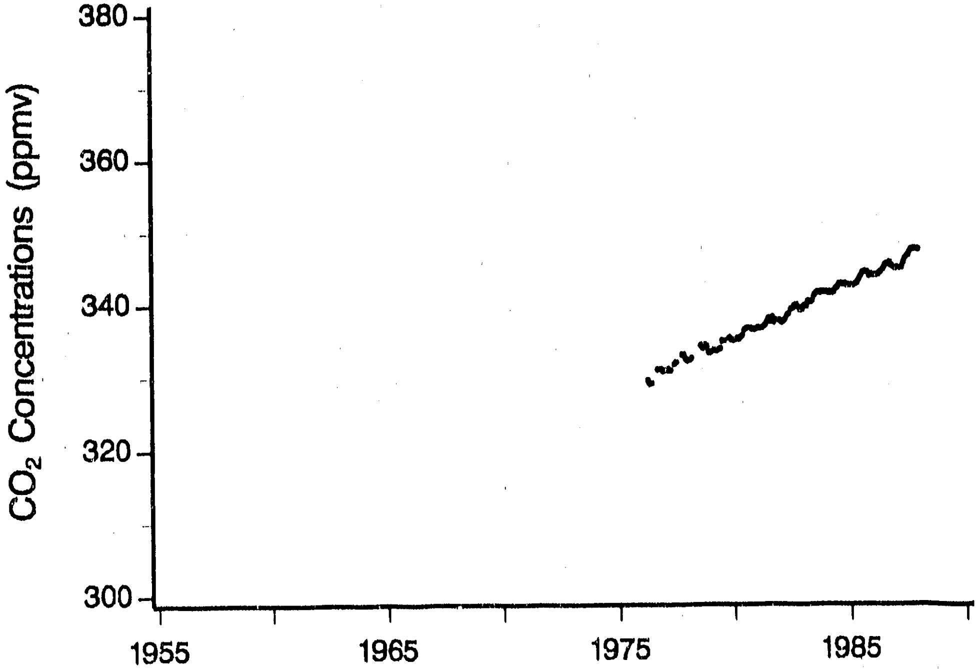
Measurement apparatus – Continuous samples are analyzed at Cape Grim with an in situ URAS nondispersive infared gas analyzer (NDIR), and flask samples are analyzed at the Aspendale laboratory with the same type of NDIR.

Data selection procedures – For continuous sampling, baseline data must have a wind direction of 190°–280°, and the individual hourly means must be part of a sequence of five consecutive hours of data from the selected direction during which the CO_2 concentrations vary by less than ±0.3 ppmv. For flask samples, baseline data must have a wind direction of 190°–280° and a wind speed >5 m/sec.

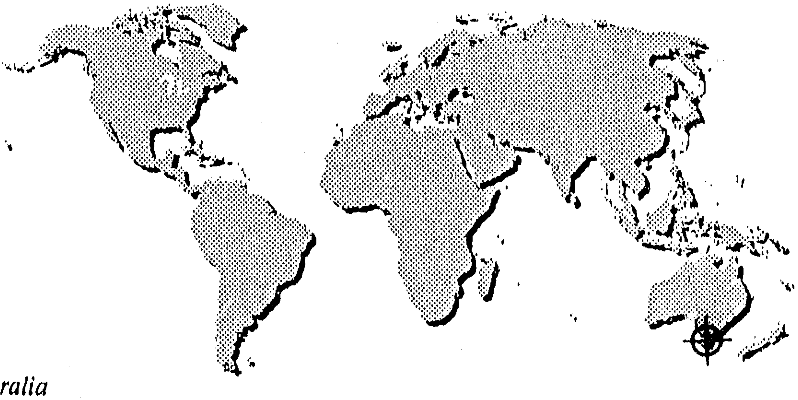
Calibration gases used – CO_2-in-air (since 2 Nov. 1982) and CO_2-in-N_2 (before 2 Nov. 1982).

Scale of data reported – WMO 1981 CO_2-in-air calibration scale for 1976–1984 and WMO 1985 CO_2-in-air calibration scale after 1984.

Data availability – These data and the total and selected daily data are available from the principal investigators and CDIAC (Beardsmore et. al 1985).



Monthly atmospheric CO_2 concentrations.



Cape Grim
Tasmania, Australia
Promontory seashore
40° 41'S, 144° 41'E
94 m above MSL

TREND

The Australian Baseline Atmospheric Observatory at Cape Grim is part of the Australian contribution to the UNEP/WMO Background Air Pollution Network. It is a station that undertakes a comprehensive program of observations of the constituents of the background atmosphere for the purposes of (1) identifying trends in constituents that may be of climatic significance; (2) describing the distribution of constituents both temporally and spatially in conjunction with other stations of the network for the purpose of improving understanding of biogeochemical cycles; and (3) using the data in studies of large-scale atmospheric dynamics (Beardsmore and Pearman 1987).

The annual average "baseline" atmospheric CO_2 concentration at Cape Grim, Tasmania, has risen from 329.97 ppmv in 1976 to 346.06 ppmv in 1987. Beardsmore and Pearman (1987) found that the mean rate of CO_2 concentration increase over the period April 1976 to December 1984 at Cape Grim was 1.49 ppmv per year, but they also reported a strong interannual variability in this rate of increase.

The seasonal cycle of atmospheric CO_2 concentrations at Cape Grim is very apparent in the baseline in situ data. Beardsmore and Pearman (1987) found the mean seasonal amplitude to be 0.92 ppmv.

Cape Grim

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1976				329.4	328.9	329.0			330.9		330.9	330.6	330.0
1977	330.8	330.7	331.0	330.8		331.7	331.9			332.9	332.9	332.3	331.7
1978	332.1	332.2	332.4					334.1	333.8	334.2	334.0	333.2	333.2
1979	333.2	333.3	333.5	333.4	333.5	333.7	334.7	334.8			335.1	334.8	334.0
1980	334.8	334.9	335.0	335.0	335.3	335.6	336.2	336.4	336.5	336.5	336.4	336.3	335.7
1981	336.4	336.5	336.5	336.6	336.8	337.2		337.7	337.9				337.0
1981							337.8	337.4	337.4	337.3	337.6	337.5	337.5
1982	337.5	337.3	337.4	337.7	338.2	338.4	339.0	339.1	339.5	339.6	339.4	339.0	338.5
1983	339.0	339.5	339.5	340.1	340.0	340.3	340.9	341.3	341.4	341.3	341.4	341.4	340.5
1984	341.4	341.3	341.3	341.2	341.4	341.8	342.1	342.5	342.5	342.4	342.1	342.3	341.9
1985	342.4	342.3	342.3	342.5	342.7	343.2	343.6	344.0	344.2	344.1	343.6	343.8	343.2
1986	343.7	343.7	343.7	343.8	344.0	344.3	344.7	345.1	345.2	345.4	345.0	344.9	344.5
1987	344.7	344.8	344.7	344.8	345.4	346.0	346.3	346.9	347.3	347.3	347.4	347.3	346.1

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*The monthly and annual means provided are selected baseline data that have been rounded by CDIAC to the nearest tenth. In 1981, the in situ equipment in the permanent laboratory was installed. For 1981, two sets of values are given. The first set is derived from the in situ equipment (Mark I) in the temporary laboratory, and the second set (Mark II), from the permanent laboratory. Atmospheric CO_2 measurements in parts per million by volume (ppmv).

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Alert

BACKGROUND

Principal investigators

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Canada

Air sample collection – Once every week a pair of evacuated 2-L flasks are exposed around noon local time by Atmospheric Environment Service (AES) personnel to obtain samples of the ambient air.

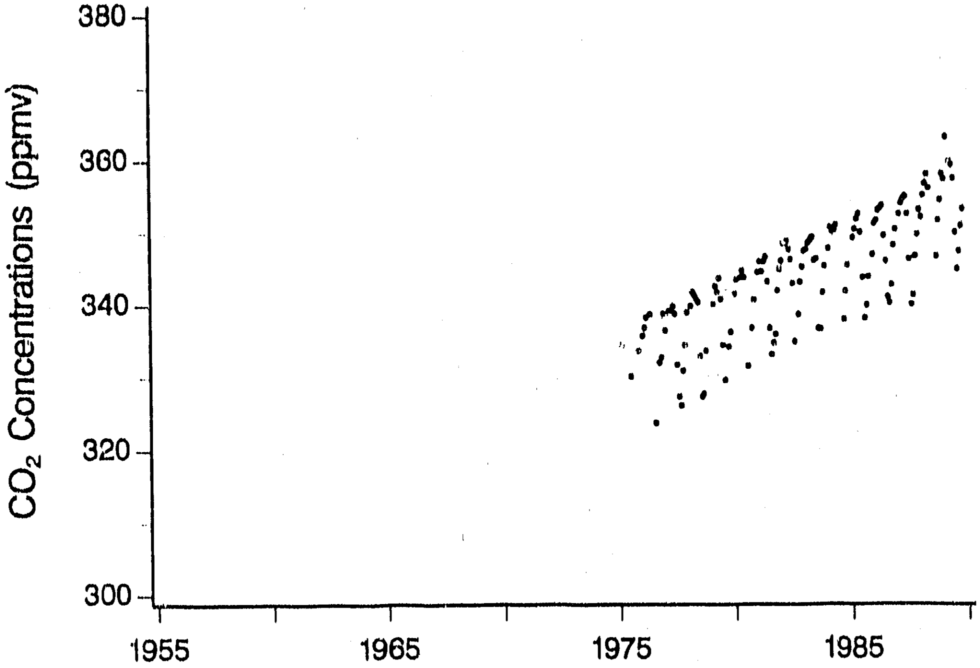
Measurement apparatus – The flask samples were analyzed for CO_2 concentrations at the Institute of Ocean Sciences (IOS) by using a URAS 2T nondispersive infrared gas analyzer (NDIR). Since 1988, AES has been collecting and analyzing the data with URAS 3E and UNOR 4N NDIR.

Data selection procedures – Two flask samples are collected per daily sample. From each flask, two aliquots are analyzed. The flask data are given primary and secondary classifications according to criteria described in Trivett and Higuchi (1989).

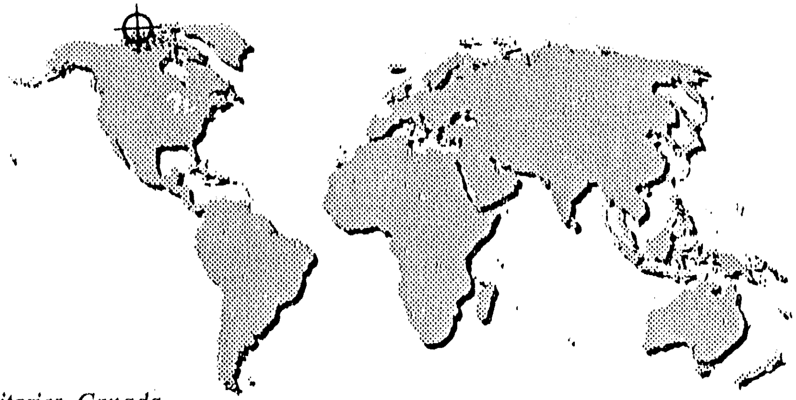
Calibration gases used – CO_2-in-air.

Scale of data reported – WMO 1983 scale.

Data availability – The daily "good" flask data, along with these monthly and annual averages, have been archived and are available from CDIAC. Monthly and annual means have also been reported by WMO (1989).



Monthly atmospheric CO_2 concentrations.



Alert
Northwest Territories, Canada
Tundra
82° 31'N, 62° 18'W
142 m above MSL

TREND

These data are from the Canadian monitoring program, which began in 1969 at Ocean Weather Station "P" as a joint effort between Scripps Institution of Oceanography and the Institute for Ocean Sciences at Sidney, British Columbia (see Wong et al. 1984). The sampling site at Alert, Northwest Territories, was established in 1975 by the Atmospheric Environment Service as a result of the Stockholm Conference in 1974. At the same time, a station was established on Sable Island off the coast of Nova Scotia. Alert is located about 800 km from the North Pole on the northern tip of Ellesmere Island. Currently, both continuous and grab flask sampling programs are conducted at Alert.

The flask data from Alert show an increase in the annual atmospheric CO_2 concentration from 331.7 ppmv in 1975 to 354.3 ppmv in 1989. Trivett and Higuchi (1989) reported a mean annual rate of increase, obtained from the slope of a least squares regression line through the annual averages, for Alert to be 1.49 ppmv per year. For comparison, Conway et al. (1988) reported a 1.22 ppmv mean annual growth rate at the nearest NOAA/CMDL site (Mould Bay, Northwest Territories) for 1981–1984. Wong et al. (1984) reported a mean annual CO_2 concentration of 338.73 ppmv for Alert in 1980.

Atmospheric CO_2 concentrations at Alert show a seasonal pattern with the annual drawdown measured during the late summer (August–September) and the annual maximum measurements recorded during the early spring (April–May).

Alert

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1975							330.0				333.5		331.7
1976	335.6	336.7	338.1		338.5		329.6	323.6		331.9	332.6	338.6	333.9
1977	336.3		339.0		339.6	338.6	331.6	327.2	326.0	330.8	334.3	338.8	334.2
1978		339.7	341.6	341.2	340.7	340.2	332.8	327.2	327.6	333.5			336.1
1979		339.9	342.4	341.6	343.5	340.6	334.3	329.5		334.1	336.1		338.0
1980	341.3	343.3		343.6	344.5	343.6		331.4		336.6	340.5		340.6
1981	344.3	345.8	344.4	345.8	346.4	343.0	336.6	333.0	334.6	335.8	341.8	344.7	341.4
1982	345.9	348.3	348.3	348.6	347.5	346.1	342.8	334.8		338.5	343.0	345.1	344.4
1983	347.3	347.5	348.4	348.7	349.2	346.0	346.2	336.6	336.5	341.5	345.2		344.8
1984	347.6	350.5	350.0	350.1	350.8			337.4	337.8	341.7	345.3		346.7
1985		349.1	350.3	351.7	352.4	349.9	343.6	338.0	339.8	343.8		346.8	346.5
1986	351.1	351.5	352.9	353.1	353.5	349.4	345.9	340.9	340.1	342.6	348.1	350.3	348.3
1987		352.4	353.9	354.5	354.8	352.4	346.2	339.9	341.2	346.6	349.6	353.0	349.5
1988	352.0	355.0	356.6	357.9	356.0				346.6	351.6	354.4	358.0	354.2
1989	357.3	363.1		359.7	359.3	357.4	350.0	344.9	347.4	350.9	353.2		354.3

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

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Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

Higuchi, K., and S.M. Daggupaty. 1985. On variability of atmospheric CO_2 at station Alert. *Atmospheric Environment* 19:2039–44.

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Wong, C.S., Y.H. Chan, J.S. Page, R.D. Bellegay, and K.G. Pettit. 1984. Trends of atmospheric CO_2 over Canadian WMO background stations at Ocean Weather Station P, Sable Island, and Alert. *Journal of Geophysical Research* 89:9527–39.

World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

Cape St. James

BACKGROUND

Principal investigators

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Institute of Ocean Sciences
Sidney, British Columbia
Canada

Air sample collection – Once every week a pair of evacuated 2-L flasks are exposed around noon local time by Atmospheric Environment Service (AES) personnel to obtain samples of the ambient air.

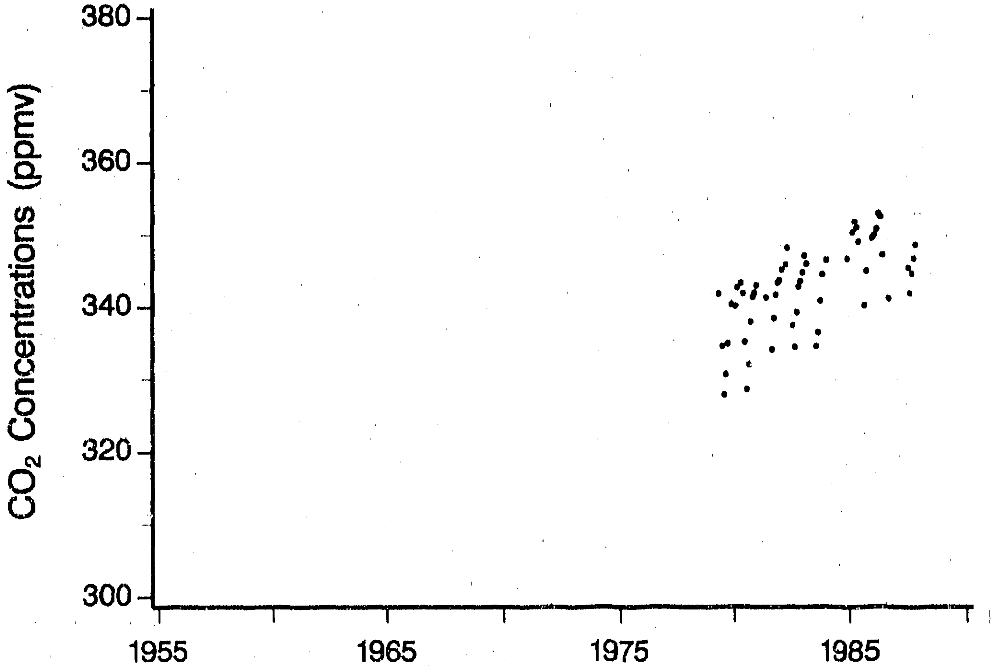
Measurement apparatus – The flask samples were analyzed for CO_2 concentrations at the Institute of Ocean Sciences (IOS) by using a URAS 2T nondispersive infrared gas analyzer (NDIR). Since 1988, AES has been collecting and analyzing the data with URAS 3E and UNOR 4N NDIRs.

Data selection procedures – Two flask samples are collected per daily sample. From each flask, two aliquots are analyzed. The flask data are given primary and secondary classifications according to criteria described in Trivett and Higuchi (1989).

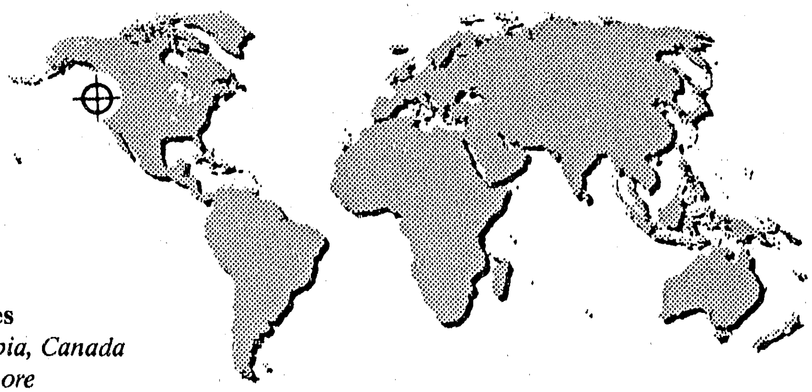
Calibration gases used – CO_2-in-air.

Scale of data reported – WMO 1983 scale.

Data availability – Monthly means have been reported by WMO (1989). The daily "good" flask and continuous data have been archived and are available from CDIAC.



Monthly atmospheric CO_2 concentrations.



Cape St. James
British Columbia, Canada
Island seashore
51° 56′N, 131° 01′W
89 m above MSL

TREND

These data are from the Canadian monitoring program, which began in 1969 at Ocean Weather Station "P" as a joint effort between Scripps Institution of Oceanography and the Institute for Ocean Sciences at Sidney, British Columbia (see Wong et al. 1984). Following the Stockholm Conference in 1974, the Atmospheric Environment Service (AES) established two stations at Sable Island, Nova Scotia, and Alert, Northwest Territories. The sampling site at Cape St. James on Queen Charlotte Islands was established in 1978 as a replacement for Ocean Station "P," which was taken out of service in 1982.

The flask data from Cape St. James show an increase in the annual atmospheric CO_2 concentration from 335.2 ppmv in 1979 to 353.4 ppmv in 1989. However, these annual estimates are derived from monthly means, which for some years are few in number and are based on few flask samples. For Cape St. James, Trivett and Higuchi (1989) reported a mean annual rate of increase, obtained from the slope of a least squares regression line through the annual averages, to be 1.43 ppmv per year. For comparison, Conway et al. (1988) reported a 1.22-ppmv mean annual growth rate at all NOAA/CMDL flask sites for 1981–1984. Wong et al. (1984) reported a mean annual increase of 1.4 ppmv based on data for 1975–1981 from Ocean Station "P," Sable Island, and Alert.

Cape St. James

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1979					341.7		336.1	327.8	330.6	334.8		340.2	335.2
1980		340.0	342.5		343.1	341.7	334.0	328.5	331.9	337.8	341.2		337.9
1981	342.8								334.0	338.3	341.6	343.2	340.0
1982	343.5	345.0		345.7	348.0			337.3	334.3	339.1	342.6	342.7	342.0
1983	344.6	346.9	345.8					334.4	336.3	341.2	345.2		342.1
1984												346.5	346.5
1985			350.4	351.6	351.5	348.7			340.1	344.9			347.9
1986	349.3	349.8	350.8	352.3	352.3	347.0			341.0	345.7			348.5
1987							345.3	341.8	344.5	346.6	348.5		345.3
1988	354.0	353.6	354.4	355.9	355.7	353.0	349.7	341.5		351.0	353.4	354.2	352.4
1989	356.8	356.6	357.3	358.3		355.9	348.5	347.2	348.4	351.9			353.4

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Conway, T.J., P. Tans, L.S. Waterman, K.W. Thoning, K.A. Masarie, and R.H. Gammon. 1988. Atmospheric carbon dioxide measurements in the remote global troposphere, 1981–1984. *Tellus* 40(B):81–115.

Higuchi, K., and S.M. Daggupaty. 1985. On variability of atmospheric CO_2 at station Alert. *Atmospheric Environment* 19:2039–44.

Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor, and K.W. Thoning. 1985. Global atmospheric CO_2 distributions and variations from 1968–82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–96.

Trivett, N.B.A., and K. Higuchi. 1989. Trends and seasonal cycles of atmospheric CO_2 over Alert, Sable Island, and Cape St. James, as analyzed by forward stepwise regression technique. pp. 27–42. IN *The Statistical Treatment of CO_2 Data Records*, W.P. Elliott, (ed.). Air Resources Laboratory, Silver Spring, Maryland.

Wong, C.S., Y.H. Chan, J.S. Page, R.D. Bellegay, and K.G. Pettit. 1984. Trends of atmospheric CO_2 over Canadian WMO background stations at Ocean Weather Station P, Sable Island, and Alert. *Journal of Geophysical Research* 89:9527–39.

World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

Garmisch-Partenkirchen

BACKGROUND

Principal investigators

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F.R.G.

Air sample collection – Air samples are collected continuously, and water vapor is removed by chemical filters. Details about the measurement methodology and calibrations are given in Reiter et al. (1986).

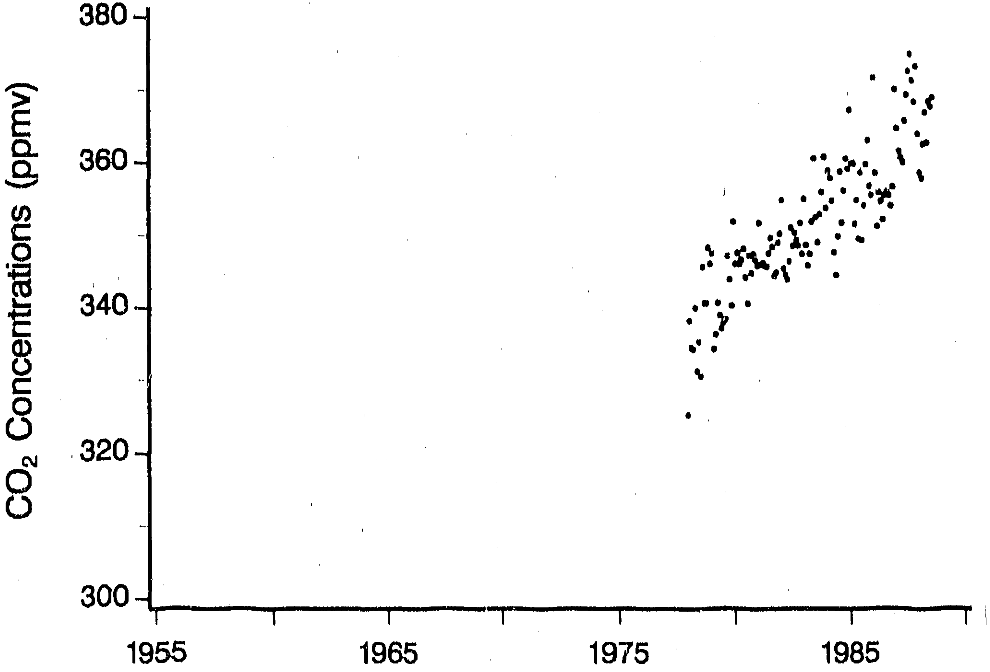
Measurement apparatus – The air samples from the Garmisch-Partenkirchen station are analyzed for CO_2 concentrations with a Siemens ULTRAMAT-3 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – Values are rejected only when the instruments malfunction or when data are considered by the principal investigators to be technically invalid.

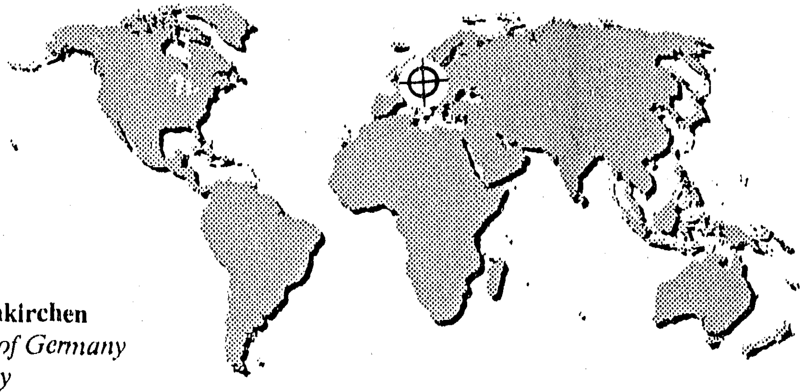
Calibration gases used – CO_2-in-N_2.

Scale of data reported – WMO 1974 Scale.

Data availability – In addition to being available from the principal investigators, the monthly and annual CO_2 measurements from Wank Peak and Zugspitze have been provided to and reported by WMO. The data from Garmisch-Partenkirchen, Wank Peak, and Zugspitze are archived and available from CDIAC.



Monthly atmospheric CO_2 concentrations.



Garmisch-Partenkirchen
Federal Republic of Germany
Grassland valley
47° 28'N, 11° 03'E
740 m above MSL

TREND

These data are from the Federal Republic of Germany monitoring program. The monitoring site outside Garmisch-Partenkirchen is complemented by the Wank Peak and Zugspitze monitoring stations. Collectively, these three neighboring mountain stations provide reliable continuous CO_2 measurements from three elevations. The medium-elevation station (Wank Peak) is a WMO-BAPMoN station with an extended program.

Because of local vegetation influences, the CO_2 concentrations at Garmisch-Partenkirchen are higher and show greater seasonal amplitudes than the concentrations measured at Wank Peak or Zugspitze. Annual atmospheric CO_2 concentrations have risen at Garmisch-Partenkirchen from 337.0 ppmv in 1978 to 367.5 ppmv in 1987. Reiter et al. (1986) reported a mean value of 353 ppmv in 1985 compared to an initial value of 337 ppmv in 1978. Reiter et al. (1986) reported that the steepest increase of CO_2 occurred in the valley from 1978 to 1980 but that the increase has since slowed.

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1978	325.2	338.1	334.4	334.2	339.9	331.2	335.2	330.5	345.5	340.6	340.5	348.1	337.0
1979	345.9	347.3	334.2	336.2	340.5	338.8	337.0	337.8	338.2	346.9	343.7	340.1	340.6
1980	351.6	345.8	347.3	345.8	346.4	347.9	344.0	340.4	347.0	344.6	347.2	346.4	346.2
1981	345.6	351.5	345.8	346.0	345.6	345.5	347.3	349.4	348.2	344.2	344.7	348.8	346.9
1982	350.0	354.6	345.2	344.3	343.7	346.2	350.8	348.3	350.1	349.1	348.3	351.4	348.5
1983	347.2	354.7	348.4	345.6	347.2	351.6	360.3	352.2	348.8	352.6	355.7	360.5	352.1
1984	353.5	358.6	357.6	354.5	347.4	344.3	349.6	358.5	351.5	355.9	360.3	358.9	354.2
1985	367.0	359.6	359.6	351.3	354.6	349.3	358.4	349.1	353.9	359.5	362.8	356.5	356.8
1986	355.3	371.4	358.3	351.0	355.6	354.4	351.9	355.2	355.7	355.2	353.8	356.4	356.2
1987	369.8	364.4	361.3	360.4	359.8	365.5	369.1	372.3	374.7	371.1	368.2	373.1	367.5
1988	363.8	358.5	357.7	362.4	366.8	362.6	368.3	367.6	368.8				

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Reiter, R., and H.J. Kanter. 1980. First results of simultaneous recordings of the CO_2-concentration from a valley station and a neighboring mountain station at an altitude difference of about 1 km. *Archiv fuer Meteorologie, Geophysik, und Bioklimatologie.* 28:1–13.

Reiter, R., and H.J. Kanter. 1982. Time behavior of CO_2 and O_3 in the lower troposphere based on recordings from neighboring mountain stations between 0.7 and 3.0 km ASL including the effects of meteorological parameters. *Archiv fuer Meteorologie, Geophysik, und Bioklimatologie.* 30:191–225.

Reiter, R., K. Munzert, and H.J. Kanter. 1985. *Parameterization of the variation of CO_2 and O_3 in the lower troposphere based on 5-year recordings at 0.7/1.8/3.0 km ASL with consideration of the most important magnitudes of meteorology, biomass, and anthropogenic effects.* World Meteorological Organization, Special Environmental Report No. 16. WMO No. 647. TECOMAC. Geneva.

Reiter, R., R. Sladkovic, and H.J. Kanter. 1986. Concentration of trace gases in the lower troposphere, Part I: Carbon dioxide. *Meteorology and Atmospheric Physics* 35:187–200.

World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD-No. 306. Geneva.

Wank Peak

BACKGROUND

Principal Investigators

Reinhold Reiter
Rudolf Sladkovic
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Fraunhofer-Institute for Atmospheric Research
Kreuzeckbahnstrasse 19
D-1800 Garmisch-Partenkirchen
F.R.G.

Air sample collection – Air samples are collected continuously, and water vapor is removed by chemical filters. Details about the measurement methodology and calibrations are given in Reiter et al. (1986).

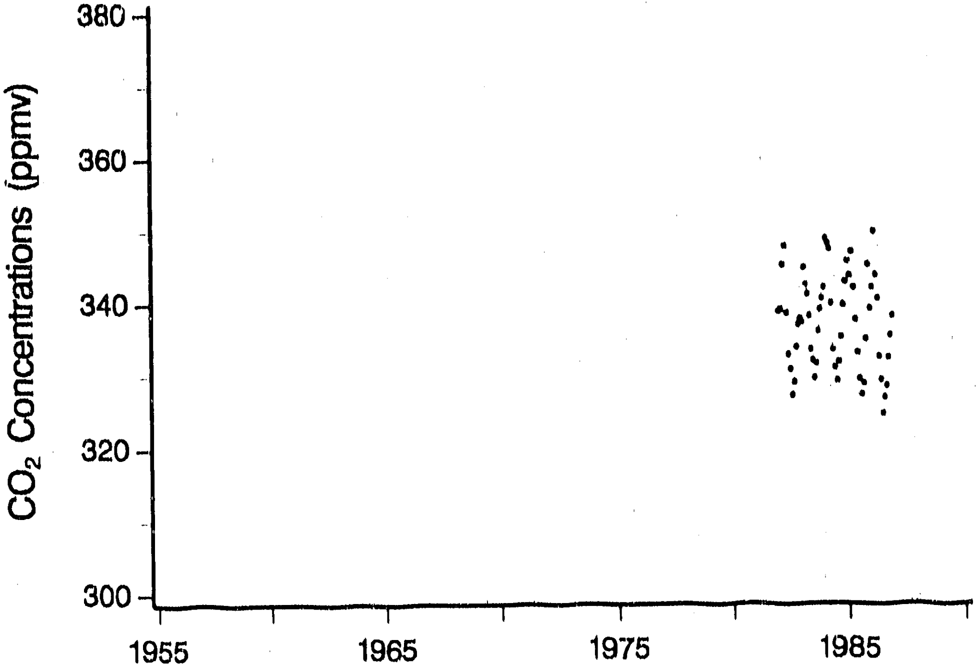
Measurement apparatus – The air samples from the Wank station are analyzed for CO_2 concentrations by using a Siemens ULTRAMAT-3 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – Values are rejected only when the instruments malfunction or when data are considered by the principal investigators to be technically invalid.

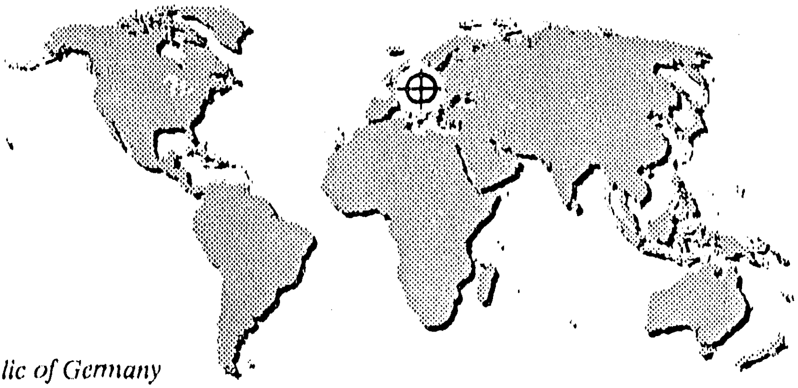
Calibration gases used – CO_2-in-N_2.

Scale of data reported – WMO 1974 Scale.

Data availability – In addition to being available from the principal investigators, the monthly and annual CO_2 measurements from Wank Peak and Zugspitze have been provided to and reported by WMO. The monthly and annual concentrations from Garmisch-Partenkirchen, Wank Peak, and Zugspitze are archived and available from CDIAC.



Monthly atmospheric CO_2 concentrations.



Wank Peak
Federal Republic of Germany
Mountain peak
47° 30′N, 11° 08′E
1776 m above MSL

TREND

These data are from the Federal Republic of Germany monitoring program. The monitoring site at Wank Peak is a WMO-BAPMoN station at which numerous atmospheric measurements, including CO_2 concentrations, are collected. This station is complemented by the nearby Garmisch-Partenkirchen and Zugspitze monitoring stations. The Wank Peak Mountain Observatory is located just above the timberline but surrounded by closed flat grass cover and isolated low alpine pines. Collectively, these three neighboring mountain stations provide reliable continuous CO_2 measurements from three elevations.

Unlike the monitoring site at Garmisch-Partenkirchen, which is subject to considerable local vegetation influences, the CO_2 measurements obtained at Wank Peak are not considered to be frequently influenced by vegetation or tourism. Reiter et al. (1986) reported a slight increase in the mean annual value from 331 ppmv in 1978 to 339 ppmv in 1984. Reiter et al. (1986) also reported the mean annual amplitude to be greater at Wank Peak than at Zugspitze.

Wank Peak

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1982	338.8	339.1	345.2	347.8	338.6	332.9	330.9	327.3	329.1	333.9	337.0	337.8	336.5
1983	337.3	344.8	342.4	341.1	338.1	333.5	332.0	329.6	331.6	336.0	339.0	340.5	337.2
1984	342.0	348.7	348.1	347.3	339.8	333.5	331.0	329.2	331.8	335.2	339.6	342.8	339.1
1985	345.6	343.6	346.9	342.0	337.6	333.1	329.5	327.4	328.9	335.0	345.2	339.2	337.8
1986	342.1	349.8	343.8	340.6	332.6	329.4	324.8	327.0	328.6	332.5	335.5	338.2	335.4

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Reiter, R., and H.J. Kanter. 1980. First results of simultaneous recordings of the CO_2-concentration from a valley station and a neighboring mountain station at an altitude difference of about 1 km. *Archiv fuer Meteorologie, Geophysik, und Bioklimatologie* 28:1–13.

Reiter, R., and H.J. Kanter. 1982. Time behavior of CO_2 and O_3 in the lower troposphere based on recordings from neighboring mountain stations between 0.7 and 3.0 km ASL including the effects of meteorological parameters. *Archiv fuer Meteorologie, Geophysik, und Bioklimatologie* 30:191–225.

Reiter, R., K. Munzert, and H.J. Kanter. 1985. *Parameterization of the variation of CO_2 and O_3 in the lower troposphere based on 5-year recordings at 0.7/1.8/3.0 km ASL with consideration of the most important magnitudes of meteorology, biomass, and anthropogenic effects*. World Meteorological Organization, Special Environmental Report No. 16, WMO No. 647, TECOMAC, Geneva, Switzerland.

Reiter, R., R. Sladkovic, and H.J. Kanter. 1986. Concentration of trace gases in the lower troposphere, Part I: Carbon dioxide. *Meteorology and Atmospheric Physics* 35:187–200.

World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987*. WMO/TD-No. 306. Geneva.

Zugspitze

BACKGROUND

Principal investigators

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Kreuzeckbahnstrasse 19
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F.R.G.

Air sample collection – Air samples are collected continuously, and water vapor is removed by chemical filters. Greater details about the measurement methodology and calibrations are given in Reiter et al. (1986).

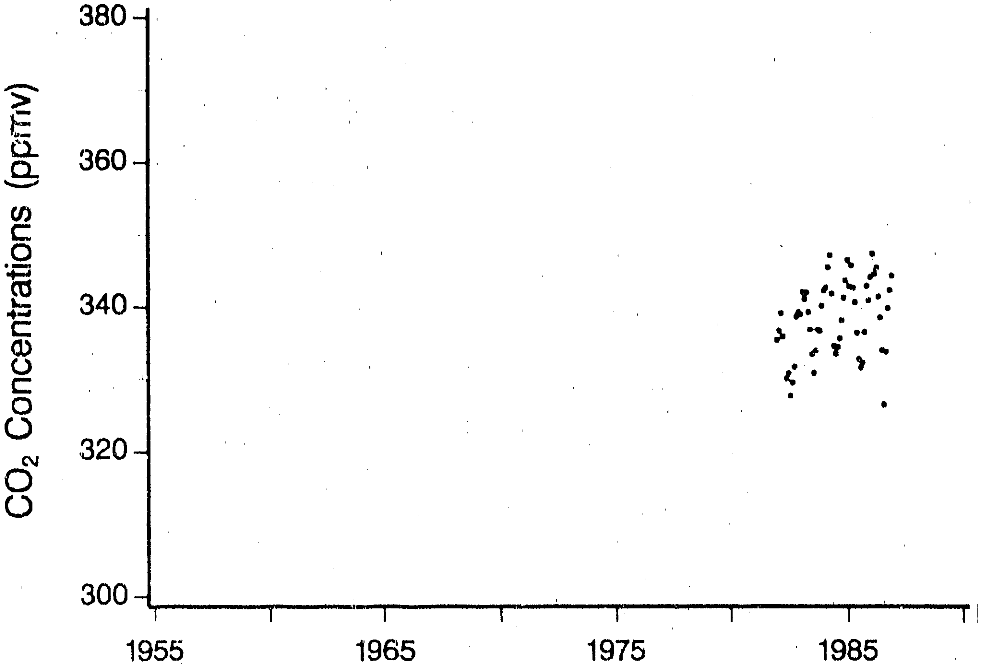
Measurement apparatus – The air samples from the Wank station are analyzed for CO_2 concentrations with a Siemens ULTRAMAT-3 semiautomatic nondispersive infrared gas analyzer.

Data selection procedures – Values are rejected only when the instruments malfunction or when data are considered by the principal investigators to be technically invalid.

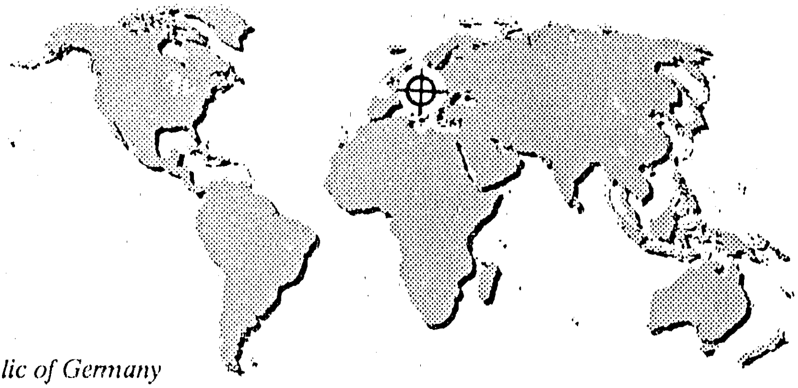
Calibration gases used – CO_2-in-N_2.

Scale of data reported – WMO 1974 Scale.

Data availability – In addition to being available from the principal investigators, the monthly and annual CO_2 measurements from Wank Peak and Zugspitze have been provided to and reported by WMO. The monthly and annual concentrations from Garmisch-Partenkirchen, Wank Peak, and Zugspitze are archived and available from CDIAC.



Monthly atmospheric CO_2 concentrations.



Zugspitze
Federal Republic of Germany
Mountain peak
47° 25′N, 10° 59′E
2962 m above MSL

TREND

These data are from the Federal Republic of Germany monitoring program. The monitoring station at Zugspitze is complemented by the nearby Garmisch-Partenkirchen and Wank Peak monitoring stations. The station at Zugspitze is located above the timberline and approximately 250 m below the main peak of Zugspitze. A balcony, closed to all sides, on a very steep rock wall is used for the CO_2 recordings. Collectively, these three neighboring mountain stations provide reliable continuous CO_2 measurements from three elevations.

Unlike the monitoring sites at Garmisch-Partenkirchen and Wank Peak, which are subject to local influences (e.g., vegetation, automobile exhaust, and tourism), the CO_2 measurements obtained at Zugspitze are considered to be free of regional contamination. Annual atmospheric CO_2 concentrations have risen at Zugspitze from 334.0 ppmv in 1982 to 340.0 ppmv in 1986. Reiter et al. (1986) reported that the annual mean value of the CO_2 concentration increases slowly in uneven annual steps and that the 10-day mean values vary greatly. Reiter et al. (1986) also reported that the maximum values at Zugspitze are recorded in April, while the minimum values are recorded between July and August.

Zugspitze

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1982	335.3	336.6	339.0	335.8		330.0	330.7	327.6	329.4	331.6	338.5	339.1	334.0
1983	338.8	341.9	340.9	341.8	339.1	336.7	333.3	330.7	333.8	336.7	336.5	340.0	337.5
1984	342.1	342.5	345.3	347.0	341.7	334.5	333.4	334.3	335.5	338.0	341.1	343.5	339.9
1985	346.3	342.7	345.6	342.5	340.5	336.3	332.7	331.5	332.2	336.4	342.8	340.8	339.9
1986	344.0	347.2	344.4	345.3	341.3	338.4	333.9	326.4	333.7	339.7	342.2	344.2	340.0

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on monthly means. All numbers have been rounded to the nearest tenth.

REFERENCES

Reiter, R., and H.J. Kanter. 1980. First results of simultaneous recordings of the CO_2-concentration from a valley station and a neighboring mountain station at an altitude difference of about 1 km. *Archiv fuer Meteorologie, Geophysik, und Bioklimatologie* 28:1–13.

Reiter, R., and H.J. Kanter. 1982. Time behavior of CO_2 and O_3 in the lower troposphere based on recordings from neighboring mountain stations between 0.7 and 3.0 km ASL including the effects of meteorological parameters. *Archiv fuer Meteorologie, Geophysik, und Bioklimatologie* 30:191–225.

Reiter, R., K. Munzert, and H.J. Kanter. 1985. *Parameterization of the variation of CO_2 and O_3 in the lower troposphere based on 5-year recordings at 0.7/1.8/3.0 km ASL with consideration of the most important magnitudes of meteorology, biomass, and anthropogenic effects.* World Meteorological Organization, Special Environmental Report No. 16, WMO No. 647, TECOMAC, Geneva, Switzerland.

Reiter, R., R. Sladkovic, and H.J. Kanter. 1986. Concentration of trace gases in the lower troposphere, Part I: Carbon dioxide. *Meteorology and Atmospheric Physics* 35:187–200.

World Meteorological Organization. 1989. *Provisional daily atmospheric carbon dioxide concentrations as measured at BAPMoN sites for the years 1986 and 1987.* WMO/TD No. 306. Geneva.

Osnabrück

BACKGROUND

Principal investigators
Dieter Overdieck
Manfred Forstreuter
Universitat Osnabrück
Biologie/Chemie
Postfach 44 69
D-4500 Osnabrück
F.R.G.

Air sample collection – Continuous, every 144 s.

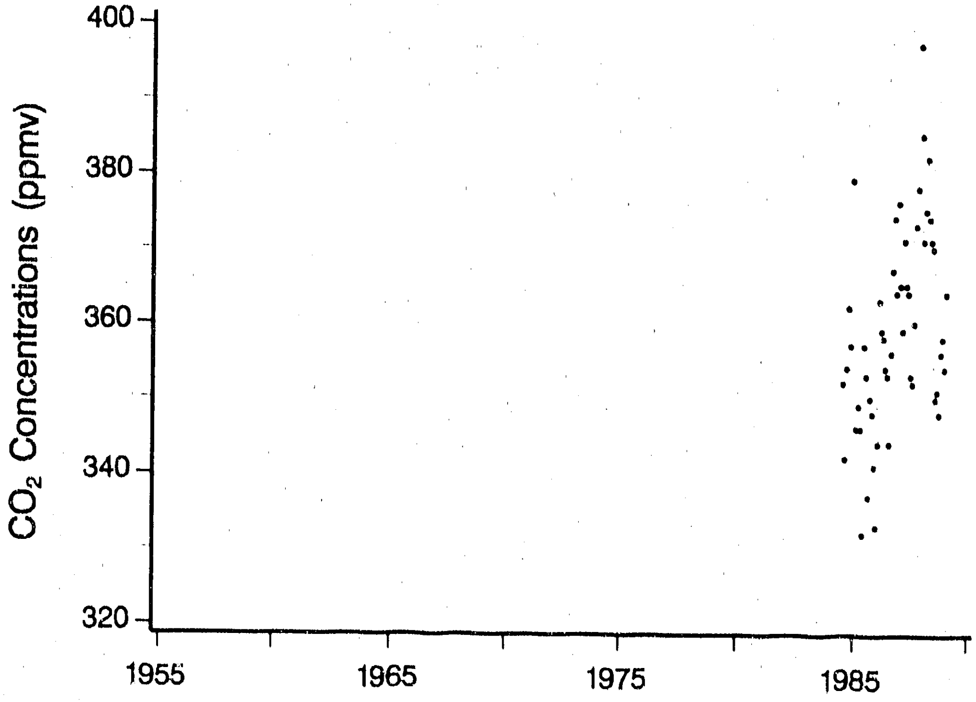
Measurement apparatus – Air samples are analyzed for CO_2 concentrations by using a Hartmann & Braun URAS 2T nondispersive infrared gas analyzer.

Data selection procedures – After digitizing, the data are reduced to half-hour means from which the monthly averages are calculated. Since the data at Osnabrück are collected for vegetative response research, the data selection procedures are not as sophisticated as those at sites monitoring for climate analysis purposes.

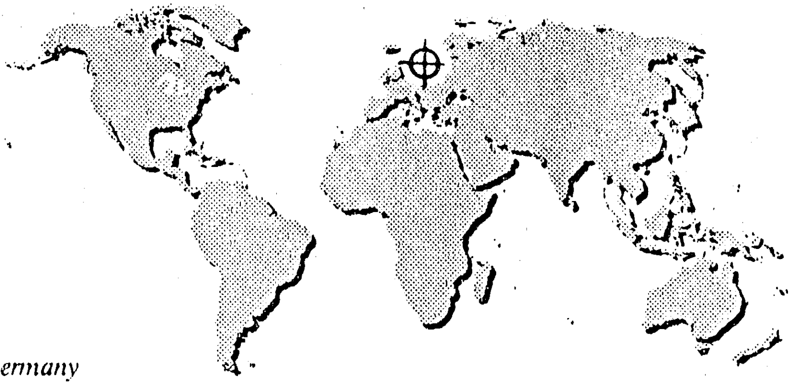
Calibration gases used – CO_2-in-N_2.

Scale of data reported – WMO 1985 Scale.

Data availability – Monthly means from Osnabrück have been archived and are available from CDIAC.



Monthly atmospheric CO_2 concentrations.



Osnabrück
Westerberg
Federal Republic of Germany
Urban (city of approximately 160,000)
58° 18'N, 8° 2'E
95 m above MSL

TREND

The CO_2 monitoring conducted at Osnabrück is not part of the WMO BAPMoN network. The monitoring at Osnabrück is conducted for research examining the vegetative response to elevated levels of CO_2. The monitoring of ambient air CO_2 concentration levels provides the control data for long-term field experiments about the effects of tropospheric CO_2 enrichment on single plants, grassland model-ecosystems, and other vegetation types. Because these measurements are subject to local sources of contamination and because of the purpose for which they are collected, these measurements are not indicative of the background air conditions near Osnabrück. Despite the seasonal variability shown by these data, these measurements support the rising trend of atmospheric CO_2 concentrations seen at other regional sites.

Osnabrück

Atmospheric Concentrations of Carbon Dioxide*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1984								352	342	354	362	357	
1985	379	346	349	346	332	357	353	337	350	348	341		
1986	333	344	363	359	358	354	353	344	356	367	374	364	356
1987	376	365	359	371	365	364	353	352	360	373	378	397	368
1988	385	371	375	382	374	371	370	350	351	348	356	358	366
1989	354	364											

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*Atmospheric CO_2 in parts per million by volume (ppmv). Annual averages based on available monthly means.

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Overdieck, D. 1986. Long-term effects of an increased CO_2 concentration on terrestrial plants in model ecosystems. Morphology and reproduction of *Trifolium repens* L. and *Lolium perenne* L. *International Journal of Biometeorology* 30(4):323–32.

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Overdieck, D., and F. Reining. 1986. Effect of atmospheric CO_2 enrichment on perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) competing in managed model ecosystems. I. Phytomass production. *Acta Oecologica Oecologia Plantarum* 7(4):357–66.

Overdieck, D., and F. Reining. 1986. Effect of atmospheric CO_2 enrichment on perennial ryegrass and white clover competing in managed model ecosystems. II. Nutrient uptake (*Lolium perenne* L. and *Trifolium repens* L.). *Acta Oecologica Oecologia Plantarum* 7(4):367–78.

Overdieck, D., C. Reid, and B.R. Strain. 1988. The effects of preindustrial and future CO_2 concentrations on growth, dry matter production and the C/N relationship in plants at low nutrient supply. *Vigna unguiculata* (Cowpea), *Abelmoschus esculentus* (Okra) and *Raphanus sativus* (Radish). Angewandte Botanik 62:119–34.

Global and National CO2 Emissions from Fossil Fuel Burning, Cement Production, and Gas Flaring

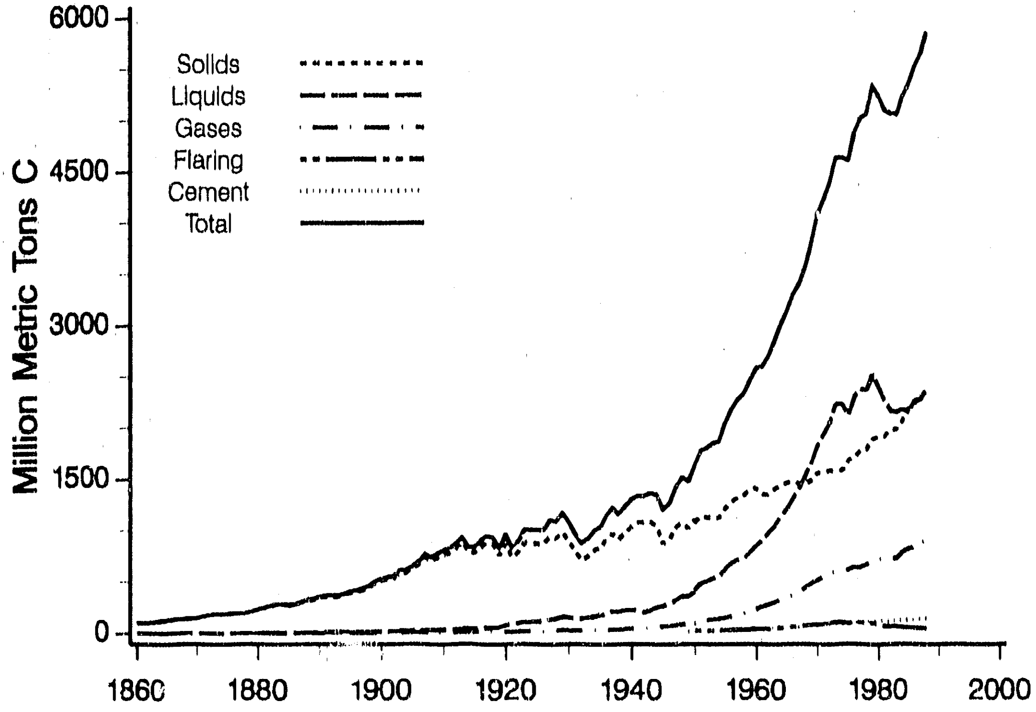
Introduction

Atmospheric CO_2 is produced both from natural sources and human activities. Of human activities, the most important source of CO_2 is the release of carbon during the burning of fossil fuels. Since the Industrial Revolution, CO_2 emissions from fossil fuel consumption have risen dramatically (see figure). In 1988, ~5.9 gigatons of carbon was emitted to the atmosphere as a result of fossil fuel burning, cement manufacturing, and gas flaring. These emission estimates, although small in comparison with the amounts of carbon stored in the oceans and terrestrial biosphere, represent a significant component of global carbon cycling and the greenhouse effect and, more important, quantify the largest human contribution to the global carbon budget.

Keeling (1973) was the first to establish a systematic method for estimating the amount of CO_2 emitted from fossil fuel consumption. He used energy data from the U.N. Department of International Economic and Social Affairs. Since 1973, both the energy data collection and the procedures for estimating CO_2 emissions have been refined and improved (Marland and Rotty 1984; Marland et al. 1989; United Nations 1989).

The following section presents Keeling's 1860–1953 emission estimates along with more-recent global and national annual emission estimates calculated by Marland and Boden. These more recent estimates cover the period 1950–1988 and were calculated by using the methods of Marland and Rotty (1984). The data used for the calculations were energy and population statistics from the U.N., cement manufacturing data from the U.S. Bureau of Mines, and gas flaring data from the U.N. and the U.S. Department of Energy.

For emphasis and brevity, national estimates are provided only for the 20 highest emitting countries in 1988. The data are presented in descending order, with the highest emitting country, the United States, presented first. These 20 countries contributed ~81.6% of all the 1988 world emissions from fossil fuel consumption. The top three countries, the United States, Soviet Union, and People's Republic of China, were responsible for over half (51.0%) of the world emissions from fossil fuel burning in 1988. Spain, the twentieth highest emitting nation, contributed slightly less than 1% to this total.



Global CO_2 emissions from fossil fuel burning, cement production, and gas flaring, 1860–1988.

Global

BACKGROUND

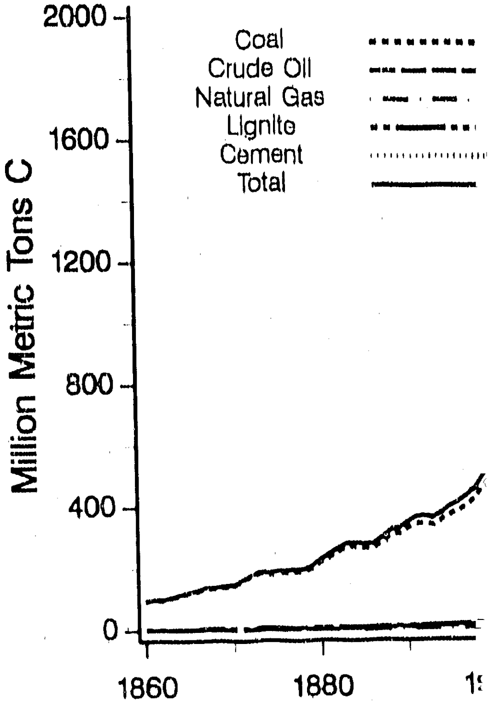
Principal investigator
Charles D. Keeling
Scripps Institution of Oceanography
University of California
La Jolla, California 92093, U.S.A.

Sponsoring agency
National Science Foundation

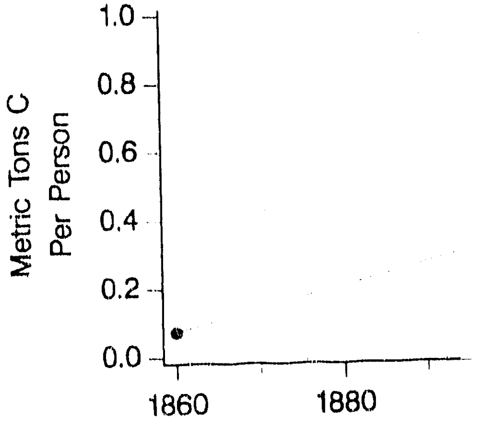
Period of record – 1860–1953.

Method – Global CO_2 emission estimates from industrial sources were calculated by using energy statistics and fuel production data published by the United Nations (1955; 1951–1969). The energy data were compiled from U.N. questionnaires supplemented by official national statistical publications. U.S. Bureau of Mines data (*Minerals Year Book* 1949–1969) were used to estimate CO_2 emitted during cement production.

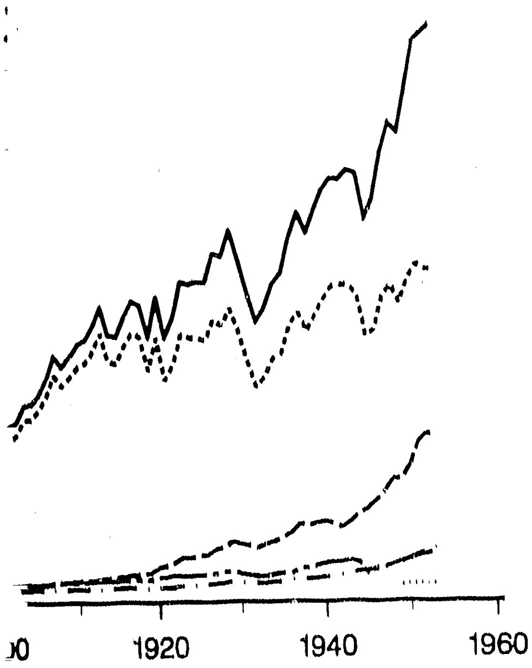
Data availability – These data were published by Keeling (1973) and are documented and available in machine-readable form from CDIAC. Updates to the global estimates, along with national estimates, are available from CDIAC. The U.N. energy statistics (1950–1988) are available on magnetic tape from the U.N. Energy Statistics Unit. The cement and gas flaring data are available from the U.S. Bureau of Mines and the U.S. Department of Energy, respectively.



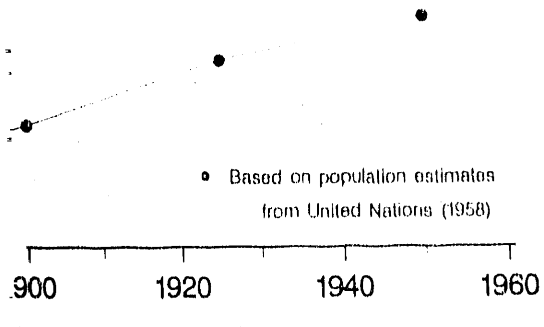
Annual CO_2 emissions from fossil



Global per capita emi



uel burning and cement production.



ion estimates, 1860–1953.

TREND

These global carbon emission estimates compiled by Keeling (1973) represent the first fully documented emission estimates from cement production and world industry fossil fuel consumption and the only fully documented estimates that extend back to the mid-1800s. More-recent estimates have been made by Marland and Rotty (1984), Rotty (1987), and Marland et al. (1989). This series of emission estimates shows an increase from 93.3 million tons of carbon in 1860 to 1808 million tons of carbon in 1953. Keeling (1973) estimated that the cumulative increase in carbon in the short-term carbon cycle, resulting from man's industrial and domestic activities up to 1970, was $1.12 \pm 0.14 \times 10^{17}$ g of carbon ($4.1 \pm 0.5 \times 10^{17}$ g of CO_2), or about 18% of the amount of CO_2 in the atmosphere during the late nineteenth century.

Global

Year	Coal	Lignite	Crude petroleum	Natural gas	Cement production†	Total
1860	91.5	1.7	0.1	0.0	NA	93.3
1861	96.7	1.8	0.2	0.0	NA	98.7
1862	96.1	2.0	0.3	0.0	NA	98.4
1863	103.5	2.1	0.3	0.0	NA	106.0
1864	112.5	2.4	0.2	0.0	NA	115.1
1865	119.0	2.6	0.3	0.0	NA	121.9
1866	125.7	2.6	0.4	0.0	NA	128.7
1867	134.7	2.8	0.4	0.0	NA	137.9
1868	133.3	3.0	0.4	0.0	NA	136.7
1869	138.1	3.2	0.5	0.0	NA	141.8
1870	141.0	3.4	0.6	0.0	NA	145.0
1871	157.4	3.9	0.6	0.0	NA	161.9
1872	170.9	4.3	0.7	0.0	NA	175.9
1873	182.5	4.8	1.2	0.0	NA	188.4
1874	177.3	5.3	1.2	0.0	NA	183.8
1875	182.8	5.3	1.1	0.0	NA	189.2
1876	184.9	5.5	1.2	0.0	NA	191.6
1877	188.8	5.5	1.7	0.0	NA	196.0
1878	188.9	5.7	1.9	0.0	NA	196.5
1879	199.1	6.0	2.5	0.0	NA	207.6
1880	217.5	6.4	3.2	0.0	NA	227.1
1881	234.0	6.8	3.4	0.2	NA	244.4
1882	251.3	7.1	3.8	0.3	NA	262.5
1883	268.8	7.6	3.2	0.4	NA	280.0
1884	269.9	7.8	3.8	0.6	NA	282.1
1885	263.8	8.0	3.8	0.8	NA	276.4
1886	264.4	8.3	5.0	1.0	NA	278.7
1887	282.8	8.6	5.0	1.3	NA	297.7
1888	305.8	9.2	5.5	1.5	NA	321.9
1889	310.5	9.8	6.5	1.7	NA	328.5
1890	328.9	10.8	8.1	2.0	NA	349.7
1891	342.2	11.5	9.6	2.0	NA	365.4
1892	345.5	11.7	9.4	2.1	NA	368.7
1893	337.6	12.2	9.7	2.2	NA	361.6
1894	352.9	12.5	9.4	2.3	NA	377.1
1895	371.7	13.6	10.9	2.4	NA	398.6
1896	382.4	14.5	12.1	2.7	NA	411.6
1897	400.0	15.7	12.8	3.0	NA	431.5
1898	421.5	16.7	13.2	3.2	NA	454.6
1899	462.2	17.7	13.8	3.5	NA	497.3
1900	485.6	19.8	15.8	3.7	NA	524.9
1901	497.2	21.3	17.7	4.1	NA	540.3
1902	508.5	20.9	19.1	4.4	NA	552.9
1903	559.5	21.7	20.5	4.7	NA	606.4
1904	563.0	22.6	23.0	4.9	NA	613.4
1905	594.2	24.1	22.7	5.6	NA	646.6
1906	641.6	25.8	22.5	6.1	NA	696.1

Global Carbon Dioxide Emission Estimates*

Year	Total	Gas	Liquid	Solid	Cement	Gas flaring	Per capita
1950	1638	97	423	1077	18	23	0.7
1951	1775	115	479	1137	20	24	0.7
1952	1803	124	504	1127	22	26	0.7
1953	1848	131	533	1132	24	27	0.7
1954	1871	138	557	1123	27	27	0.7
1955	2050	150	625	1215	30	31	0.7
1956	2185	161	679	1281	32	32	0.8
1957	2278	178	714	1317	34	35	0.8
1958	2338	192	732	1344	36	35	0.8
1959	2471	214	790	1390	40	36	0.8
1960	2586	235	850	1419	43	39	0.9
1961	2602	254	905	1356	45	42	0.9
1962	2708	277	981	1358	49	44	0.9
1963	2855	300	1053	1404	51	47	0.9
1964	3016	328	1138	1442	57	51	0.9
1965	3154	351	1221	1468	59	55	1.0
1966	3314	380	1325	1485	63	60	1.0
1967	3420	410	1424	1455	65	66	1.0
1968	3596	445	1552	1456	70	73	1.0
1969	3809	487	1674	1494	74	80	1.1
1970	4090	515	1838	1571	78	87	1.1
1971	4241	553	1946	1571	84	88	1.1
1972	4409	582	2056	1587	89	95	1.2
1973	4647	607	2240	1594	95	110	1.2
1974	4655	616	2244	1591	96	108	1.2
1975	4628	620	2131	1686	95	95	1.1
1976	4894	644	2313	1723	103	111	1.2
1977	5034	645	2390	1786	108	105	1.2
1978	5082	673	2383	1802	116	107	1.2
1979	5365	713	2535	1899	119	100	1.2
1980	5263	724	2409	1921	120	89	1.2
1981	5129	734	2272	1930	121	72	1.1
1982	5093	732	2178	1993	121	70	1.1
1983	5084	735	2163	1998	125	63	1.1
1984	5260	796	2191	2088	128	57	1.1
1985	5379	826	2172	2196	130	55	1.1
1986	5561	842	2277	2253	136	53	1.1
1987	5680	888	2290	2313	142	48	1.1
1988	5893	919	2392	2385	150	48	1.2

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

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United States

BACKGROUND

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Sponsoring agency
U.S. Department of Energy
Carbon Dioxide Research Program

Period of record – 1950–1988.

Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

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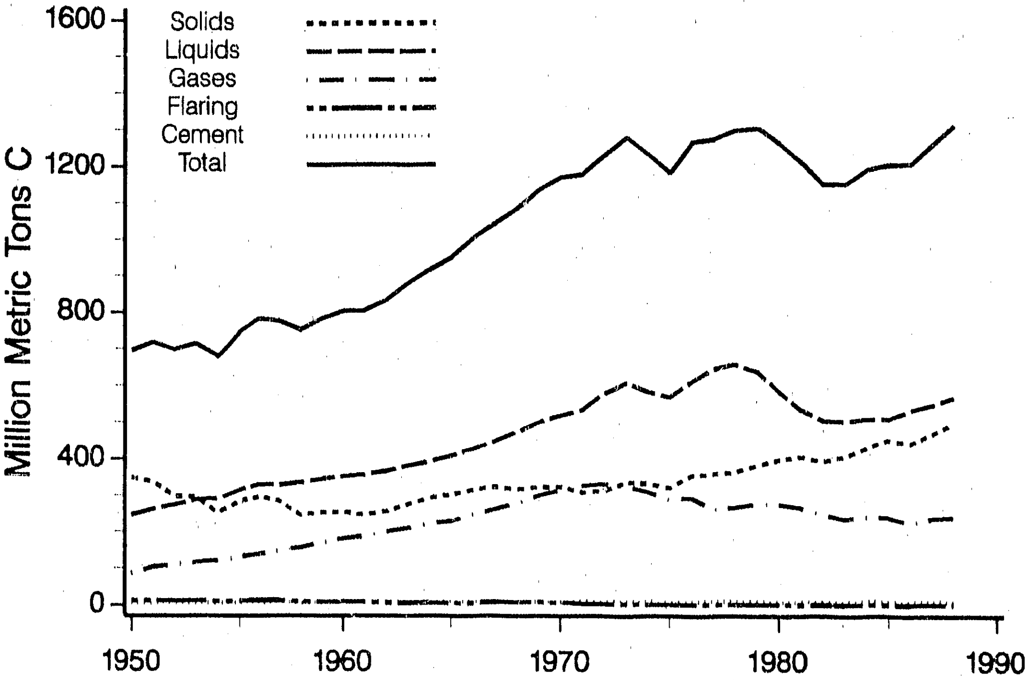
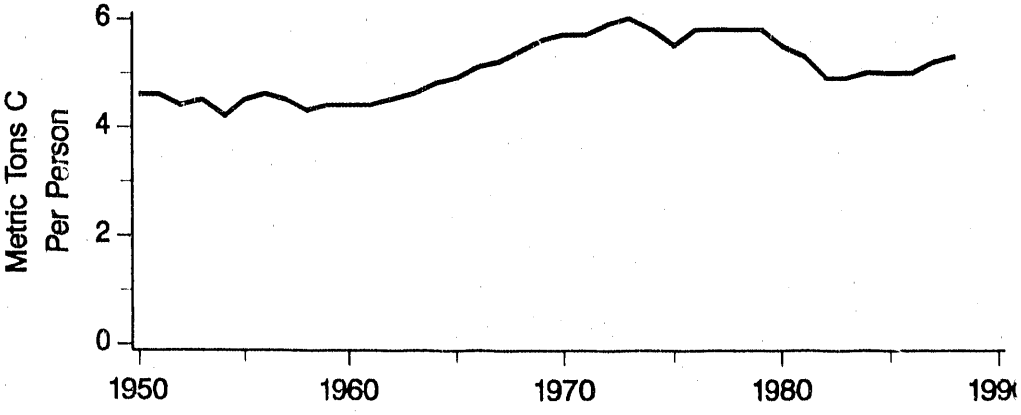


CO_2 emissions from the United States.



Per capita CO_2 emission estimates for the United States .

United States

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	696.1	347.1	244.8	87.1	5.3	11.8	4.6
1951	716.7	334.5	262.2	102.7	5.7	11.7	4.6
1952	697.9	296.6	273.2	109.9	5.8	12.5	4.4
1953	714.5	294.3	286.6	115.5	6.1	11.9	4.5
1954	680.5	252.2	290.2	121.2	6.3	10.6	4.2
1955	746.0	283.3	313.3	130.8	7.2	11.4	4.5
1956	781.9	295.0	328.5	138.1	7.6	12.7	4.6
1957	775.1	282.7	325.8	147.6	7.1	11.9	4.5
1958	750.8	245.3	333.0	155.8	7.5	9.3	4.3
1959	781.4	251.5	343.5	169.9	8.1	8.4	4.4
1960	799.5	253.4	349.8	180.4	7.6	8.3	4.4
1961	801.9	245.0	354.1	187.4	7.7	7.7	4.4
1962	831.5	254.2	364.3	198.7	8.0	6.3	4.5
1963	875.6	272.5	378.8	210.3	8.4	5.6	4.6
1964	912.9	289.7	389.7	219.8	8.8	5.0	4.8
1965	948.3	301.1	405.6	228.0	8.9	4.7	4.9
1966	999.7	312.7	425.9	246.4	9.1	5.5	5.1
1967	1039.2	321.1	443.6	258.5	8.8	7.2	5.2
1968	1081.0	314.8	471.9	277.4	9.4	7.6	5.4
1969	1132.0	319.7	497.4	297.8	9.5	7.7	5.6
1970	1165.5	322.4	514.8	312.1	9.0	7.2	5.7
1971	1173.2	305.7	530.5	323.3	9.7	4.2	5.7
1972	1227.3	310.4	575.5	327.6	10.2	3.6	5.9
1973	1275.4	334.0	605.4	321.7	10.6	3.6	6.0
1974	1231.1	330.1	580.7	307.9	10.0	2.4	5.8
1975	1179.0	317.6	565.1	286.0	8.4	1.9	5.5
1976	1262.0	351.6	608.1	291.3	9.0	2.0	5.8
1977	1269.7	355.6	641.9	260.5	9.7	2.0	5.8
1978	1293.4	361.2	655.0	264.7	10.4	2.2	5.8
1979	1300.9	378.7	634.6	274.8	10.4	2.4	5.8
1980	1259.3	394.6	581.0	272.5	9.3	1.8	5.5
1981	1210.6	403.0	533.1	264.2	8.8	1.4	5.3
1982	1146.9	390.1	502.2	245.4	7.8	1.4	4.9
1983	1149.4	405.5	500.1	233.8	8.7	1.4	4.9
1984	1187.5	427.8	507.1	241.5	9.6	1.6	5.0
1985	1201.3	448.0	505.6	236.7	9.6	1.4	5.0
1986	1204.5	439.7	531.1	222.6	9.7	1.4	5.0
1987	1257.5	465.8	545.3	235.0	9.6	1.8	5.2
1988	1310.2	493.6	566.4	238.6	9.5	2.1	5.3

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

Union of Soviet Socialist Republics

BACKGROUND

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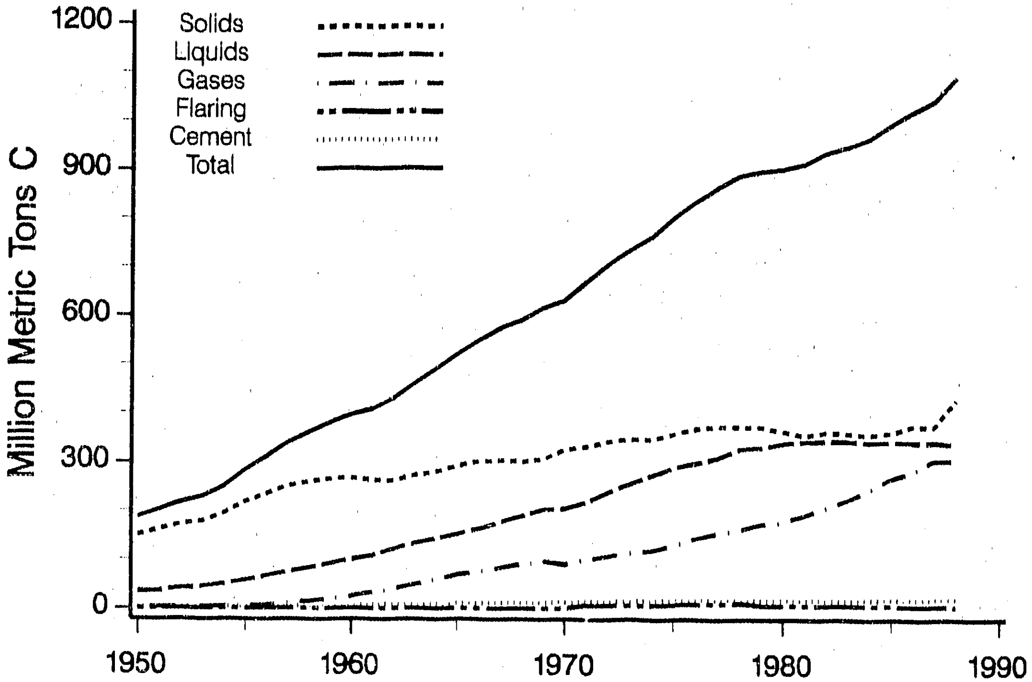
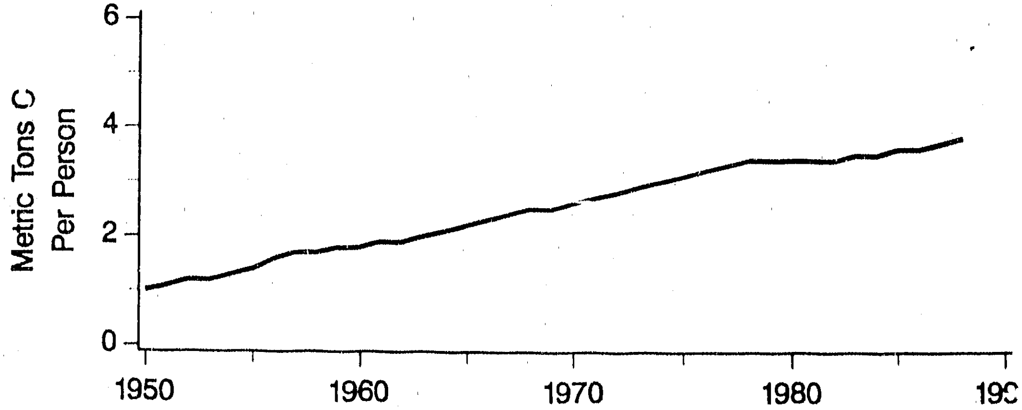


CO_2 emissions from the Union of Soviet Socialist Republics.



Per capita CO_2 emission estimates for the Union of Soviet Socialist Republics.

TREND

CO_2 emissions from the U.S.S.R. increased 4.7% from 1987 to 1988, continuing the virtually unbroken trend of 4.5% annual growth that has been maintained since 1950. During that interval, the U.S.S.R. share/contribution has increased from 11 to 18% of total global emissions. Recent growth has resulted largely from rapid exploitation of huge natural gas resources, and 28% of Soviet emissions now come from natural gas. Since 1950, the contribution of coal has shrunk from 80 to 39% of total emissions, and both coal and petroleum have been static over the last decade. Per capita emissions continue to grow and are now 31% higher than in 1973 and 13% higher than in 1979. Gas flaring data for the U.S.S.R. are poor and partly estimated, but gas flaring contributes only a small fraction of total emissions – only 0.4% in 1988.

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Union of Soviet Socialist Republics

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	185.8	148.6	32.7	3.1	1.4	0.0	1.0
1951	201.4	161.1	35.2	3.4	1.7	0.0	1.1
1952	215.7	170.6	39.7	3.4	1.9	0.0	1.2
1953	228.1	178.4	43.9	3.7	2.2	0.0	1.2
1954	249.1	193.8	48.7	4.0	2.6	0.0	1.3
1955	282.8	217.9	57.1	4.8	3.1	0.0	1.4
1956	310.1	234.1	66.2	6.5	3.4	0.0	1.6
1957	338.9	250.4	74.5	10.1	3.9	0.0	1.7
1958	361.7	258.9	83.3	15.0	4.5	0.0	1.7
1959	380.3	264.9	91.0	19.2	5.3	0.0	1.8
1960	396.1	266.0	99.5	24.4	6.2	0.0	1.8
1961	408.5	262.1	107.8	31.6	6.9	0.0	1.9
1962	428.8	261.1	120.5	39.4	7.8	0.0	1.9
1963	459.6	271.0	132.1	48.2	8.3	0.0	2.0
1964	488.7	279.5	141.7	58.7	8.8	0.0	2.1
1965	518.5	289.5	151.2	68.0	9.8	0.0	2.2
1966	547.7	299.5	161.9	75.4	10.9	0.0	2.3
1967	572.6	302.2	176.4	82.6	11.5	0.0	2.4
1968	588.7	299.4	187.9	89.5	11.9	0.0	2.5
1969	613.1	303.8	201.3	95.8	12.2	0.0	2.5
1970	628.2	323.3	203.2	88.8	13.0	0.0	2.6
1971	666.8	330.1	216.7	100.5	13.6	5.9	2.7
1972	701.2	340.1	235.6	105.7	14.2	5.7	2.8
1973	730.5	343.8	253.4	111.7	14.9	6.8	2.9
1974	757.8	344.9	271.4	118.4	15.7	7.4	3.0
1975	795.9	355.3	286.4	129.3	16.6	8.2	3.1
1976	828.3	365.4	294.7	142.2	16.9	9.2	3.2
1977	857.3	371.3	306.2	152.6	17.3	9.9	3.3
1978	882.5	370.0	324.5	160.1	17.3	10.6	3.4
1979	890.6	370.0	327.6	170.5	16.7	5.8	3.4
1980	895.5	359.6	335.8	177.3	17.0	5.8	3.4
1981	906.0	352.3	340.2	190.5	17.3	5.8	3.4
1982	929.4	358.9	342.4	205.5	16.8	5.7	3.4
1983	941.4	356.6	340.9	220.9	17.4	5.6	3.5
1984	959.3	354.0	338.8	243.2	17.7	5.6	3.5
1985	987.6	358.4	340.2	265.3	17.8	5.9	3.6
1986	1014.2	372.4	339.2	279.1	18.4	5.2	3.6
1987	1036.4	371.3	339.2	302.4	18.7	4.8	3.7
1988	1086.0	425.3	334.4	302.6	18.9	4.8	3.8

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

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People's Republic of China

BACKGROUND

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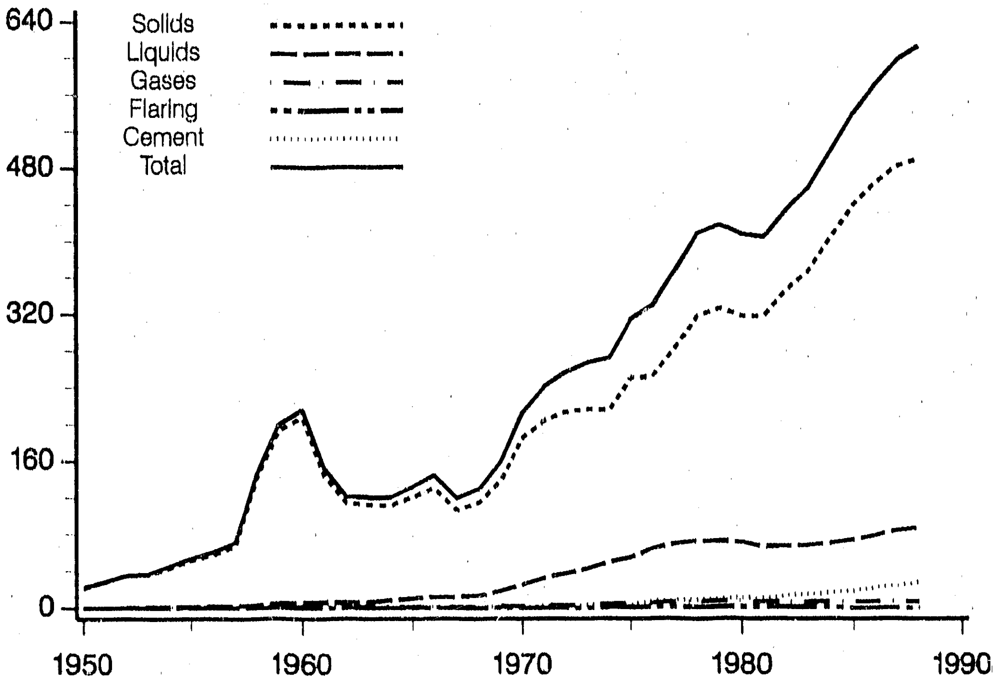
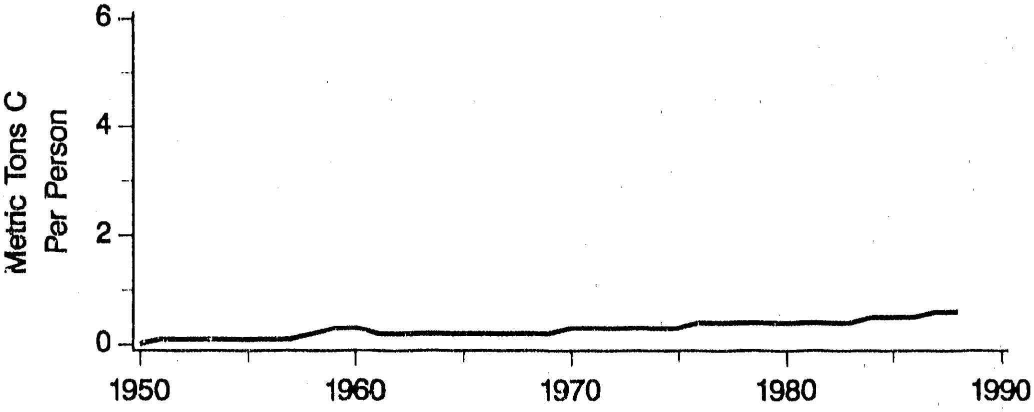


CO_2 emissions from the People's Republic of China.



Per capita CO_2 emission estimates for the People's Republic of China.

TREND

Chinese emissions of CO_2 have grown phenomenally since 1950, when China stood tenth among nations. Per capita emissions increased by a factor of 14.2 over this interval, and, combined with a doubling of population, total CO_2 emissions in 1988 were 28.1 times the 1950 level. Growth has been largely in the use of coal, which accounted for 99% of the total in 1950 and still 80% in 1988. Liquid fuels now contribute 14% of emissions, but growth has been stalled since about 1978. The anomalous peak in the data for 1958–1961 is common in Chinese data. These years are part of the period of "The Great Leap Forward," and it is not clear whether the anomaly represents a real event in CO_2 emissions or a data residual. Growth from 1967 to 1988 has been fairly regular at 7.2% per year with a minor offset in 1980–1981.

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

People's Republic of China

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	21.7	21.4	0.2	0.0	0.1	0.0	0.04
1951	28.1	27.6	0.3	0.0	0.2	0.0	0.05
1952	35.4	34.6	0.4	0.0	0.4	0.0	0.06
1953	37.0	36.0	0.5	0.0	0.5	0.0	0.06
1954	44.5	43.0	0.9	0.0	0.6	0.0	0.08
1955	52.7	50.6	1.5	0.0	0.6	0.0	0.09
1956	59.7	56.6	2.2	0.0	0.9	0.0	0.10
1957	70.7	67.3	2.5	0.0	0.9	0.0	0.11
1958	145.0	140.3	3.4	0.1	1.3	0.0	0.23
1959	199.0	192.0	5.2	0.2	1.7	0.0	0.31
1960	215.3	206.6	6.3	0.5	1.8	0.0	0.33
1961	152.2	144.3	6.1	0.8	1.1	0.0	0.24
1962	121.4	113.7	5.9	0.6	1.1	0.0	0.19
1963	120.4	112.1	6.4	0.5	1.4	0.0	0.18
1964	120.4	110.9	7.6	0.6	1.4	0.0	0.17
1965	131.2	119.6	9.6	0.6	1.5	0.0	0.18
1966	144.1	129.7	12.2	0.7	1.5	0.0	0.20
1967	119.4	105.9	11.6	0.8	1.1	0.0	0.16
1968	129.2	114.0	13.3	0.7	1.2	0.0	0.17
1969	159.0	138.4	18.2	1.0	1.4	0.0	0.20
1970	211.6	183.9	24.9	1.5	1.4	0.0	0.26
1971	240.5	203.3	31.8	2.0	3.1	0.2	0.29
1972	255.5	212.8	36.8	2.5	3.1	0.3	0.30
1973	265.7	216.4	42.4	3.1	3.4	0.3	0.30
1974	271.0	214.3	48.9	3.9	3.4	0.4	0.30
1975	314.3	250.3	54.7	4.6	4.1	0.5	0.34
1976	328.2	251.4	64.3	5.3	6.7	0.5	0.35
1977	366.2	282.3	69.4	6.3	7.6	0.6	0.39
1978	407.4	317.2	73.4	7.2	8.9	0.7	0.43
1979	416.2	325.4	72.3	7.6	10.1	0.8	0.43
1980	406.4	316.6	70.7	7.5	10.9	0.8	0.42
1981	402.6	317.5	66.3	6.7	11.4	0.7	0.41
1982	431.5	345.1	66.8	6.3	12.8	0.7	0.43
1983	455.2	365.0	68.4	6.4	14.7	0.7	0.45
1984	494.8	400.9	70.0	6.6	16.5	0.9	0.48
1985	537.3	437.0	74.1	6.8	19.4	0.0	0.52
1986	567.4	459.7	78.4	7.2	22.0	0.0	0.54
1987	594.4	479.0	83.6	7.3	24.4	0.0	0.56
1988	609.9	487.9	86.9	7.5	27.6	0.0	0.56

*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

REFERENCES

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U.S. Department of Energy. 1988. *International Energy Annual.* DOE/EIA-0219(88). Energy Information Administration, Washington, D.C.

Japan

BACKGROUND

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Sponsoring agency
U.S. Department of Energy
Carbon Dioxide Research Program

Period of record – 1950–1988.

Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

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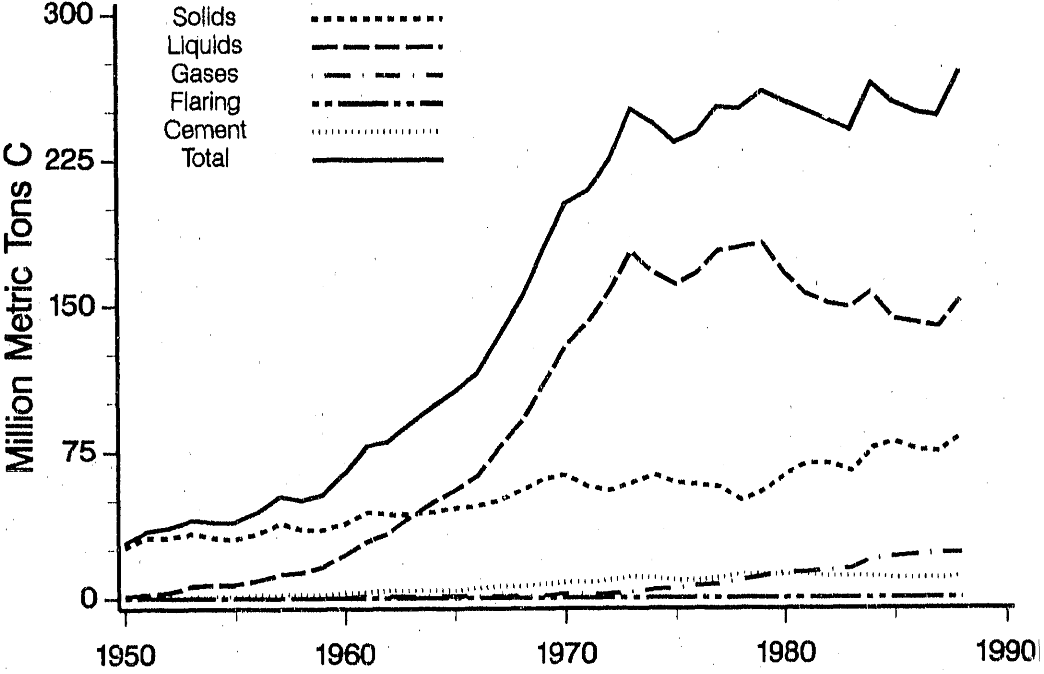
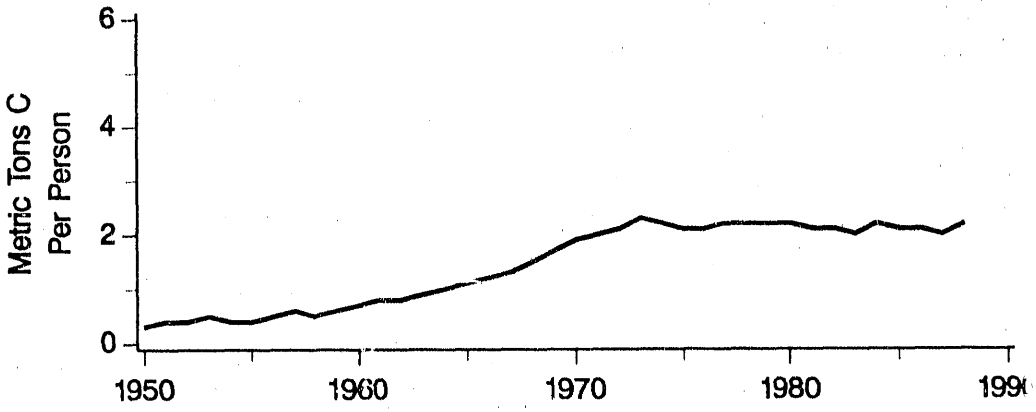


CO_2 emissions from Japan.



Per capita CO_2 emission estimates for Japan.

TREND

The history of CO$_2$ emissions from Japan is remarkable for the abrupt change that occurred in 1973. With postwar growth at 9.6% per year from 1950 to 1973, total emissions have been virtually constant since 1973. Rising consumption of liquid petroleum products halted in 1973, and constant CO$_2$ emissions reflect the increasing contributions of coal and natural gas as the petroleum share has shrunk from 71% in 1973 to 57% in 1988. Japan is the world's largest consumer of liquified natural gas and imported over 39 billion cubic meters in 1987. Per capita emissions are approaching levels comparable to the 1973 maximum although they are 7 times larger than the very low value that prevailed in 1950.

1990

Note—Growth rates were calculated (before rounding) by performing a linear regression of log CO$_2$ emissions versus time and calculating the slope of the regression line.

1990

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas Flaring	Per Capita
1950	28.3	26.4	1.2	0.0	0.6	0.0	0.3
1951	34.0	30.6	2.5	0.0	0.9	0.0	0.4
1952	35.9	31.4	3.5	0.0	1.0	0.0	0.4
1953	40.2	32.9	6.0	0.0	1.2	0.0	0.5
1954	39.3	31.2	6.5	0.0	1.5	0.0	0.4
1955	39.1	30.1	7.5	0.0	1.4	0.0	0.4
1956	44.2	33.5	8.8	0.1	1.8	0.0	0.5
1957	51.8	37.5	12.0	0.2	2.1	0.0	0.6
1958	49.8	34.9	12.6	0.3	2.0	0.0	0.5
1959	53.0	34.7	15.6	0.3	2.3	0.0	0.6
1960	63.9	38.4	22.0	0.4	3.1	0.0	0.7
1961	77.7	44.4	29.4	0.6	3.4	0.0	0.8
1962	80.4	42.6	33.2	0.7	3.9	0.0	0.8
1963	89.2	42.9	41.2	1.0	4.1	0.0	0.9
1964	98.5	44.2	48.7	1.1	4.5	0.0	1.0
1965	106.0	45.8	54.8	1.0	4.4	0.0	1.1
1966	115.0	47.1	61.7	1.0	5.2	0.0	1.2
1967	134.2	50.1	77.1	1.2	5.8	0.0	1.4
1968	154.0	55.3	91.2	1.2	6.5	0.0	1.5
1969	179.0	61.0	109.7	1.3	7.0	0.0	1.8
1970	202.4	63.3	129.3	2.1	7.8	0.0	2.0
1971	209.5	57.0	142.2	2.2	8.1	0.0	2.0
1972	224.9	55.3	158.4	2.2	9.0	0.0	2.1
1973	250.7	59.3	177.8	2.9	10.6	0.0	2.3
1974	244.1	63.3	166.9	3.9	9.9	0.0	2.2
1975	233.7	58.9	161.2	4.7	8.9	0.0	2.1
1976	239.3	57.6	166.7	5.6	9.3	0.0	2.1
1977	251.6	56.6	178.3	6.7	9.9	0.0	2.2
1978	250.7	49.9	179.8	9.4	11.5	0.0	2.2
1979	260.2	54.7	182.3	11.2	11.9	0.0	2.2
1980	254.9	62.8	167.0	13.1	12.0	0.0	2.2
1981	249.9	68.9	156.2	13.3	11.5	0.0	2.1
1982	244.6	68.5	151.5	13.6	11.0	0.0	2.1
1983	239.9	65.2	149.1	14.6	11.0	0.0	2.0
1984	264.3	76.9	157.1	19.6	10.7	0.0	2.2
1985	254.2	80.5	142.8	21.0	9.9	0.0	2.1
1986	248.9	76.3	140.7	22.1	9.7	0.0	2.1
1987	246.9	75.2	139.4	22.5	9.7	0.0	2.0
1988	269.8	82.9	152.8	23.5	10.5	0.0	2.2

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

REFERENCES

Keeling, C.D. 1973. Industrial production of carbon dioxide from fossil fuels and limestone. *Tellus* 25:174–198.

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Federal Republic of Germany

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Sponsoring agency
U.S. Department of Energy
Carbon Dioxide Research Program

Period of record – 1950–1988.

Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

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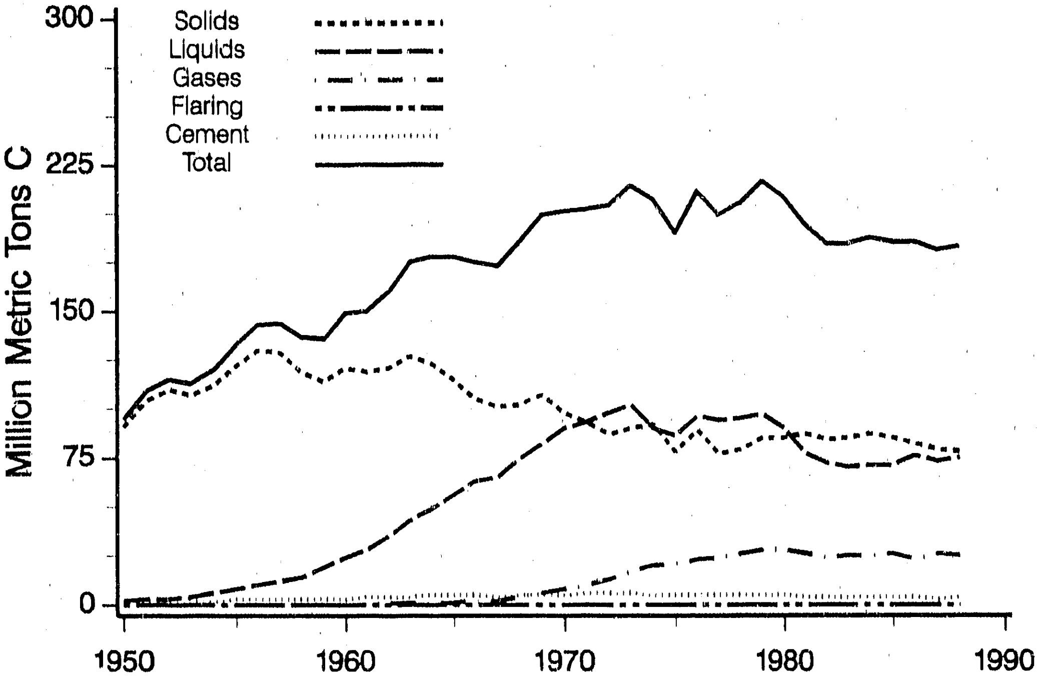
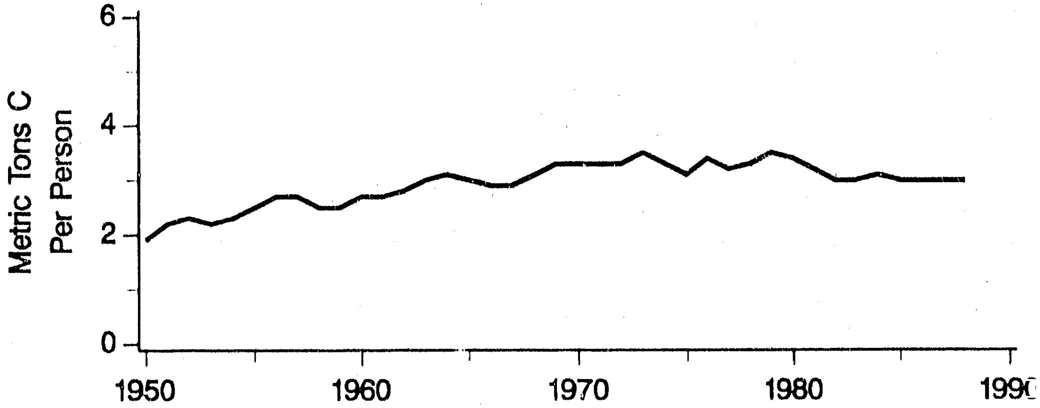


CO_2 emissions from the Federal Republic of Germany.



Per capita CO_2 emission estimates for the Federal Republic of Germany.

TREND

Emissions of CO_2 from the Federal Republic of Germany rose slightly in 1988 to 182.7 million metric tons of carbon. This slight increase maintains the generally constant trend which has prevailed since 1982. Per capita emissions also remained generally constant and are now near the 1963 value and 14% below the 1979 high. Although the largest fraction of emissions (43%) is from burning of solid fuels, the use of coal has been in general decline since a maximum in 1956, at which time 91% of total emissions was from coal burning. Natural gas burning first contributed over 1% of total emissions in 1966 and is now 14% of the total, a share that has been fairly constant since 1978.

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Federal Republic of Germany

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	94.9	91.3	2.0	0.0	1.5	0.0	1.9
1951	108.8	104.3	2.8	0.0	1.7	0.0	2.2
1952	115.4	110.4	3.2	0.0	1.8	0.0	2.3
1953	113.2	106.7	4.3	0.1	2.1	0.0	2.2
1954	120.1	111.7	6.1	0.1	2.3	0.0	2.3
1955	132.9	122.5	7.7	0.2	2.5	0.0	2.5
1956	143.0	130.2	9.9	0.3	2.6	0.0	2.7
1957	143.9	129.5	11.6	0.2	2.6	0.0	2.7
1958	136.7	119.5	14.3	0.3	2.7	0.0	2.5
1959	135.9	113.9	18.5	0.3	3.2	0.0	2.5
1960	148.6	121.1	23.8	0.3	3.4	0.0	2.7
1961	150.5	118.6	27.8	0.4	3.7	0.0	2.7
1962	159.9	120.8	34.8	0.5	3.9	0.0	2.8
1963	174.6	126.9	43.1	0.7	4.0	0.0	3.0
1964	178.3	123.4	49.4	1.0	4.6	0.0	3.1
1965	177.5	115.0	56.4	1.5	4.6	0.0	3.0
1966	174.6	105.4	62.8	1.8	4.7	0.0	2.9
1967	172.8	100.9	65.3	2.4	4.3	0.0	2.9
1968	184.9	102.3	74.2	3.9	4.5	0.0	3.1
1969	199.4	106.9	82.2	5.5	4.8	0.0	3.3
1970	200.9	98.0	89.8	7.8	5.2	0.0	3.3
1971	202.5	93.2	93.2	10.4	5.6	0.0	3.3
1972	204.1	86.9	97.9	13.5	5.9	0.0	3.3
1973	213.8	89.6	101.8	16.9	5.6	0.0	3.5
1974	206.6	91.6	89.7	20.4	4.9	0.0	3.3
1975	190.4	78.3	86.1	21.5	4.6	0.0	3.1
1976	211.5	88.6	95.5	22.5	4.8	0.0	3.4
1977	199.1	77.2	93.7	23.7	4.5	0.0	3.2
1978	204.8	79.0	95.2	25.9	4.8	0.0	3.3
1979	215.6	85.2	97.0	28.3	5.0	0.0	3.5
1980	208.0	85.5	90.0	27.9	4.6	0.0	3.4
1981	193.9	87.1	76.6	26.0	4.3	0.0	3.2
1982	184.5	84.1	72.3	23.9	4.1	0.0	3.0
1983	183.6	84.8	70.0	24.7	4.1	0.0	3.0
1984	187.0	87.0	70.6	25.5	3.9	0.0	3.1
1985	185.2	84.6	71.4	25.8	3.5	0.0	3.0
1986	185.0	82.4	75.8	23.1	3.6	0.0	3.0
1987	181.2	78.5	73.2	25.6	3.4	0.4	3.0
1988	182.7	78.0	75.0	25.1	4.2	0.3	3.0

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

India

BACKGROUND

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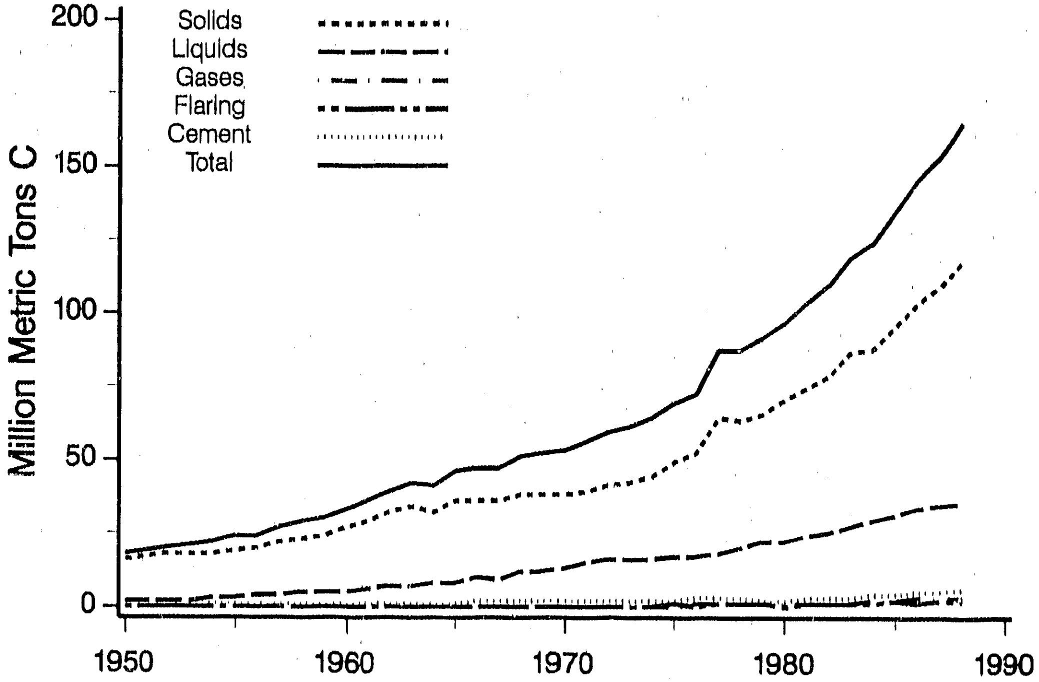
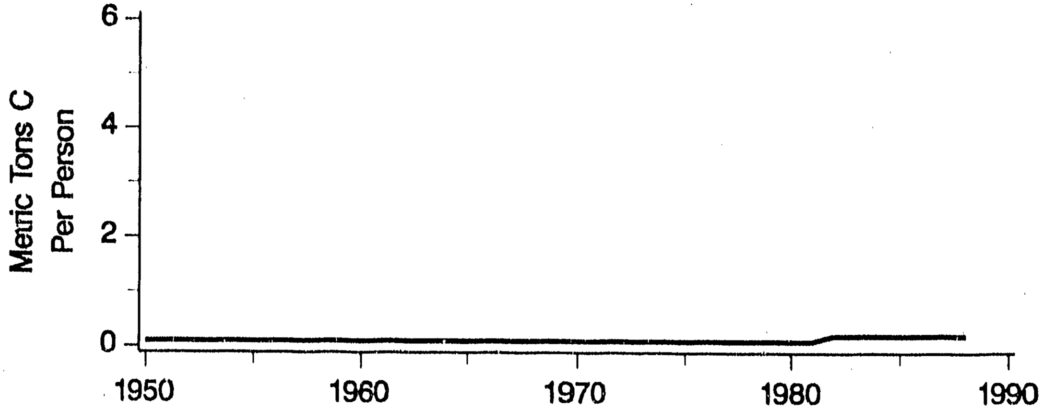


CO_2 emissions from India.



Per capita CO_2 emission estimates for India.

TREND

India has experienced dramatic recent growth in CO_2 emissions. Emissions have grown 5.6% per year since 1950 as India climbed from 13th to 6th place as a national contributor. Total emissions increased 8.9 times over this interval and per capita emissions increased 3.9 times. Emissions in India continue to be largely from coal burning. Coal contributed 87% of emissions in 1950 and 72% in 1988 as the oil fraction increased from 11 to 22%. Indian emissions data reveal little impact from the oil price increases that affected emissions in the United States and western Europe so dramatically in the late 1970s and early 1980s. Per capita emissions in 1988 were less than 4% of the U.S. value.

Note — Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

India

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	18.4	16.0	2.0	0.0	0.4	0.0	0.1
1951	19.2	16.6	2.1	0.0	0.4	0.0	0.1
1952	20.3	17.7	2.1	0.0	0.5	0.0	0.1
1953	20.6	18.0	2.1	0.0	0.5	0.0	0.1
1954	21.7	18.5	2.6	0.0	0.6	0.0	0.1
1955	23.5	19.4	3.5	0.0	0.6	0.0	0.1
1956	24.4	19.9	3.8	0.0	0.7	0.0	0.1
1957	27.3	22.2	4.3	0.0	0.8	0.0	0.1
1958	28.6	23.1	4.6	0.0	0.8	0.0	0.1
1959	30.2	24.3	5.0	0.0	0.9	0.0	0.1
1960	33.2	26.8	5.3	0.0	1.1	0.0	0.1
1961	35.9	29.0	5.8	0.0	1.1	0.0	0.1
1962	39.5	31.5	6.8	0.0	1.2	0.0	0.1
1963	42.4	33.7	7.4	0.0	1.3	0.0	0.1
1964	41.4	32.3	7.7	0.0	1.3	0.1	0.1
1965	45.6	35.5	8.4	0.1	1.4	0.2	0.1
1966	47.2	35.7	9.7	0.1	1.5	0.2	0.1
1967	47.4	36.3	8.9	0.1	1.6	0.4	0.1
1968	51.5	37.7	11.5	0.2	1.6	0.4	0.1
1969	52.4	37.6	12.4	0.3	1.8	0.3	0.1
1970	53.3	37.7	13.1	0.3	1.8	0.4	0.1
1971	56.2	38.7	14.7	0.3	2.0	0.4	0.1
1972	59.4	41.0	15.6	0.3	2.1	0.3	0.1
1973	61.1	42.0	16.4	0.3	2.0	0.4	0.1
1974	63.6	44.4	16.4	0.4	1.9	0.5	0.1
1975	69.1	49.2	16.7	0.5	2.2	0.5	0.1
1976	72.2	51.5	17.1	0.6	2.5	0.5	0.1
1977	86.5	64.2	18.4	0.7	2.6	0.6	0.1
1978	87.0	62.9	20.2	0.7	2.7	0.5	0.1
1979	90.8	64.8	22.2	0.8	2.5	0.6	0.1
1980	95.5	69.7	22.4	0.7	2.4	0.3	0.1
1981	102.7	74.1	24.1	0.8	2.8	0.9	0.1
1982	109.2	78.4	25.5	1.2	3.1	1.0	0.2
1983	118.5	85.7	26.7	1.4	3.4	1.2	0.2
1984	122.5	86.8	28.6	1.7	3.9	1.4	0.2
1985	134.3	94.8	31.4	2.0	4.5	1.6	0.2
1986	143.6	101.5	32.9	2.8	5.0	1.4	0.2
1987	152.1	108.5	33.7	3.2	5.0	1.7	0.2
1988	163.8	117.4	35.3	3.5	5.5	2.0	0.2

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

REFERENCES

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United Kingdom

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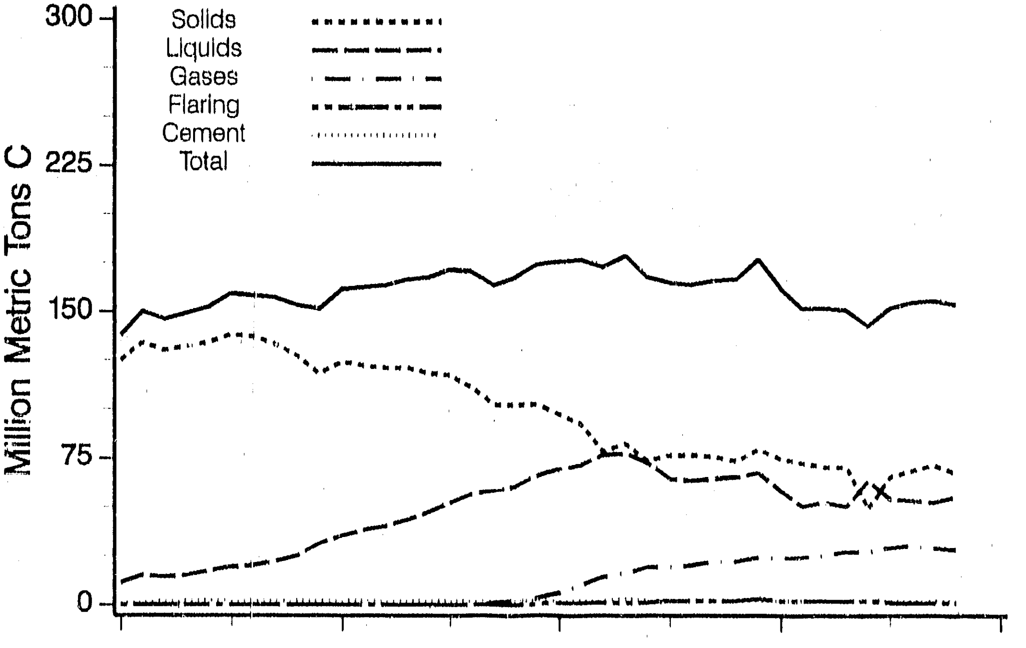
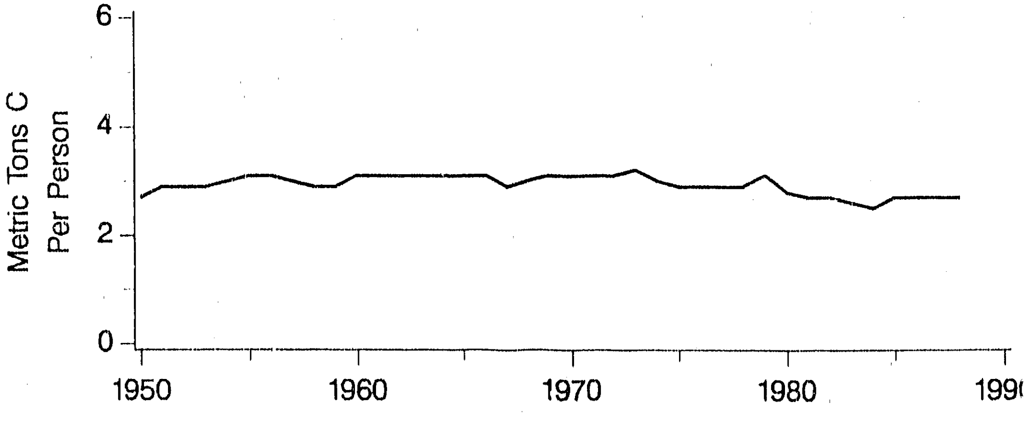


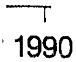
CO_2 emissions from the United Kingdom.



Per capita CO_2 emission estimates for the United Kingdom.

TREND

CO_2 emissions in the United Kingdom dropped from 155.0 to 152.5 million metric tons during 1987–1988. This decline differs from the general increasing trend observed during the previous three years (1984–1987) but conforms to the longer trend in which emissions declined 19% from 1979 to 1984. After at least 23 years of increases in emissions from liquid fuels and generally declining emissions from coal burning, 1974 was the year in which emissions from both fuels began to decline simultaneously. Emissions from natural gas grew rapidly in the late 1960s and early 1970s and have continued to increase. Natural gas burning now accounts for nearly 20% of total emissions of CO_2. Total emissions were only 10.5% higher in 1988 than in 1950, by far the smallest increase among the top 20 nations. Over this interval the United Kingdom dropped from third to seventh in rank among CO_2-emitting nations.



Note—Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	138.0	125.3	11.4	0.0	1.3	0.0	2.7
1951	150.3	134.2	14.6	0.0	1.4	0.0	2.9
1952	145.7	129.7	14.5	0.0	1.5	0.0	2.9
1953	148.9	132.1	15.3	0.0	1.6	0.0	2.9
1954	152.4	133.6	17.1	0.0	1.7	0.0	3.0
1955	159.0	138.0	19.2	0.0	1.7	0.0	3.1
1956	158.2	136.6	19.8	0.0	1.8	0.0	3.1
1957	157.2	133.2	22.3	0.0	1.7	0.0	3.0
1958	153.2	126.7	24.9	0.0	1.6	0.0	2.9
1959	150.5	117.5	31.2	0.0	1.7	0.0	2.9
1960	160.8	123.7	35.2	0.0	1.8	0.0	3.1
1961	162.0	122.3	37.7	0.0	2.0	0.0	3.1
1962	163.2	120.7	40.5	0.1	1.9	0.0	3.1
1963	166.1	121.3	42.8	0.1	1.9	0.0	3.1
1964	167.3	117.7	47.2	0.1	2.3	0.0	3.1
1965	171.2	116.6	51.8	0.5	2.3	0.0	3.1
1966	170.0	111.4	55.9	0.5	2.3	0.0	3.1
1967	162.8	101.7	57.9	0.8	2.4	0.0	2.9
1968	166.8	102.2	60.3	1.7	2.4	0.1	3.0
1969	172.8	101.6	65.0	3.3	2.4	0.4	3.1
1970	175.4	97.4	68.6	6.3	2.3	0.8	3.1
1971	176.1	91.6	71.0	10.2	2.4	0.9	3.1
1972	172.2	77.8	76.5	14.4	2.5	1.1	3.1
1973	178.1	81.7	76.8	15.6	2.7	1.3	3.2
1974	167.2	72.7	72.0	18.6	2.4	1.5	3.0
1975	164.1	76.3	64.4	19.5	2.3	1.6	2.9
1976	163.0	75.9	63.1	20.2	2.1	1.6	2.9
1977	164.6	74.9	64.3	21.6	2.1	1.7	2.9
1978	165.7	73.5	65.4	22.2	2.2	2.3	2.9
1979	175.6	78.7	66.9	24.3	2.2	3.4	3.1
1980	160.6	74.4	57.8	24.1	2.0	2.2	2.8
1981	151.1	72.3	50.4	24.5	1.7	2.2	2.7
1982	150.7	69.6	51.7	25.5	1.8	2.0	2.7
1983	150.1	70.2	49.7	26.5	1.8	2.0	2.6
1984	142.4	48.5	63.1	27.2	1.8	1.8	2.5
1985	151.3	64.7	54.0	29.5	1.8	1.4	2.7
1986	153.6	68.1	53.1	29.5	1.8	1.0	2.7
1987	155.0	71.0	51.8	29.3	1.8	1.1	2.7
1988	152.5	66.7	55.0	27.8	1.8	1.1	2.7

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

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Poland

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Carbon Dioxide Research Program

Period of record – 1950–1988.

Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

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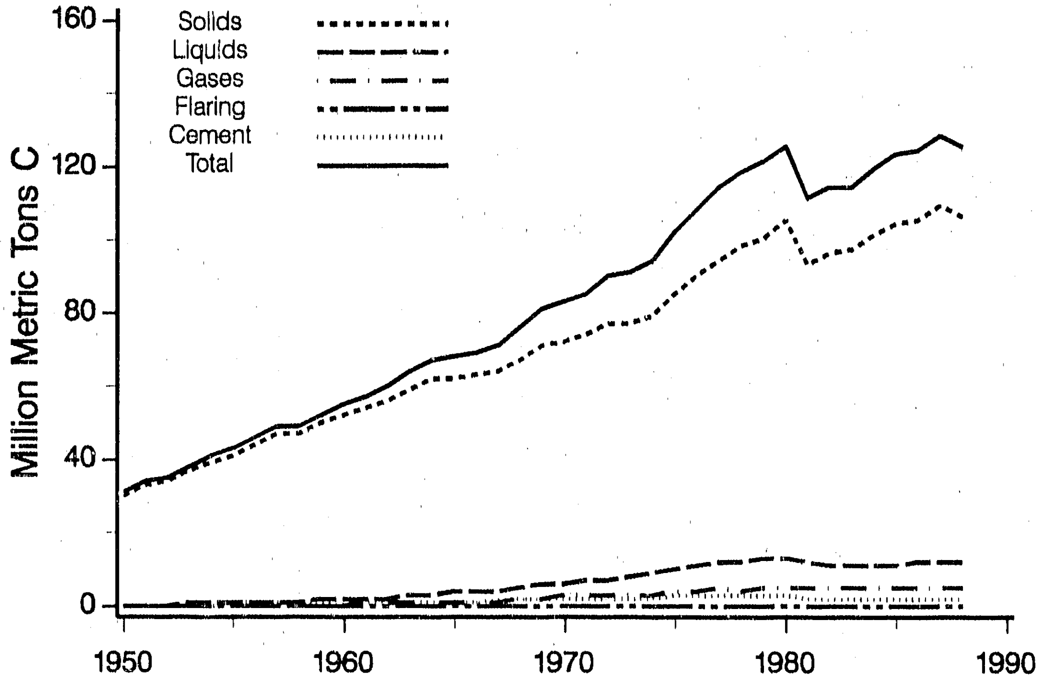
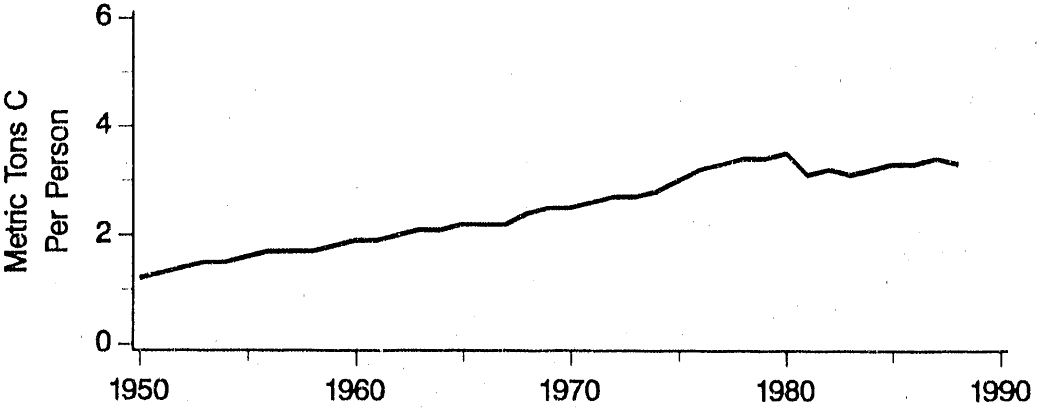


CO_2 emissions from Poland.



Per capita CO_2 emission estimates for Poland.

TREND

CO_2 emissions from Poland climbed at a remarkably steady rate of 4.4% per year until 1980, when they dropped abruptly (11.6%). CO_2 emissions crept back up throughout the 1980s and in 1987 they exceeded the previous high in 1980. Emissions are predominantly from coal burning, 97% in 1950 and still 85% in 1988. The drop following 1980 is apparent in rates of liquid fuel burning but was predominantly in coal consumption. Total emissions increased over 4 times from 1950 to 1988, with per capita emissions accounting for most of the rise, increasing 2.65 times.

Note—Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Poland

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	31.0	30.1	0.4	0.1	0.3	0.0	1.2
1951	33.7	32.8	0.4	0.2	0.4	0.0	1.3
1952	35.3	34.3	0.5	0.2	0.4	0.0	1.4
1953	38.4	37.2	0.6	0.2	0.4	0.0	1.5
1954	40.7	39.2	0.9	0.2	0.5	0.0	1.5
1955	42.6	40.8	1.0	0.3	0.5	0.0	1.6
1956	45.9	44.0	1.1	0.3	0.5	0.0	1.7
1957	49.3	47.2	1.2	0.3	0.6	0.0	1.7
1958	48.8	46.5	1.3	0.3	0.7	0.0	1.7
1959	52.3	49.8	1.5	0.3	0.7	0.0	1.8
1960	55.0	52.1	1.6	0.4	0.9	0.0	1.9
1961	57.2	53.7	1.9	0.5	1.0	0.0	1.9
1962	59.7	55.8	2.3	0.6	1.0	0.0	2.0
1963	63.6	59.4	2.6	0.6	1.0	0.0	2.1
1964	66.9	61.9	3.1	0.7	1.2	0.0	2.1
1965	68.0	62.1	3.7	0.9	1.3	0.0	2.2
1966	69.4	63.0	4.1	1.0	1.4	0.0	2.2
1967	71.2	64.0	4.4	1.3	1.5	0.0	2.2
1968	75.8	67.2	5.3	1.7	1.6	0.0	2.4
1969	80.6	71.0	5.7	2.4	1.6	0.0	2.5
1970	82.8	71.9	6.2	3.0	1.7	0.0	2.5
1971	85.2	73.7	6.6	3.1	1.8	0.0	2.6
1972	89.7	77.3	7.3	3.2	1.9	0.0	2.7
1973	91.1	77.3	8.3	3.4	2.1	0.0	2.7
1974	93.9	79.5	8.8	3.5	2.3	0.0	2.8
1975	101.8	85.3	10.0	4.0	2.5	0.0	3.0
1976	108.2	90.0	11.0	4.4	2.7	0.0	3.2
1977	113.6	94.1	12.1	4.5	2.9	0.0	3.3
1978	117.6	97.7	12.4	4.5	3.0	0.0	3.4
1979	120.5	99.7	13.3	4.9	2.6	0.0	3.4
1980	125.4	104.9	13.2	4.9	2.5	0.0	3.5
1981	110.8	92.6	11.5	4.8	1.9	0.0	3.1
1982	114.2	96.3	10.8	4.8	2.2	0.0	3.2
1983	114.4	96.5	10.7	5.0	2.2	0.0	3.1
1984	119.3	100.9	11.1	5.1	2.3	0.0	3.2
1985	122.6	104.2	11.4	4.9	2.0	0.0	3.3
1986	124.5	105.3	11.8	5.3	2.1	0.0	3.3
1987	127.9	108.6	11.6	5.5	2.2	0.0	3.4
1988	125.3	106.0	11.9	5.4	2.0	0.0	3.3

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

Canada

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Carbon Dioxide Research Program

Period of record – 1950–1988.

Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

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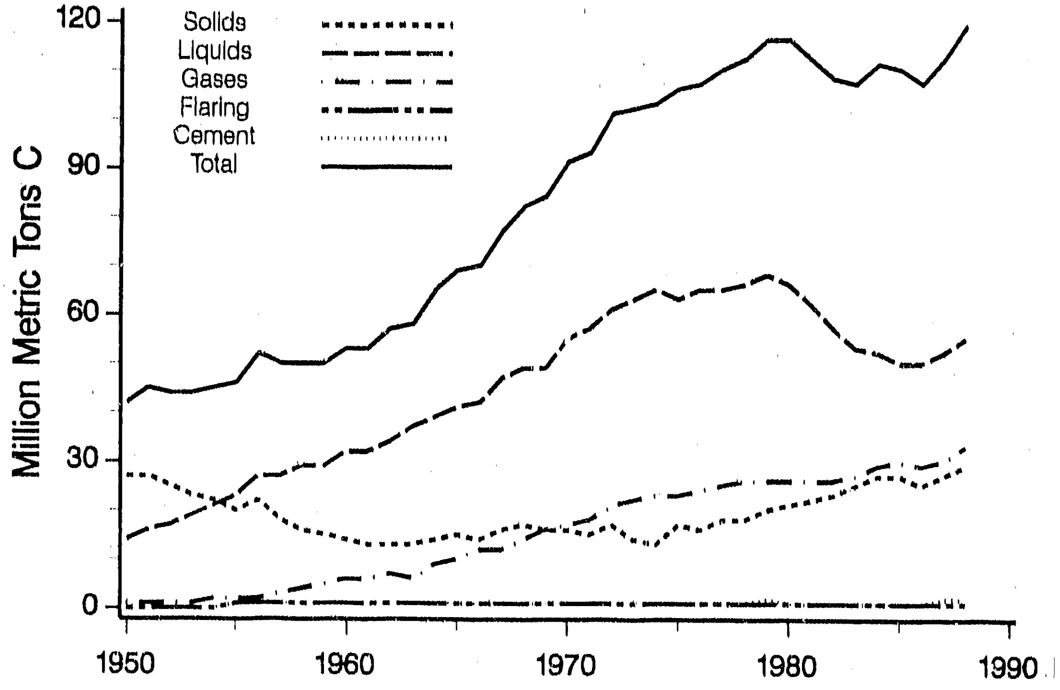
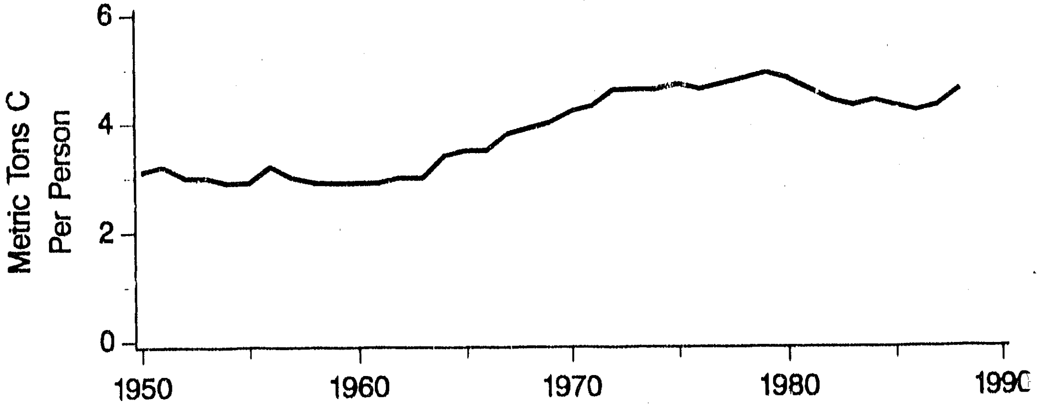


CO_2 emissions from Canada.



Per capita CO_2 emission estimates for Canada.

TREND

Driven by a 6.0% per year increase in emissions from liquid fuels, total CO_2 emissions from Canada increased by a factor of 2.4 from 1950 to 1974. Continuing growth until 1979 was maintained by continuing expansion of natural gas consumption and an upturn in coal consumption. The post-1979 drop was comparable to that observed in the United States, and the pattern from 1980 to 1986 was erratic but basically at a constant level. During the past 2 years, emissions have increased by 4.6% and 6.6%, respectively. Emissions from coal burning comprised 63% of the total in 1950 but declined in both absolute and relative terms until 1974. Since emissions from liquid fuels turned down in 1974, emissions from coal have turned back up, growing at an average rate of 5.0% per year. In 1988, coal contributed 24% of total emissions, barely half of the liquid fuel contribution and marginally less than natural gas. Per capita CO_2 emissions from Canada peaked in 1979 at 4.9 metric tons of carbon per capita, a value exceeded only by the German Democratic Republic and the United States among the major CO_2 emitting nations.

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Canada

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	42.3	26.6	14.3	1.0	0.4	0.0	3.1
1951	44.6	26.7	16.5	1.1	0.4	0.0	3.2
1952	43.7	24.7	17.4	1.2	0.4	0.0	3.0
1953	44.0	22.8	19.1	1.3	0.5	0.3	3.0
1954	44.7	22.0	20.5	1.6	0.5	0.0	2.9
1955	46.4	19.9	23.4	2.0	0.5	0.6	2.9
1956	52.0	21.6	26.5	2.3	0.6	0.9	3.2
1957	50.0	17.9	27.3	3.0	0.7	1.1	3.0
1958	49.8	15.7	28.5	3.7	0.8	1.1	2.9
1959	50.5	14.7	29.4	4.7	0.8	0.9	2.9
1960	52.7	13.6	31.6	5.9	0.7	0.9	2.9
1961	53.0	12.5	32.4	6.3	0.8	1.1	2.9
1962	56.6	12.9	34.5	7.1	0.8	1.3	3.0
1963	57.7	12.8	36.6	6.1	0.9	1.2	3.0
1964	64.9	14.3	39.2	9.3	1.0	1.2	3.4
1965	68.9	14.9	41.4	10.4	1.0	1.1	3.5
1966	70.1	14.4	41.9	11.6	1.1	1.2	3.5
1967	77.0	15.7	46.8	12.3	1.0	1.1	3.8
1968	81.7	16.6	48.9	14.0	1.0	1.2	3.9
1969	83.7	16.2	49.3	15.9	1.0	1.2	4.0
1970	90.6	16.1	55.1	17.1	1.0	1.3	4.2
1971	93.5	15.3	57.4	18.4	1.1	1.2	4.3
1972	101.2	17.0	60.9	20.9	1.2	1.2	4.6
1973	101.7	14.2	62.6	22.3	1.4	1.2	4.6
1974	103.1	13.2	64.7	22.8	1.4	1.0	4.6
1975	105.8	16.7	63.5	23.4	1.4	0.7	4.7
1976	106.8	16.1	64.6	24.1	1.3	0.7	4.6
1977	109.7	17.7	65.0	25.1	1.3	0.6	4.7
1978	111.6	18.3	65.6	25.6	1.4	0.7	4.8
1979	116.0	19.6	67.7	26.3	1.6	0.8	4.9
1980	115.8	21.3	65.9	26.4	1.4	0.9	4.8
1981	112.1	22.1	62.0	25.8	1.4	0.8	4.6
1982	108.3	23.3	56.8	26.2	1.1	0.8	4.4
1983	106.8	24.9	53.0	27.0	1.1	0.8	4.3
1984	110.6	27.2	52.2	28.8	1.2	1.2	4.4
1985	109.6	26.8	50.0	30.1	1.4	1.4	4.3
1986	107.1	24.8	50.5	29.0	1.4	1.3	4.2
1987	112.0	27.1	52.4	29.6	1.7	1.3	4.3
1988	119.4	28.9	54.9	32.5	1.7	1.4	4.6

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

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Italy

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Period of record – 1950–1988.

Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

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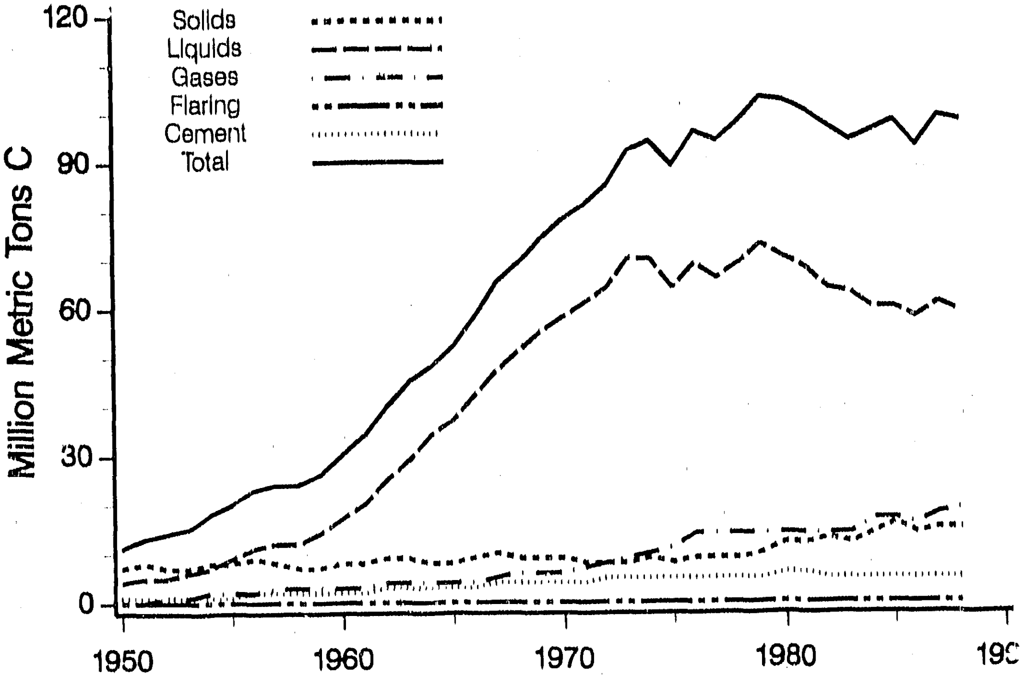
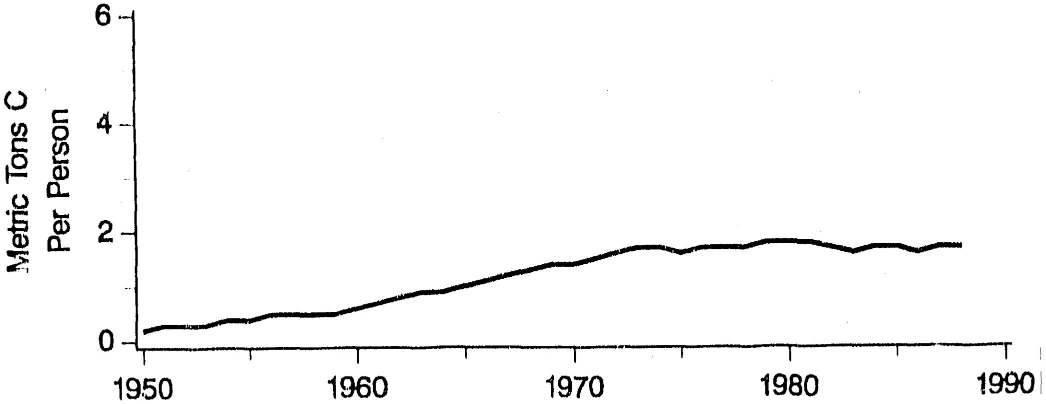


CO_2 emissions from Italy.



Per capita CO_2 emission estimates for Italy.

TREND

As was the case for many industrialized nations, CO_2 emissions from Italy rose steeply from 1950 until the growth was abruptly terminated in 1974. Since 1974, emissions from liquid fuels have vacillated but generally declined, dropping from 75 to 60% of a static, but vacillating, total. Significant increases in natural gas consumption and a slight upturn in coal burning have compensated for the drop in oil consumption. Coal usage was virtually constant from 1950 to 1974 and has nearly doubled since 1974. Per capita CO_2 emissions grew rapidly from 1950 to 1974, increasing by a factor of 7, but have been nearly constant since 1974.

990

1990

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Italy

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	11.4	6.8	3.7	0.3	0.7	0.0	0.2
1951	13.4	7.6	4.5	0.5	0.8	0.0	0.3
1952	13.9	7.2	5.1	0.7	0.9	0.0	0.3
1953	15.4	7.4	5.8	1.2	1.1	0.0	0.3
1954	17.9	7.7	7.4	1.5	1.2	0.0	0.4
1955	20.1	8.0	8.8	1.9	1.4	0.0	0.4
1956	22.9	8.6	10.6	2.3	1.5	0.0	0.5
1957	23.9	8.2	11.5	2.6	1.6	0.0	0.5
1958	24.1	7.4	12.2	2.6	1.7	0.0	0.5
1959	25.8	7.2	13.6	3.1	2.0	0.0	0.5
1960	30.1	7.7	17.0	3.3	2.2	0.0	0.6
1961	34.2	8.3	20.0	3.5	2.5	0.0	0.7
1962	40.2	8.8	25.1	3.6	2.7	0.0	0.8
1963	45.2	9.0	29.5	3.7	3.0	0.0	0.9
1964	48.3	7.7	33.6	3.9	3.1	0.0	0.9
1965	51.8	8.4	36.6	4.0	2.8	0.0	1.0
1966	58.3	8.7	42.2	4.3	3.0	0.0	1.1
1967	64.8	9.7	46.8	4.7	3.6	0.0	1.2
1968	69.2	9.0	50.7	5.5	4.0	0.0	1.3
1969	74.4	9.1	55.0	6.1	4.3	0.0	1.4
1970	78.0	9.1	58.4	6.0	4.5	0.0	1.5
1971	80.9	8.4	61.3	6.8	4.3	0.0	1.5
1972	84.9	8.0	64.4	7.9	4.6	0.0	1.6
1973	92.0	8.1	70.0	8.9	4.9	0.0	1.7
1974	93.5	8.7	69.9	10.0	4.9	0.0	1.7
1975	88.6	8.4	64.1	11.4	4.7	0.0	1.6
1976	96.2	8.5	68.9	13.8	4.9	0.0	1.7
1977	93.6	8.6	66.3	13.6	5.2	0.0	1.7
1978	98.0	9.2	69.5	14.2	5.2	0.0	1.8
1979	102.8	10.5	73.1	13.8	5.3	0.0	1.8
1980	101.6	11.7	70.0	14.2	5.7	0.0	1.8
1981	99.8	12.5	67.9	13.7	5.7	0.0	1.8
1982	96.8	13.2	63.8	14.4	5.4	0.0	1.7
1983	93.6	11.6	62.6	14.0	5.3	0.0	1.6
1984	95.7	14.5	59.5	16.6	5.1	0.0	1.7
1985	97.8	15.8	60.0	17.0	5.0	0.0	1.7
1986	93.1	14.3	57.8	16.2	4.8	0.0	1.6
1987	98.5	15.1	60.6	18.0	4.9	0.0	1.7
1988	98.1	14.5	59.3	19.2	5.1	0.0	1.7

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

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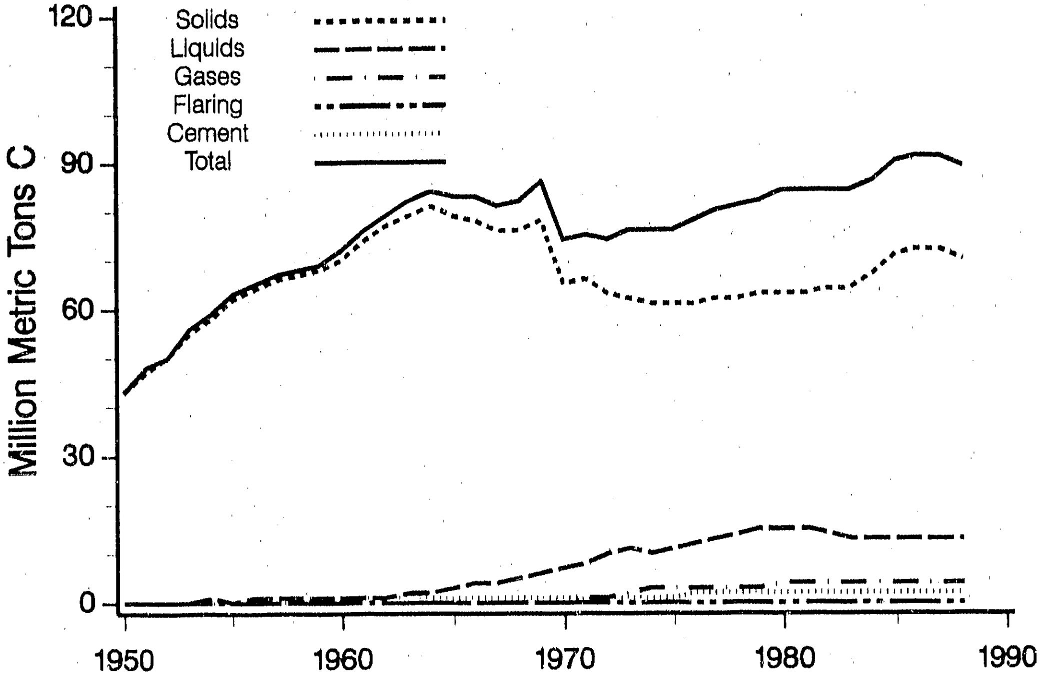
Carbon Dioxide Research Program

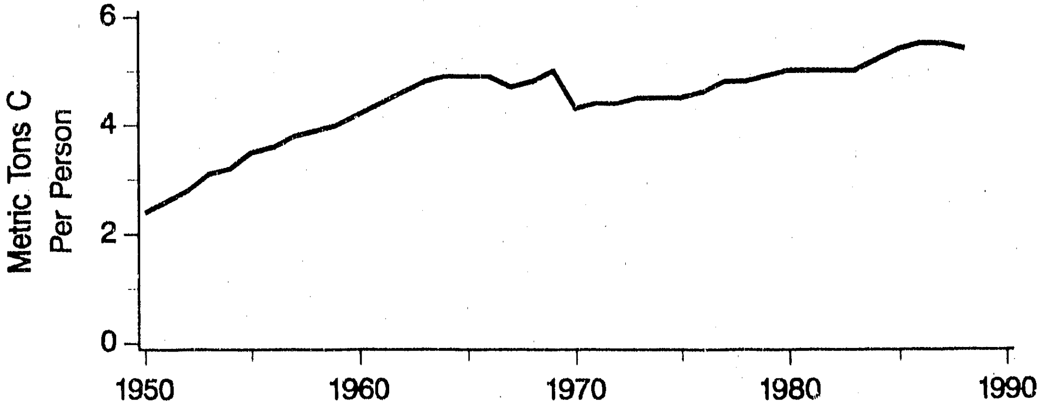
Period of record – 1950–1988.

Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

Data availability – Global and national CO_2 emission estimates, along with the data used in calculating these estimates, are documented and available from CDIAC (Marland et al. 1989). The U.N. energy statistics are available on magnetic tape from the U.N. Energy Statistics Unit. The cement and gas flaring data are available from the U.S. Bureau of Mines and the U.S. Department of Energy, respectively.



CO_2 emissions from the German Democratic Republic.



Per capita CO_2 emission for the German Democratic Republic.

TREND

CO_2 emissions from the German Democratic Republic grew steadily from 1950 to 1964 and then stalled for 5 years before dropping by 14% in 1970. Emissions have grown slowly but steadily since 1970. Per capita emissions have been consistently high and since 1982 have been the highest among the major economies of the world. The current level is 5.4 tons of carbon per capita, 2.3 times the 1950 value. Growth to 1970 was based largely on coal consumption, with coal contributing as much as 91% of emissions in 1969 and still over 79% in 1988. Petroleum became a significant contributor in the mid-1960s and, in spite of dropping slightly since 1980, still contributes 14% of CO_2 emissions.

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

German Democratic Republic

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	43.5	43.3	0.0	0.0	0.2	0.0	2.4
1951	47.6	47.2	0.2	0.0	0.2	0.0	2.6
1952	50.4	49.7	0.4	0.0	0.3	0.0	2.8
1953	55.8	55.1	0.4	0.0	0.3	0.0	3.1
1954	58.7	57.8	0.6	0.0	0.4	0.0	3.2
1955	63.2	62.4	0.4	0.0	0.4	0.0	3.5
1956	64.8	63.7	0.7	0.0	0.4	0.0	3.6
1957	67.0	65.6	0.8	0.0	0.5	0.0	3.8
1958	68.2	67.0	0.7	0.0	0.5	0.0	3.9
1959	68.8	67.5	0.7	0.0	0.6	0.0	4.0
1960	71.9	70.3	0.9	0.0	0.7	0.0	4.2
1961	75.7	73.8	1.1	0.0	0.7	0.0	4.4
1962	79.3	77.1	1.4	0.0	0.7	0.0	4.6
1963	81.6	79.0	1.8	0.0	0.7	0.0	4.8
1964	84.1	80.8	2.5	0.0	0.8	0.0	4.9
1965	82.6	78.7	3.0	0.0	0.8	0.0	4.9
1966	83.1	78.2	3.9	0.0	0.9	0.0	4.9
1967	80.8	75.6	4.2	0.0	1.0	0.0	4.7
1968	81.8	75.6	5.1	0.1	1.0	0.0	4.8
1969	85.6	78.2	6.3	0.1	1.0	0.0	5.0
1970	73.8	65.0	7.4	0.3	1.1	0.0	4.3
1971	75.1	65.7	7.8	0.5	1.2	0.0	4.4
1972	74.5	62.6	9.8	0.9	1.2	0.0	4.4
1973	75.6	62.1	10.5	1.6	1.3	0.0	4.5
1974	75.6	61.1	10.5	2.7	1.4	0.0	4.5
1975	75.9	60.7	11.1	2.8	1.4	0.0	4.5
1976	77.9	61.3	12.0	3.0	1.5	0.0	4.6
1977	79.9	62.0	13.2	3.0	1.6	0.0	4.8
1978	80.7	62.2	14.0	2.9	1.7	0.0	4.8
1979	82.4	62.9	14.9	3.0	1.7	0.0	4.9
1980	83.7	63.1	15.3	3.6	1.7	0.0	5.0
1981	84.0	63.2	15.1	4.0	1.7	0.0	5.0
1982	84.1	64.2	14.5	3.9	1.6	0.0	5.0
1983	83.5	64.3	13.4	4.2	1.6	0.0	5.0
1984	86.0	67.1	13.2	4.2	1.6	0.0	5.2
1985	90.2	71.4	13.4	3.9	1.6	0.0	5.4
1986	91.1	72.1	13.1	4.3	1.6	0.0	5.5
1987	91.1	72.3	12.8	4.3	1.7	0.0	5.5
1988	89.3	70.5	12.8	4.2	1.7	0.0	5.4

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

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France

BACKGROUND

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Sponsoring agency

U.S. Department of Energy
Carbon Dioxide Research Program

Period of record – 1950–1988.

Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

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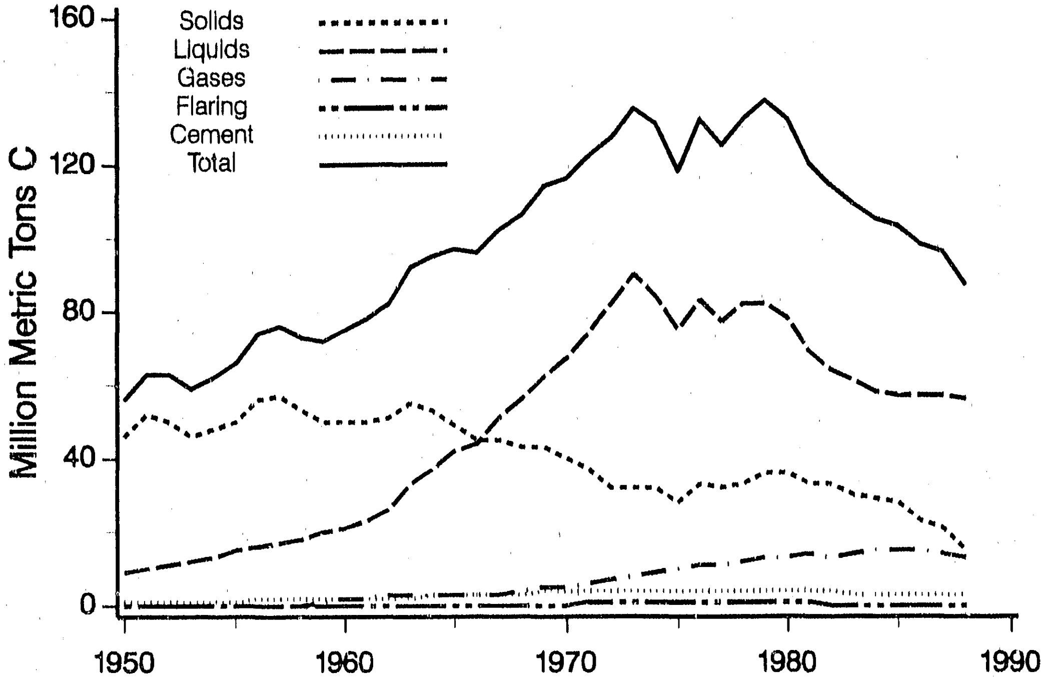
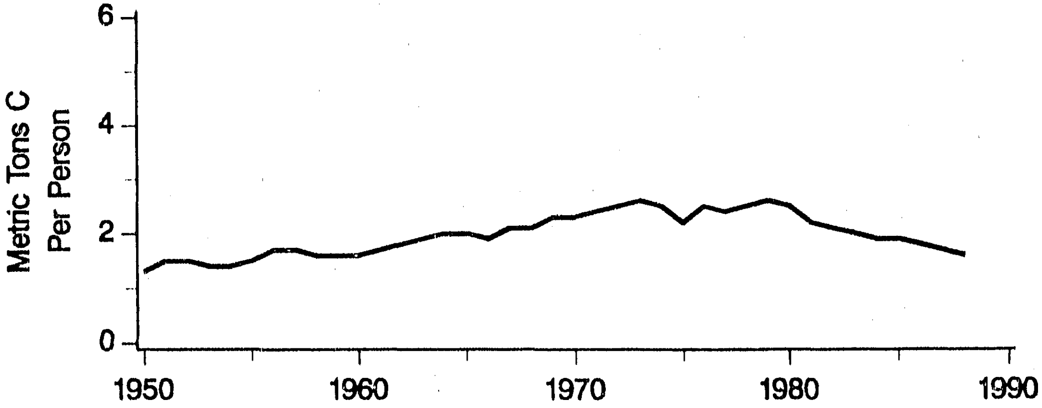


CO_2 emissions from France.



Per capita CO_2 emission estimates for France.

TREND

The CO_2 emissions history of France is striking in the decline in emissions that has occurred since 1973, particularly since 1979. The country total since 1973 is virtually a reflection of the decrease in liquid fuel use, although a late 1970s bulge in emissions from solid fuels and continuing increased use of natural gas pushed the 1979 value above the 1973 total. CO_2 emissions in 1950 were 83% from coal, but coal use declined steadily from 1963 to 1975, and even the late 1970s bulge appears to have been a temporary reaction to world oil price increases. By 1988 only 18% of emissions were from coal, and natural gas was creeping toward 15%. France made a major commitment to nuclear power and nuclear power generation grew rapidly from about 1975 until it contributed 76% of total electricity generation in 1987. France is a net exporter of electricity. Extensive use of nuclear power has clearly restrained CO_2 emissions from France; per capita emissions declined regularly from the 1973 maximum until the 1988 value, which is near that observed 33 years earlier. CO_2 emissions in 1988 were 36% less than the 1979 maximum.

1990

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

1990

France

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	55.8	46.1	8.6	0.1	1.0	0.0	1.3
1951	63.0	51.6	10.2	0.2	1.1	0.0	1.5
1952	62.5	50.2	11.0	0.2	1.2	0.0	1.5
1953	59.1	46.0	11.7	0.1	1.3	0.0	1.4
1954	62.3	47.5	13.3	0.2	1.3	0.0	1.4
1955	65.8	49.5	14.7	0.2	1.4	0.0	1.5
1956	73.9	55.7	16.5	0.2	1.6	0.0	1.7
1957	76.4	57.3	17.1	0.3	1.7	0.0	1.7
1958	73.3	52.7	18.4	0.4	1.8	0.0	1.6
1959	72.2	49.8	19.8	0.8	1.9	0.0	1.6
1960	74.8	49.9	21.4	1.6	1.9	0.0	1.6
1961	77.7	50.1	23.3	2.2	2.1	0.0	1.7
1962	82.5	51.4	26.2	2.5	2.3	0.0	1.8
1963	92.2	54.5	32.6	2.6	2.5	0.0	1.9
1964	95.3	52.5	37.1	2.7	2.9	0.0	2.0
1965	97.1	49.2	42.1	2.7	3.0	0.0	2.0
1966	95.7	45.4	44.2	2.9	3.2	0.0	1.9
1967	102.3	44.7	51.1	3.3	3.3	0.0	2.1
1968	105.7	42.8	55.6	3.9	3.5	0.0	2.1
1969	113.6	42.9	62.5	4.5	3.7	0.0	2.3
1970	116.2	40.3	66.8	5.1	3.9	0.0	2.3
1971	122.1	36.7	73.9	6.1	3.9	1.5	2.4
1972	126.8	32.4	81.7	7.2	4.1	1.4	2.5
1973	135.5	31.9	89.6	8.5	4.2	1.4	2.6
1974	130.8	31.9	84.3	8.8	4.4	1.3	2.5
1975	118.2	28.0	75.1	9.8	4.0	1.2	2.2
1976	132.3	33.0	83.4	10.6	4.0	1.3	2.5
1977	125.2	32.2	76.8	11.0	3.9	1.3	2.4
1978	132.1	33.4	81.6	12.0	3.8	1.3	2.5
1979	136.9	36.3	82.4	13.2	3.9	1.0	2.6
1980	132.1	36.3	77.7	13.4	4.0	0.8	2.5
1981	120.5	33.2	69.2	13.7	3.8	0.5	2.2
1982	114.4	33.2	64.2	13.2	3.6	0.3	2.1
1983	108.7	30.1	60.8	14.5	3.3	0.0	2.0
1984	104.7	28.6	58.4	14.6	3.1	0.0	1.9
1985	103.3	27.8	57.0	15.2	3.2	0.0	1.9
1986	98.2	23.0	56.7	15.2	3.2	0.0	1.8
1987	96.1	21.2	57.3	14.4	3.2	0.0	1.7
1988	87.3	15.5	55.6	13.0	3.3	0.0	1.6

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

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Mexico

BACKGROUND

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Sponsoring agency
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Carbon Dioxide Research Program

Period of record – 1950–1988.

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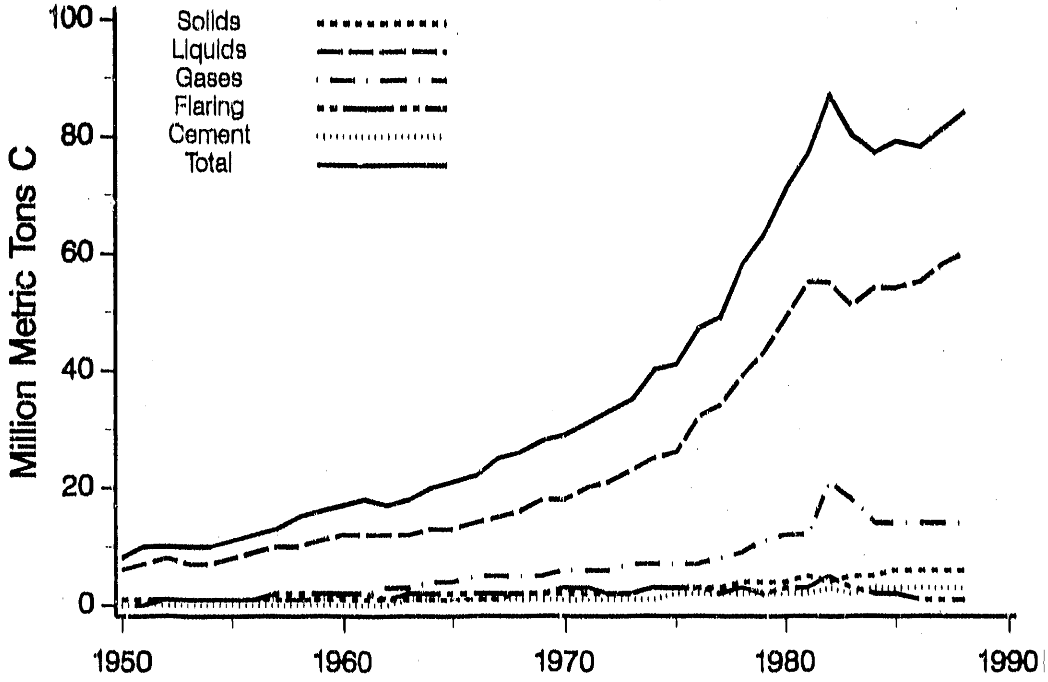
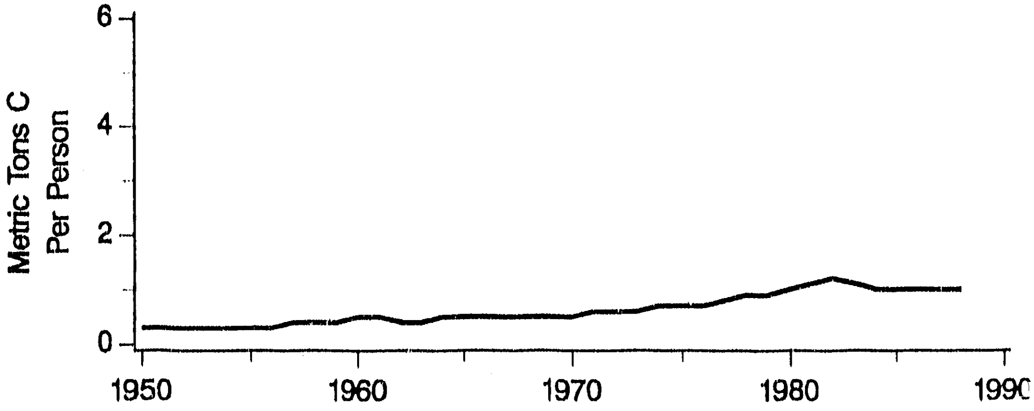


CO_2 emissions from Mexico.



Per capita CO_2 emission estimates for Mexico.

TREND

CO$_2$ emissions from Mexico grew exponentially at a rate of 6.9% per year from 1950 to 1982 but tumbled abruptly after 1982. Emissions growth was largely based on increasing oil production, and even in 1988, 71.6% of emissions were from petroleum products, the highest fraction of any of the major emitting countries. Per capita emissions also peaked in 1982 and were 16% lower by 1988. The impact of the oil price dislocations of the late 1970s and early 1980s is also reflected in a 74.5% decrease in emissions from gas flaring after 1982. Consumption of natural gas has become increasingly important in Mexico and now contributes 16.2% of CO$_2$ emissions.

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO$_2$ emissions versus time and calculating the slope of the regression line.

Mexico

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	8.3	0.5	6.5	0.4	0.2	0.7	0.3
1951	9.5	0.6	7.3	0.5	0.2	1.0	0.3
1952	10.2	0.7	7.7	0.5	0.2	1.0	0.3
1953	10.0	0.8	7.5	0.6	0.2	1.0	0.3
1954	9.9	0.7	7.3	0.6	0.2	1.0	0.3
1955	10.8	0.7	7.9	0.6	0.3	1.3	0.3
1956	11.5	0.8	8.5	0.7	0.3	1.2	0.3
1957	13.5	0.8	10.0	0.7	0.3	1.7	0.4
1958	14.8	0.8	10.3	1.3	0.3	2.0	0.4
1959	15.9	0.9	10.9	1.4	0.4	2.4	0.4
1960	17.2	1.0	11.7	1.7	0.4	2.4	0.5
1961	17.8	1.0	12.3	2.2	0.4	2.0	0.5
1962	17.4	1.0	11.5	3.2	0.5	1.2	0.4
1963	18.1	1.1	11.7	3.2	0.5	1.6	0.4
1964	20.3	1.2	12.7	3.7	0.6	2.1	0.5
1965	20.5	1.1	12.9	4.3	0.6	1.6	0.5
1966	22.1	1.2	13.7	4.6	0.7	1.8	0.5
1967	24.6	1.4	15.4	5.4	0.8	1.6	0.5
1968	25.6	1.6	16.2	5.4	0.8	1.6	0.5
1969	27.9	1.7	18.3	5.3	0.9	1.7	0.5
1970	28.9	1.9	17.8	5.6	1.0	2.6	0.5
1971	31.1	2.1	19.7	5.5	1.0	2.8	0.6
1972	32.5	2.2	20.6	6.2	1.2	2.3	0.6
1973	35.3	2.5	22.6	6.9	1.3	2.0	0.6
1974	39.5	3.0	25.1	7.2	1.4	2.7	0.7
1975	40.7	3.1	26.0	7.1	1.6	2.9	0.7
1976	47.5	3.2	32.4	7.1	1.7	3.1	0.7
1977	49.3	3.4	34.5	7.7	1.8	1.9	0.8
1978	57.6	3.9	39.4	9.5	1.9	2.9	0.9
1979	62.5	4.3	42.6	11.2	2.1	2.3	0.9
1980	71.0	4.3	49.4	12.4	2.2	2.7	1.0
1981	77.1	4.6	54.5	12.3	2.4	3.2	1.1
1982	86.9	4.5	54.5	20.6	2.6	4.7	1.2
1983	79.7	5.0	50.9	18.4	2.3	3.1	1.1
1984	77.4	5.1	53.6	14.2	2.5	2.0	1.0
1985	78.6	5.6	54.1	14.4	2.8	1.7	1.0
1986	77.6	5.5	54.8	13.5	2.7	1.1	1.0
1987	81.5	5.7	57.9	13.6	3.1	1.2	1.0
1988	83.7	5.9	59.9	13.5	3.1	1.2	1.0

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

South Africa

BACKGROUND

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Sponsoring agency
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Carbon Dioxide Research Program

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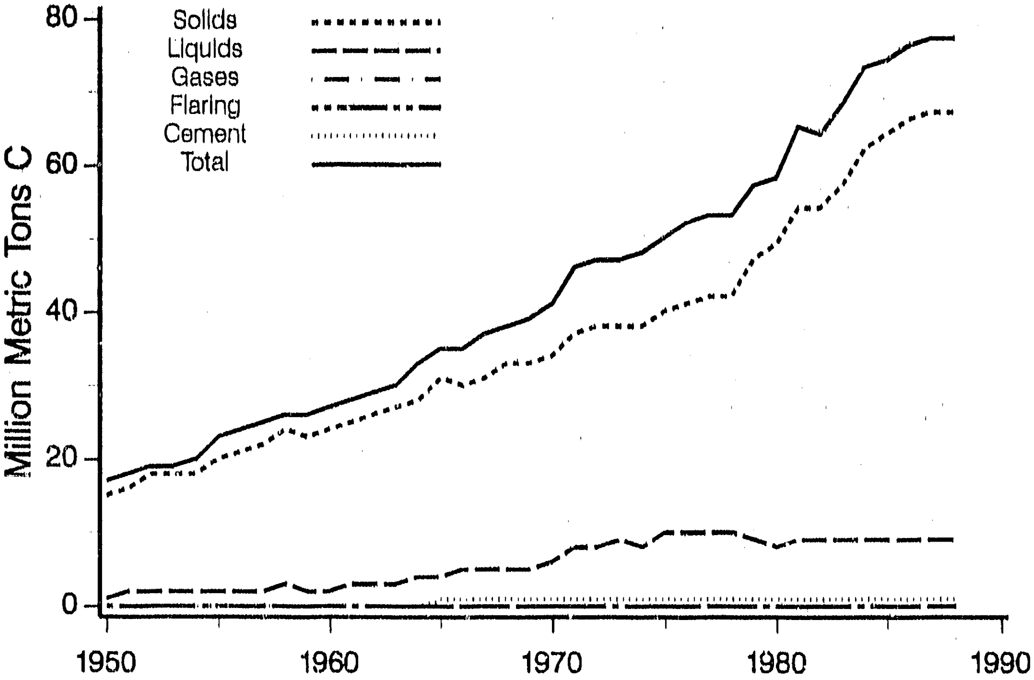
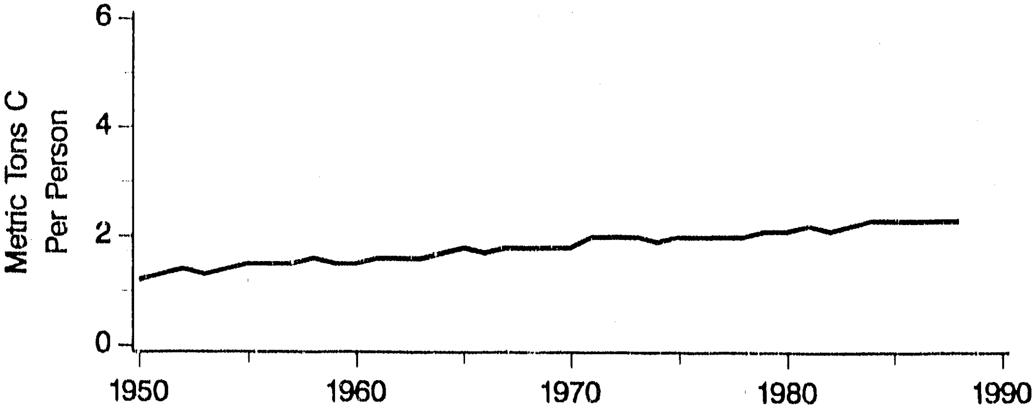


CO_2 emissions South Africa.



Per capita CO_2 emission estimates for South Africa.

TREND

With a domestic economy powered by coal, CO_2 emissions from South Africa have risen 4.7-fold since 1950, with 85–90% of emissions from coal. With no natural gas, another 12% is currently from oil consumption, and the remainder is from cement manufacture. The oil price problems so evident in other countries appear to have left only minor impact on South African CO_2 emissions. Per capita emissions have approximately doubled since 1950.

It is appropriate to note that emissions shown here are by primary fuel. Consequently, when liquid fuels are produced from coal, the emissions will still appear in these tabulations as CO_2 from solid fuels.

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

South Africa

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	16.6	15.0	1.4	0.0	0.3	0.0	1.2
1951	17.8	16.0	1.5	0.0	0.3	0.0	1.3
1952	19.5	17.6	1.6	0.0	0.3	0.0	1.4
1953	19.5	17.5	1.7	0.0	0.3	0.0	1.3
1954	20.3	18.1	1.8	0.0	0.3	0.0	1.4
1955	22.8	20.4	2.1	0.0	0.3	0.0	1.5
1956	24.0	21.4	2.3	0.0	0.3	0.0	1.5
1957	24.7	22.1	2.2	0.0	0.3	0.0	1.5
1958	26.5	23.6	2.5	0.0	0.4	0.0	1.6
1959	26.0	23.3	2.4	0.0	0.4	0.0	1.5
1960	26.9	24.1	2.5	0.0	0.4	0.0	1.5
1961	28.1	24.9	2.8	0.0	0.4	0.0	1.6
1962	29.0	25.6	3.0	0.0	0.4	0.0	1.6
1963	30.1	26.6	3.2	0.0	0.4	0.0	1.6
1964	32.8	28.2	4.2	0.0	0.5	0.0	1.7
1965	35.2	30.6	4.1	0.0	0.5	0.0	1.8
1966	35.3	30.0	4.7	0.0	0.5	0.0	1.7
1967	36.8	31.1	5.2	0.0	0.5	0.0	1.8
1968	37.9	32.6	4.7	0.0	0.6	0.0	1.8
1969	39.3	33.2	5.4	0.0	0.7	0.0	1.8
1970	40.8	34.1	6.0	0.0	0.8	0.0	1.8
1971	45.9	36.7	8.4	0.0	0.8	0.0	2.0
1972	46.8	38.0	8.0	0.0	0.8	0.0	2.0
1973	47.1	37.7	8.5	0.0	0.9	0.0	2.0
1974	47.9	38.5	8.4	0.0	1.0	0.0	1.9
1975	50.1	39.5	9.6	0.0	1.0	0.0	2.0
1976	52.3	41.1	10.3	0.0	1.0	0.0	2.0
1977	52.8	41.9	9.9	0.0	0.9	0.0	2.0
1978	53.0	42.3	9.7	0.0	0.9	0.0	2.0
1979	56.9	46.8	9.2	0.0	0.9	0.0	2.1
1980	58.2	49.3	7.9	0.0	1.0	0.0	2.1
1981	64.5	54.4	9.0	0.0	1.1	0.0	2.2
1982	63.5	53.9	8.6	0.0	1.1	0.0	2.1
1983	67.6	57.3	9.2	0.0	1.1	0.0	2.2
1984	72.6	62.4	9.1	0.0	1.1	0.0	2.3
1985	73.7	63.6	9.1	0.0	1.0	0.0	2.3
1986	75.7	65.6	9.2	0.0	0.9	0.0	2.3
1987	76.8	66.6	9.3	0.0	0.9	0.0	2.3
1988	77.5	67.0	9.4	0.0	1.1	0.0	2.3

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

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U.S. Department of Energy. 1988. *International Energy Annual*. DOE/EIA-0219(88). Energy Information Administration, Washington, D.C.

Australia

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Sponsoring agency
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Carbon Dioxide Research Program

Period of record — 1950–1988.

Method — Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

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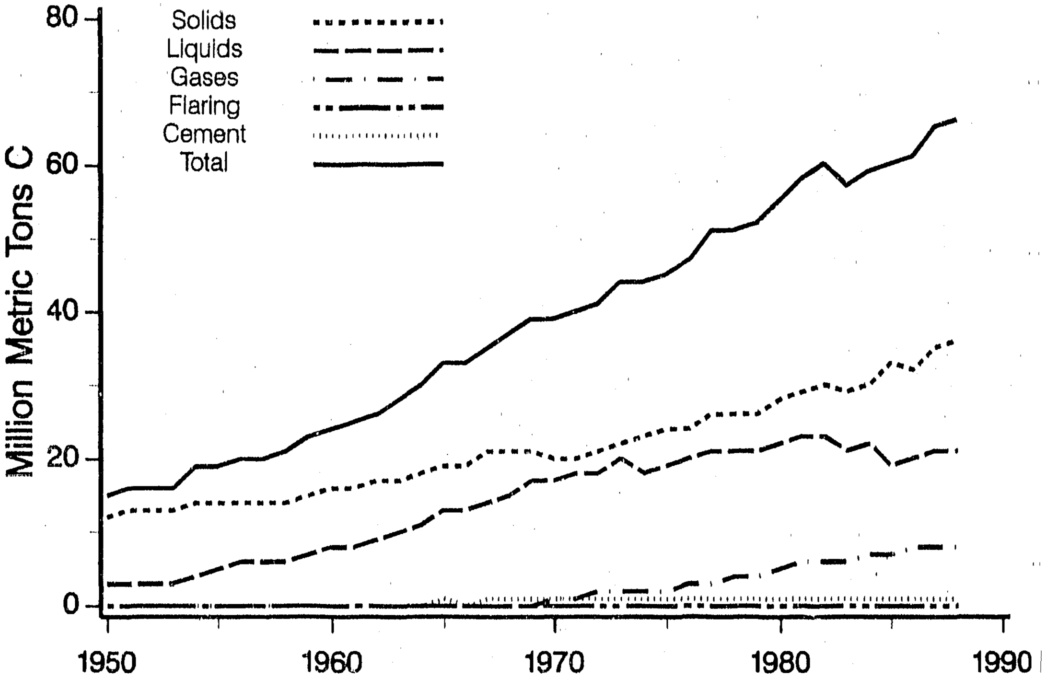
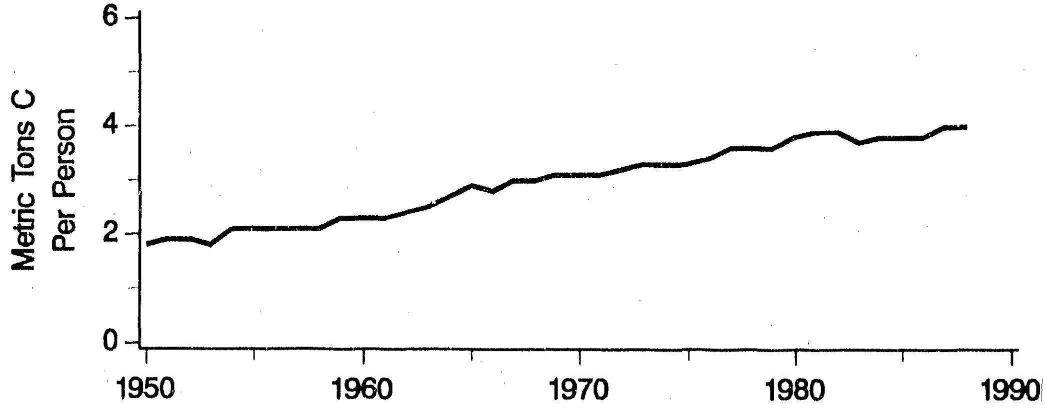


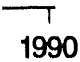
CO_2 emissions from Australia.



Per capita CO_2 emission estimates for Australia.

TREND

Australian CO_2 emissions have increased by a factor of 4.4 since 1950, with a 2.2-fold increase resulting from growing per capita emissions and a 2.0-fold increase in population. Emissions from both solid and liquid fuels have grown (although emissions from liquid fuels have been nearly constant since 1981), and since 1969 a steep growth in gas consumption has occurred. Total emissions have grown at an almost linear rate of 1.34 million tons of carbon per year. Coal remains the major contributor at 54% of the total. A small drop in emissions in 1983 is the only indication of the global trauma in oil prices that marks the post-1973 period.



Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Australia

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	15.0	12.1	2.7	0.0	0.2	0.0	1.8
1951	16.2	12.6	3.4	0.0	0.2	0.0	1.9
1952	16.5	12.9	3.4	0.0	0.2	0.0	1.9
1953	16.3	13.2	2.8	0.0	0.2	0.0	1.8
1954	18.6	14.0	4.3	0.0	0.3	0.0	2.1
1955	19.3	14.0	5.0	0.0	0.3	0.0	2.1
1956	20.0	14.0	5.7	0.0	0.3	0.0	2.1
1957	20.4	14.1	5.9	0.0	0.3	0.0	2.1
1958	21.2	14.4	6.5	0.0	0.3	0.0	2.1
1959	22.9	15.5	7.0	0.0	0.4	0.0	2.3
1960	24.1	16.1	7.6	0.0	0.4	0.0	2.3
1961	24.7	16.4	7.9	0.0	0.4	0.0	2.3
1962	25.9	16.8	8.7	0.0	0.4	0.0	2.4
1963	27.5	17.4	9.7	0.0	0.4	0.0	2.5
1964	29.7	18.3	10.9	0.0	0.5	0.0	2.7
1965	33.0	19.4	13.1	0.0	0.5	0.0	2.9
1966	32.8	19.5	12.8	0.0	0.5	0.0	2.8
1967	35.2	20.5	14.1	0.0	0.5	0.0	3.0
1968	36.7	20.9	15.3	0.0	0.5	0.0	3.0
1969	38.8	21.3	16.8	0.1	0.6	0.0	3.1
1970	38.9	20.3	17.2	0.8	0.6	0.0	3.1
1971	40.0	20.3	18.0	1.1	0.6	0.0	3.1
1972	41.3	21.2	17.8	1.6	0.7	0.0	3.2
1973	43.8	21.8	19.6	1.8	0.7	0.0	3.3
1974	44.2	23.3	18.1	2.1	0.7	0.0	3.3
1975	45.2	23.7	18.5	2.3	0.7	0.0	3.3
1976	47.0	24.2	19.5	2.5	0.7	0.0	3.4
1977	50.7	26.2	20.7	3.0	0.7	0.0	3.6
1978	51.5	25.7	21.4	3.8	0.7	0.0	3.6
1979	52.4	26.5	21.1	4.2	0.7	0.0	3.6
1980	55.3	28.1	21.7	4.8	0.7	0.0	3.8
1981	58.4	28.9	23.1	5.6	0.8	0.0	3.9
1982	59.5	29.6	22.9	6.1	0.8	0.0	3.9
1983	56.7	29.2	20.7	6.2	0.7	0.0	3.7
1984	59.4	30.2	21.9	6.6	0.7	0.0	3.8
1985	59.7	32.6	19.3	7.0	0.8	0.0	3.8
1986	60.9	32.2	20.3	7.7	0.8	0.0	3.8
1987	64.7	35.1	20.8	7.9	0.8	0.0	4.0
1988	65.8	35.8	20.9	8.2	0.8	0.0	4.0

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

Czechoslovakia

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Carbon Dioxide Research Program

Period of record – 1950–1988.

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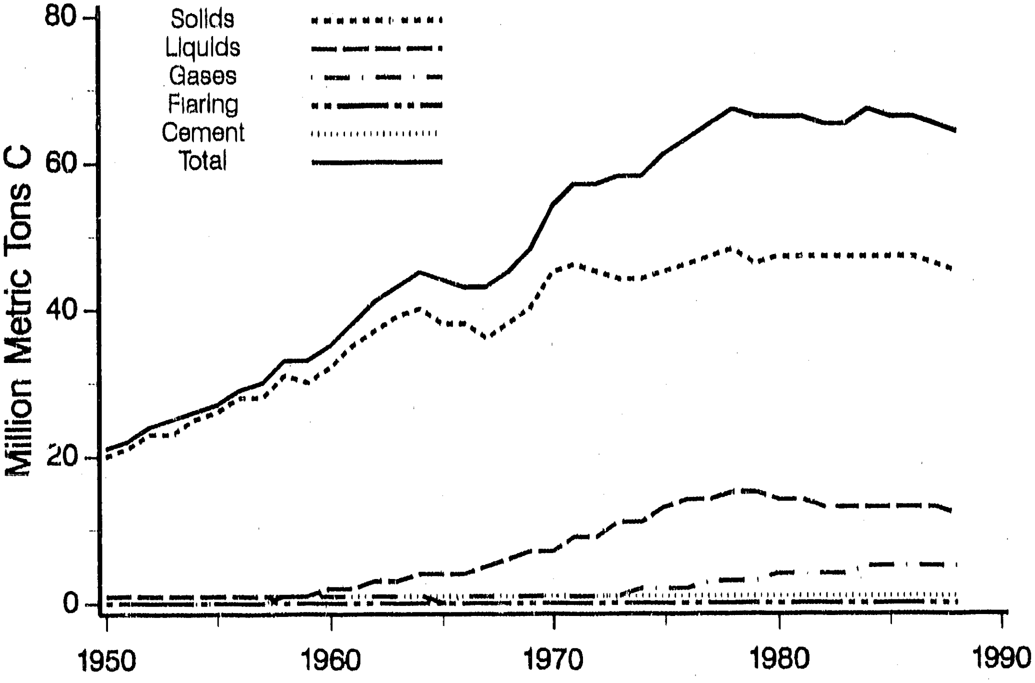
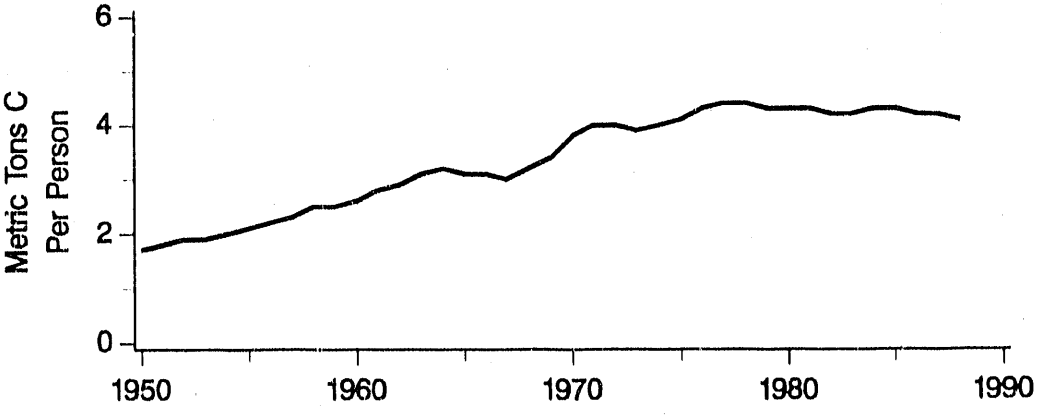


CO_2 emissions from Czechoslovakia.



Per capita CO_2 emission estimates for Czechoslovakia.

TREND

Aside from a hiatus from 1965 to 1967, CO_2 emissions from Czechoslovakia grew continuously from 1950 until 1978. Growth after 1970 was based on an increasing share from petroleum products as consumption of the dominant fuel, coal, has been virtually constant since 1970. Coal contributed over 88% of total emissions in 1964, but this share dropped to 71.2% by 1988. Population growth has not been an important factor in Czechoslovakia, as reflected in the fact that per capita emissions have followed the same pattern as total emissions, albeit at a slightly smaller growth rate. Natural gas first became a 1% contributor to CO_2 in 1957 and has now grown to 8.2%, with much of that growth occurring in the last decade.

Note—Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	20.8	20.0	0.5	0.0	0.3	0.0	1.7
1951	22.1	21.3	0.5	0.0	0.3	0.0	1.8
1952	23.6	22.7	0.6	0.1	0.3	0.0	1.9
1953	24.5	23.5	0.6	0.1	0.3	0.0	1.9
1954	26.2	24.9	0.8	0.1	0.3	0.0	2.0
1955	27.1	25.9	0.8	0.1	0.4	0.0	2.1
1956	29.1	27.7	0.9	0.1	0.4	0.0	2.2
1957	30.3	28.4	1.1	0.4	0.5	0.0	2.3
1958	33.1	30.8	1.1	0.6	0.6	0.0	2.5
1959	33.2	30.5	1.4	0.7	0.6	0.0	2.5
1960	35.4	32.2	1.8	0.7	0.7	0.0	2.6
1961	38.4	34.6	2.3	0.7	0.7	0.0	2.8
1962	40.9	36.6	2.9	0.6	0.8	0.0	2.9
1963	43.0	38.6	3.2	0.6	0.7	0.0	3.1
1964	44.8	39.5	4.0	0.5	0.7	0.0	3.2
1965	43.6	38.2	4.2	0.5	0.8	0.0	3.1
1966	43.4	37.6	4.4	0.5	0.8	0.0	3.1
1967	43.3	36.5	5.3	0.6	0.9	0.0	3.0
1968	45.3	38.0	5.6	0.8	0.9	0.0	3.2
1969	48.1	39.5	6.7	1.0	0.9	0.0	3.4
1970	54.3	44.8	7.5	1.1	1.0	0.0	3.8
1971	57.0	46.0	8.6	1.2	1.1	0.0	4.0
1972	57.4	45.5	9.5	1.3	1.1	0.0	4.0
1973	57.6	44.3	10.8	1.5	1.1	0.0	3.9
1974	58.3	44.0	11.3	1.8	1.2	0.0	4.0
1975	61.1	45.2	12.6	2.0	1.3	0.0	4.1
1976	63.4	46.3	13.6	2.2	1.3	0.0	4.3
1977	65.4	46.8	14.5	2.8	1.3	0.0	4.4
1978	67.3	47.9	14.9	3.2	1.4	0.0	4.4
1979	65.7	45.9	14.9	3.5	1.4	0.0	4.3
1980	66.1	46.5	14.1	4.0	1.4	0.0	4.3
1981	65.5	46.7	13.8	3.6	1.4	0.0	4.3
1982	64.9	46.5	12.9	4.1	1.4	0.0	4.2
1983	65.1	47.1	12.5	4.1	1.4	0.0	4.2
1984	66.6	47.2	13.4	4.5	1.4	0.0	4.3
1985	66.0	46.9	13.1	4.5	1.4	0.0	4.3
1986	65.8	46.9	12.5	5.1	1.4	0.0	4.2
1987	65.3	46.2	12.6	5.2	1.4	0.0	4.2
1988	63.7	45.4	11.7	5.2	1.4	0.0	4.1

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*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

REFERENCES

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Romania

BACKGROUND

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Period of record – 1950–1988.

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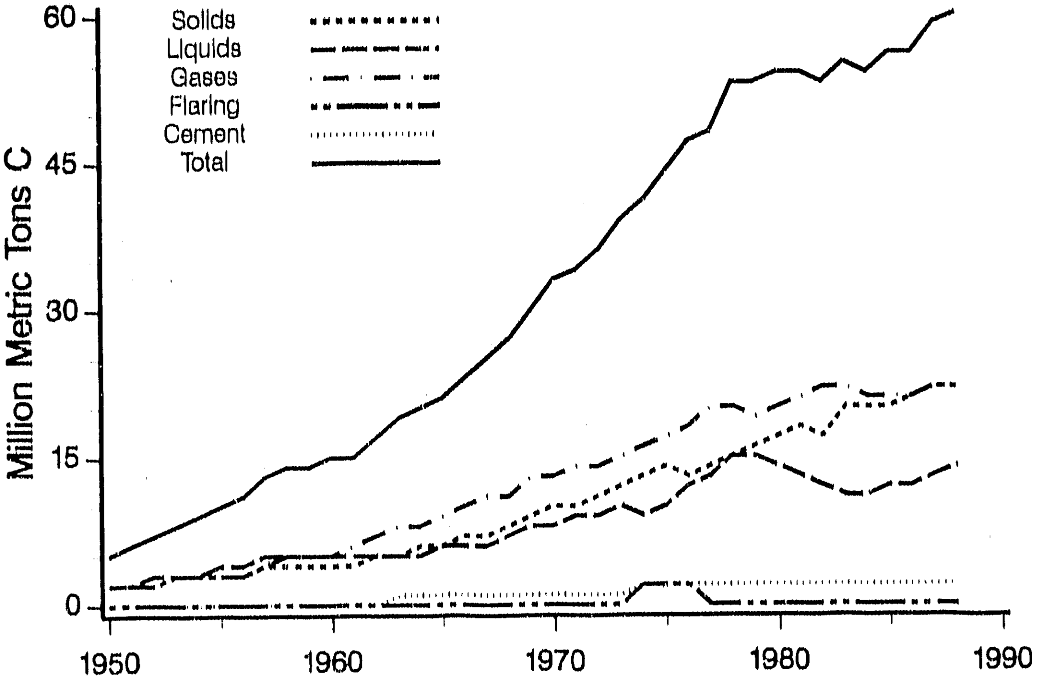
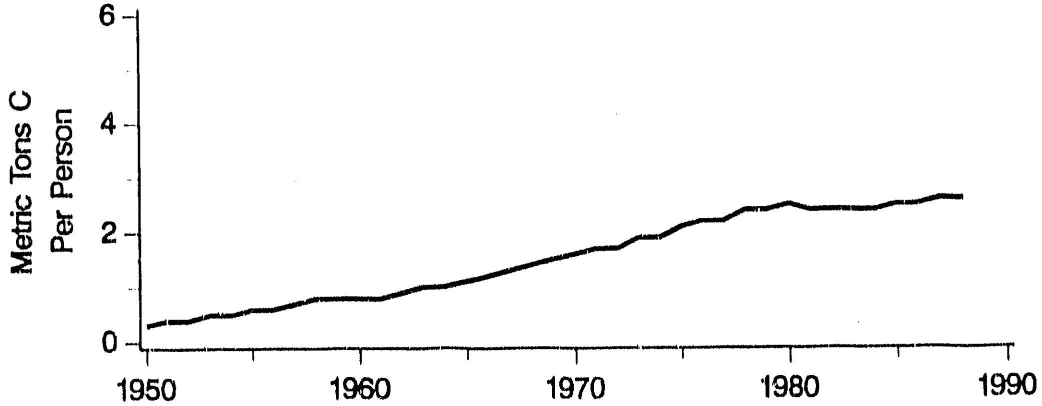


CO_2 emissions from Romania.



Per capita CO_2 emission estimates for Romania.

TREND

Broad growth in the consumption of all three fuel types from 1950 to 1978 has supported CO_2 emissions growth in Romania by a factor of 11.3 from 1950–1988. Per capita emissions grew by a factor of 8.0 from 1950 to 1987 and were at an all-time high in 1988. Romania is the only top-20 emitter for which gas fuels are the major contributor, a situation that has existed since 1959. Emissions from gas flaring are proportionally very small. Currently, 36.8% of Romanian emissions are from natural gas, 36.0% from solid fuels, and only 23.3% from liquid fuels. Emissions have shown slow but positive growth since 1978.

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Romania

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	5.3	1.8	1.7	1.7	0.1	0.0	0.3
1951	6.2	2.0	2.1	1.8	0.2	0.0	0.4
1952	7.3	2.4	2.6	2.1	0.2	0.0	0.4
1953	8.4	2.6	2.9	2.6	0.3	0.0	0.5
1954	9.2	2.8	3.4	2.7	0.2	0.0	0.5
1955	10.0	3.1	3.8	2.9	0.3	0.0	0.6
1956	11.1	3.3	4.3	3.3	0.3	0.0	0.6
1957	12.5	3.5	4.7	3.9	0.3	0.0	0.7
1958	13.6	3.7	5.1	4.5	0.3	0.0	0.8
1959	13.8	3.9	4.6	5.0	0.4	0.0	0.8
1960	14.6	4.2	4.6	5.5	0.4	0.0	0.8
1961	15.2	4.4	4.5	5.9	0.4	0.0	0.8
1962	17.4	5.1	4.9	6.9	0.5	0.0	0.9
1963	19.0	5.5	5.3	7.6	0.6	0.0	1.0
1964	19.7	5.7	5.1	8.2	0.6	0.0	1.0
1965	21.5	6.1	5.5	9.1	0.7	0.0	1.1
1966	23.0	6.6	5.7	9.8	0.8	0.0	1.2
1967	25.1	7.2	6.2	10.8	0.9	0.0	1.3
1968	27.3	8.1	6.8	11.4	1.0	0.0	1.4
1969	30.4	9.2	7.6	12.6	1.0	0.0	1.5
1970	32.6	10.2	8.1	13.0	1.1	0.1	1.6
1971	34.3	10.4	8.7	13.9	1.2	0.2	1.7
1972	36.0	11.0	9.1	14.2	1.3	0.4	1.7
1973	39.5	12.4	10.3	15.1	1.3	0.4	1.9
1974	41.0	12.8	9.5	15.6	1.5	1.6	1.9
1975	44.2	13.5	10.3	16.9	1.6	1.9	2.1
1976	47.4	13.4	11.6	18.5	1.8	2.1	2.2
1977	48.4	13.7	12.9	19.6	1.9	0.4	2.2
1978	52.7	15.3	14.7	20.2	2.0	0.4	2.4
1979	53.2	16.4	14.8	19.5	2.1	0.4	2.4
1980	54.5	17.2	14.5	20.2	2.1	0.4	2.5
1981	54.1	17.7	12.7	21.3	2.0	0.5	2.4
1982	53.4	16.8	12.5	21.6	2.0	0.5	2.4
1983	54.8	19.6	11.4	21.5	1.9	0.5	2.4
1984	54.5	19.6	11.1	21.4	1.9	0.5	2.4
1985	55.9	20.3	12.0	21.5	1.7	0.5	2.5
1986	56.4	20.6	12.0	21.4	1.9	0.5	2.5
1987	59.2	21.6	13.3	21.9	1.9	0.5	2.6
1988	60.2	21.7	14.0	22.1	1.9	0.5	2.6

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Republic of Korea

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Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

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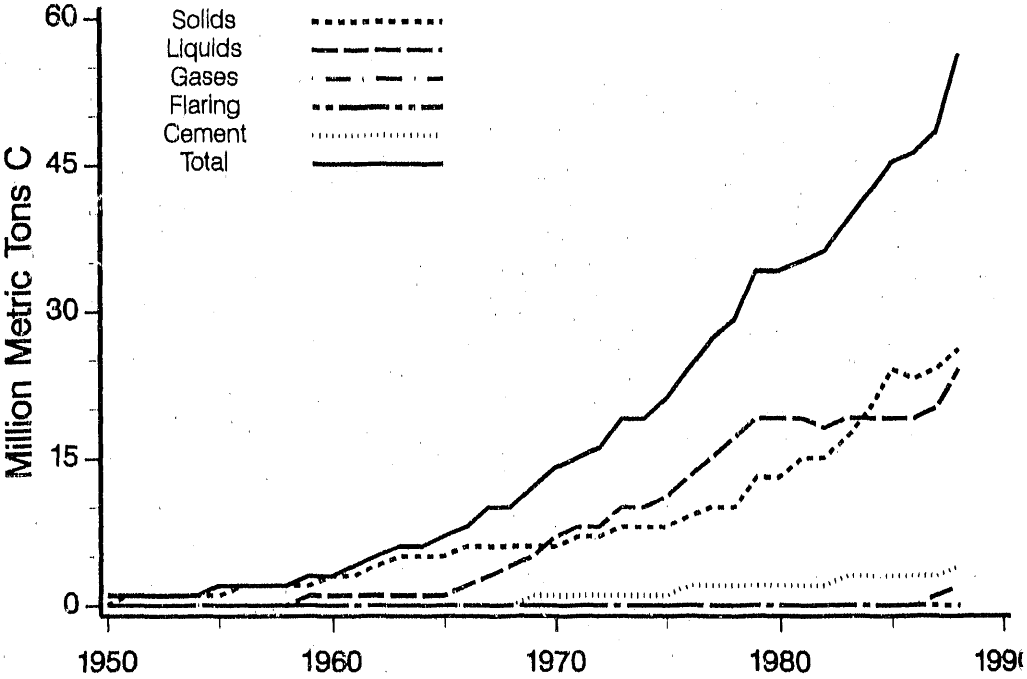
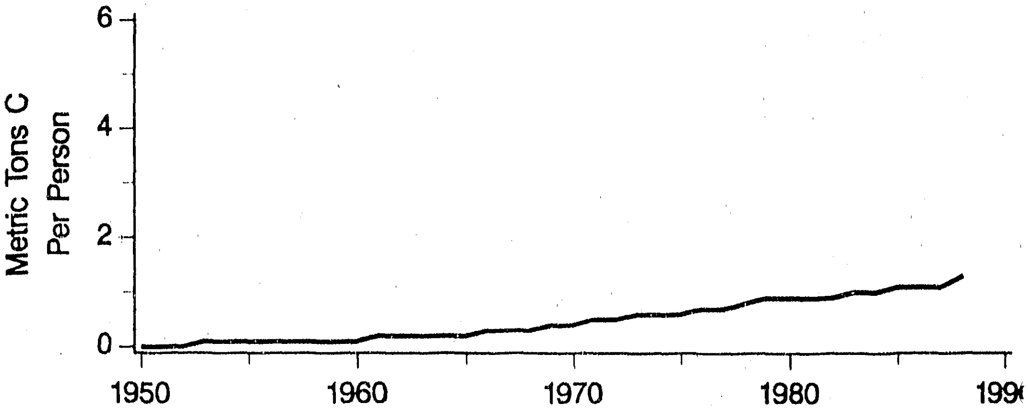


CO_2 emissions from the Republic of Korea.



Per capita CO_2 emission estimates for the Republic of Korea.

TREND

Even though minor offsets in the growth of CO_2 emissions from the Republic of Korea may have occurred during the late 1970s, the last 38 years have been dominated by growth that averaged 11.4% per year and totaled almost 93 times as much CO_2 in 1988 as in 1950. Per capita emissions have increased by a factor of 44.3. Initial growth was based on coal, but oil consumption grew rapidly from 1965 to 1979 and was the major source of CO_2 emissions from 1970 until 1983, at which time oil use was static and coal use was growing rapidly again. Natural gas became a significant contributor of CO_2 for the first time in 1987 as the Republic of Korea increased imports of liquid natural gas. The indication is that emissions from liquid fuels were starting to increase again after 1985.

1990

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

1990

Republic of Korea

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	0.6	0.5	0.1	0.0	0.0	0.0	0.0
1951	0.8	0.7	0.2	0.0	0.0	0.0	0.0
1952	1.0	0.8	0.2	0.0	0.0	0.0	0.0
1953	1.3	1.0	0.3	0.0	0.0	0.0	0.1
1954	1.4	1.1	0.3	0.0	0.0	0.0	0.1
1955	1.8	1.5	0.3	0.0	0.0	0.0	0.1
1956	2.1	1.7	0.4	0.0	0.0	0.0	0.1
1957	2.3	1.8	0.4	0.0	0.0	0.0	0.1
1958	2.5	2.0	0.5	0.0	0.0	0.0	0.1
1959	3.1	2.5	0.6	0.0	0.0	0.0	0.1
1960	3.5	2.8	0.6	0.0	0.1	0.0	0.1
1961	4.0	3.3	0.6	0.0	0.1	0.0	0.2
1962	4.8	3.8	0.8	0.0	0.1	0.0	0.2
1963	5.8	4.6	1.1	0.0	0.1	0.0	0.2
1964	6.1	5.1	0.9	0.0	0.2	0.0	0.2
1965	6.9	5.4	1.2	0.0	0.2	0.0	0.2
1966	8.3	6.2	1.8	0.0	0.3	0.0	0.3
1967	9.7	6.5	2.9	0.0	0.3	0.0	0.3
1968	10.2	5.5	4.2	0.0	0.5	0.0	0.3
1969	11.7	5.5	5.5	0.0	0.7	0.0	0.4
1970	14.2	6.4	7.0	0.0	0.8	0.0	0.4
1971	15.4	6.5	7.9	0.0	0.9	0.0	0.5
1972	16.0	6.8	8.4	0.0	0.9	0.0	0.5
1973	19.1	7.9	10.0	0.0	1.1	0.0	0.6
1974	19.4	8.2	10.0	0.0	1.2	0.0	0.6
1975	20.8	8.5	11.0	0.0	1.4	0.0	0.6
1976	23.9	9.3	12.9	0.0	1.6	0.0	0.7
1977	27.0	10.2	14.9	0.0	1.9	0.0	0.7
1978	29.3	10.4	16.9	0.0	2.1	0.0	0.8
1979	34.1	12.6	19.3	0.0	2.2	0.0	0.9
1980	34.3	13.4	18.8	0.0	2.1	0.0	0.9
1981	35.4	14.5	18.8	0.0	2.1	0.0	0.9
1982	36.3	15.4	18.5	0.0	2.4	0.0	0.9
1983	38.5	16.6	19.0	0.0	2.9	0.0	1.0
1984	41.9	20.4	18.7	0.0	2.8	0.0	1.0
1985	45.3	23.8	18.6	0.0	2.8	0.0	1.1
1986	46.0	23.5	19.3	0.0	3.2	0.0	1.1
1987	48.4	23.7	20.0	1.2	3.5	0.0	1.1
1988	55.8	25.8	24.5	1.6	3.9	0.0	1.3

---

*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

REFERENCES

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Marland, G., T.A. Boden, R.C. Griffin, S.F. Huang, P. Kanciruk, and T.R. Nelson. 1989. *Estimates of CO_2 emissions from fossil fuel burning and cement manufacturing, based on the United Nations energy statistics and the U.S. Bureau of Mines cement manufacturing data*. ORNL/CDIAC-25, NDP-030. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

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Brazil

BACKGROUND

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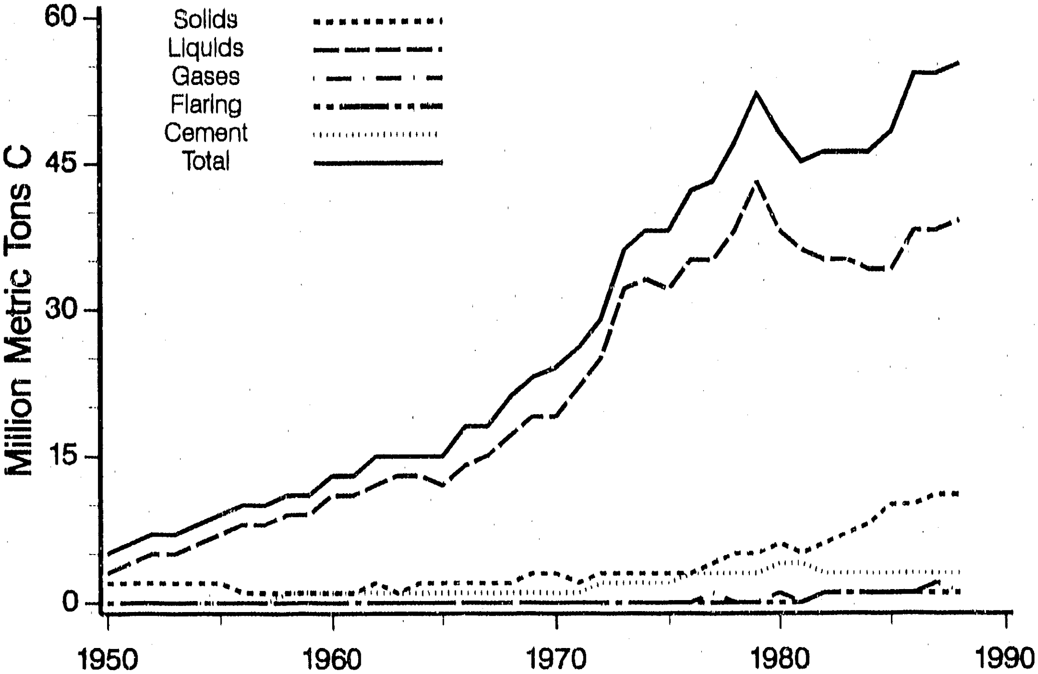
Oak Ridge, Tennessee 37831-6335
U.S.A.

Sponsoring agency
U.S. Department of Energy
Carbon Dioxide Research Program

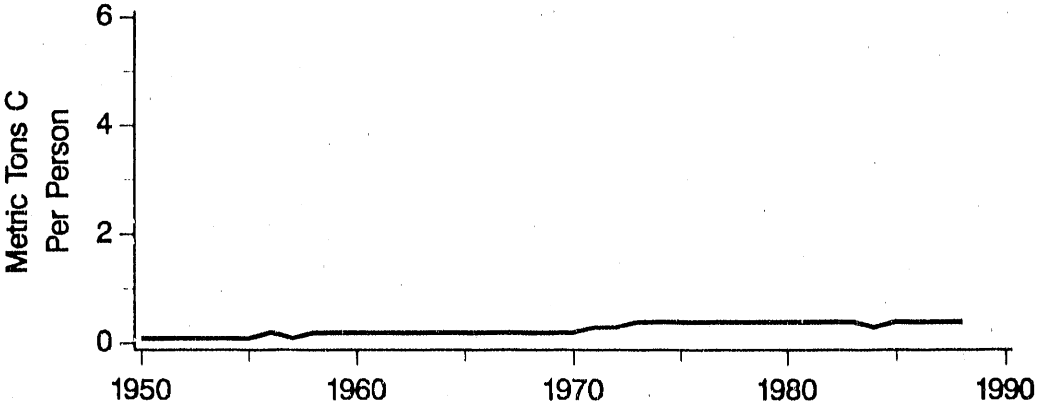
Period of record – 1950–1988.

Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

Data availability – Global and national CO_2 emission estimates, along with the data used in calculating these estimates, are documented and available from CDIAC (Marland et al. 1989). The U.N. energy statistics are available on magnetic tape from the U.N. Energy Statistics Unit. The cement and gas flaring data are available from the U.S. Bureau of Mines and the U.S. Department of Energy, respectively.



CO_2 emissions from Brazil.



Per capita CO_2 emission estimates for Brazil.

TREND

CO_2 emissions from Brazil grew rapidly from 1950 to 1979 (almost tenfold) but dropped sharply after 1979. Emissions have now increased steadily since 1982 and reached an all-time high in 1988. Historically, emissions have come largely from consumption of liquid fuels, but since 1973, when 87% of emissions were from liquid fuels, emissions from solid fuels have played an increasing role. In 1988, emissions were 70.8% from liquids and 19.2% from solids. Emissions from gas fuels have remained small (2.7% in 1988) but trebled from 1981 to 1988. Until 1974 more gas was flared than used.

Note—Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	5.4	1.8	3.4	0.0	0.2	0.0	0.1
1951	5.9	1.7	4.0	0.0	0.2	0.0	0.1
1952	6.8	1.7	4.9	0.0	0.2	0.0	0.1
1953	6.9	1.6	5.1	0.0	0.3	0.0	0.1
1954	8.1	1.6	6.2	0.0	0.3	0.0	0.1
1955	9.3	1.6	7.3	0.0	0.4	0.0	0.1
1956	10.0	1.4	8.1	0.0	0.4	0.0	0.2
1957	9.8	1.4	7.9	0.0	0.5	0.0	0.1
1958	10.7	1.1	9.0	0.0	0.5	0.0	0.2
1959	10.7	1.1	8.9	0.0	0.5	0.1	0.2
1960	12.8	1.4	10.6	0.0	0.6	0.1	0.2
1961	13.4	1.3	11.3	0.0	0.6	0.2	0.2
1962	14.7	1.6	12.2	0.0	0.7	0.1	0.2
1963	15.2	1.5	12.8	0.0	0.7	0.1	0.2
1964	15.5	1.7	12.8	0.0	0.8	0.2	0.2
1965	15.4	1.9	12.5	0.0	0.8	0.2	0.2
1966	17.6	2.3	14.2	0.0	0.8	0.2	0.2
1967	18.1	2.2	14.7	0.0	0.9	0.2	0.2
1968	21.1	2.4	17.5	0.0	1.0	0.3	0.2
1969	23.0	2.6	18.9	0.0	1.1	0.3	0.2
1970	23.6	2.6	19.4	0.0	1.2	0.4	0.2
1971	26.4	2.5	22.2	0.0	1.3	0.4	0.3
1972	29.2	2.6	24.6	0.1	1.5	0.4	0.3
1973	36.5	2.5	31.7	0.1	1.8	0.3	0.4
1974	38.4	3.0	32.9	0.3	2.0	0.3	0.4
1975	38.2	3.4	31.8	0.3	2.4	0.3	0.4
1976	41.6	3.2	35.5	0.3	2.6	0.0	0.4
1977	43.0	4.1	35.4	0.5	2.9	0.0	0.4
1978	46.5	4.9	38.0	0.4	3.0	0.2	0.4
1979	52.3	5.1	43.1	0.5	3.4	0.2	0.4
1980	48.2	5.5	38.2	0.6	3.7	0.2	0.4
1981	45.3	5.4	35.6	0.5	3.5	0.3	0.4
1982	45.8	6.1	35.1	0.6	3.5	0.5	0.4
1983	45.9	6.6	34.8	0.8	2.8	0.8	0.4
1984	46.4	7.9	33.8	1.0	2.7	0.9	0.3
1985	48.4	9.6	33.8	1.3	2.8	0.9	0.4
1986	53.5	9.7	38.2	1.5	3.4	0.7	0.4
1987	54.3	10.5	38.3	1.5	3.5	0.5	0.4
1988	55.2	10.6	39.1	1.5	3.4	0.6	0.4

---

*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

REFERENCES

Keeling, C.D. 1973. Industrial production of carbon dioxide from fossil fuels and limestone. *Tellus* 25:174–198.

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Spain

BACKGROUND

Principal investigator
Gregg Marland
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6335
U.S.A.

Sponsoring agency
U.S. Department of Energy
Carbon Dioxide Research Program

Period of record – 1950–1988.

Method – Global CO_2 emission estimates derived primarily from the U.N. energy statistics were calculated by using the methods of Marland and Rotty (1984). The energy data were compiled from U.N. questionnaires supplemented by national statistical publications. Data from the U.S. Bureau of Mines were used to estimate CO_2 emitted during cement production. Emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy and with a few global and national estimates provided by Gregg Marland.

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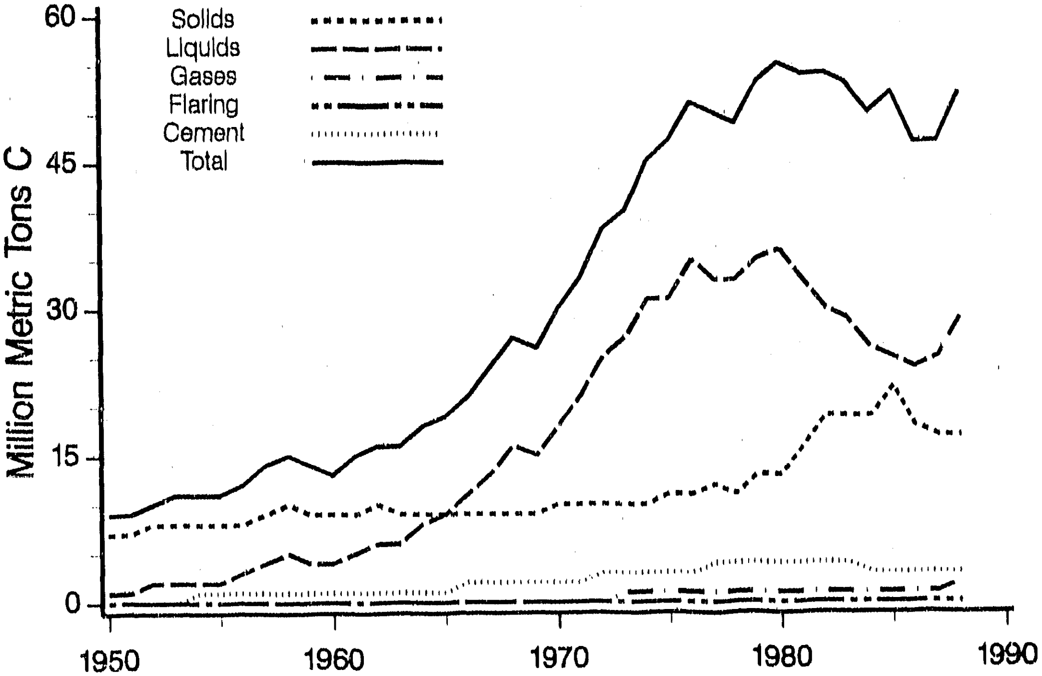
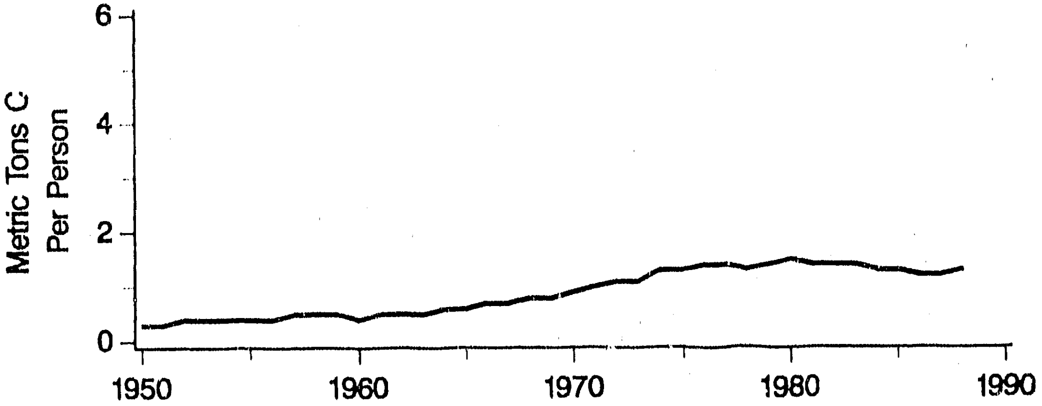


CO_2 emissions from Spain.



Per capita CO_2 emission estimates for Spain.

TREND

Spain has experienced a 19.3% drop in CO_2 emissions from liquid fuels from 1980 to 1988, a drop that occurs in both total and per capita emissions. Emissions from coal grew from 1978 until 1985, balancing some of the loss in liquid fuel burning. Liquid fuels have been the dominant source of CO_2 from Spain since 1966, contributing 56.7% of emissions in 1988 after a high of 69.7% in 1974. Coal was the dominant CO_2 source prior to 1966 and still contributed 33.1% in 1988. Per capita emissions remain low, in contrast with those of other Western European nations, at a rate of 1.3 metric tons of carbon per capita per year, a value little changed from 1973.

Note – Growth rates were calculated (before rounding) by performing a linear regression of log CO_2 emissions versus time and calculating the slope of the regression line.

Spain

Carbon Dioxide Emission Estimates*

Year	Total	Solid	Liquid	Gas	Cement	Gas flaring	Per capita
1950	9.1	7.3	1.4	0.0	0.3	0.0	0.3
1951	9.1	7.3	1.5	0.0	0.4	0.0	0.3
1952	10.3	8.0	1.9	0.0	0.4	0.0	0.4
1953	10.7	8.3	2.0	0.0	0.4	0.0	0.4
1954	10.9	8.3	2.1	0.0	0.5	0.0	0.4
1955	11.1	8.2	2.3	0.0	0.6	0.0	0.4
1956	11.6	8.1	2.8	0.0	0.6	0.0	0.4
1957	13.8	9.2	3.9	0.0	0.7	0.0	0.5
1958	15.3	10.0	4.7	0.0	0.7	0.0	0.5
1959	14.3	9.0	4.5	0.0	0.8	0.0	0.5
1960	13.4	8.8	3.9	0.0	0.8	0.0	0.4
1961	14.7	9.2	4.6	0.0	0.9	0.0	0.5
1962	16.5	9.5	6.0	0.0	1.0	0.0	0.5
1963	16.1	9.5	5.6	0.0	1.1	0.0	0.5
1964	17.6	9.0	7.5	0.0	1.2	0.0	0.6
1965	19.5	9.5	8.7	0.0	1.3	0.0	0.6
1966	21.3	8.8	10.8	0.0	1.6	0.0	0.7
1967	23.7	8.8	13.0	0.0	1.8	0.0	0.7
1968	26.6	9.0	15.5	0.0	2.0	0.0	0.8
1969	26.5	9.0	15.2	0.0	2.2	0.0	0.8
1970	30.2	10.0	17.9	0.0	2.3	0.0	0.9
1971	33.4	9.6	21.2	0.2	2.3	0.0	1.0
1972	37.6	9.9	24.5	0.4	2.7	0.0	1.1
1973	40.0	9.6	26.8	0.6	3.0	0.0	1.1
1974	45.1	10.1	31.4	0.6	3.0	0.0	1.3
1975	46.6	11.3	31.3	0.7	3.3	0.0	1.3
1976	50.6	11.1	35.1	0.9	3.4	0.0	1.4
1977	49.8	12.2	33.0	0.8	3.8	0.0	1.4
1978	49.4	11.2	33.2	0.8	4.1	0.0	1.3
1979	53.0	13.1	35.2	1.0	3.8	0.0	1.4
1980	54.5	13.4	36.2	1.1	3.8	0.0	1.5
1981	54.5	16.0	33.4	1.2	3.9	0.0	1.4
1982	54.5	18.9	30.2	1.3	4.0	0.0	1.4
1983	53.2	19.0	28.7	1.3	4.2	0.0	1.4
1984	49.8	19.1	25.9	1.3	3.5	0.0	1.3
1985	51.8	21.8	25.2	1.5	3.3	0.0	1.3
1986	47.1	18.0	24.4	1.4	3.3	0.0	1.2
1987	46.9	17.1	25.0	1.5	3.2	0.0	1.2
1988	51.5	17.1	29.2	1.9	3.3	0.0	1.3

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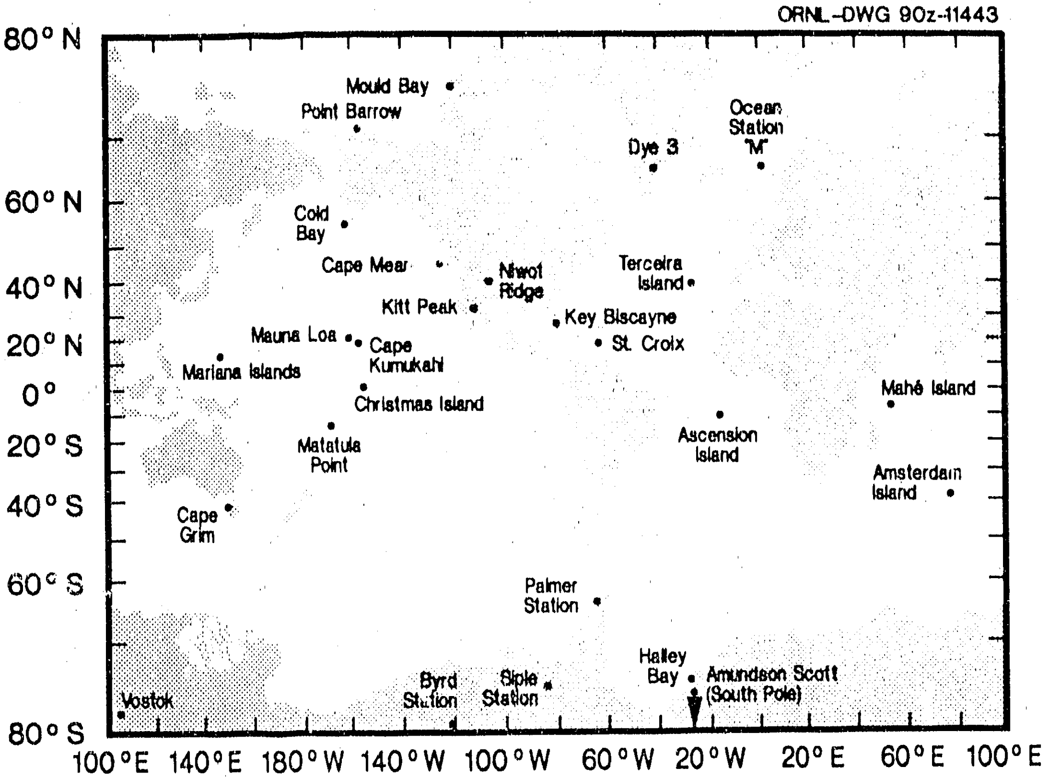
*Emission estimates rounded and expressed in million metric tons of carbon; per capita estimates rounded and expressed in metric tons of carbon.

Atmospheric Methane Concentrations



Sampling Stations

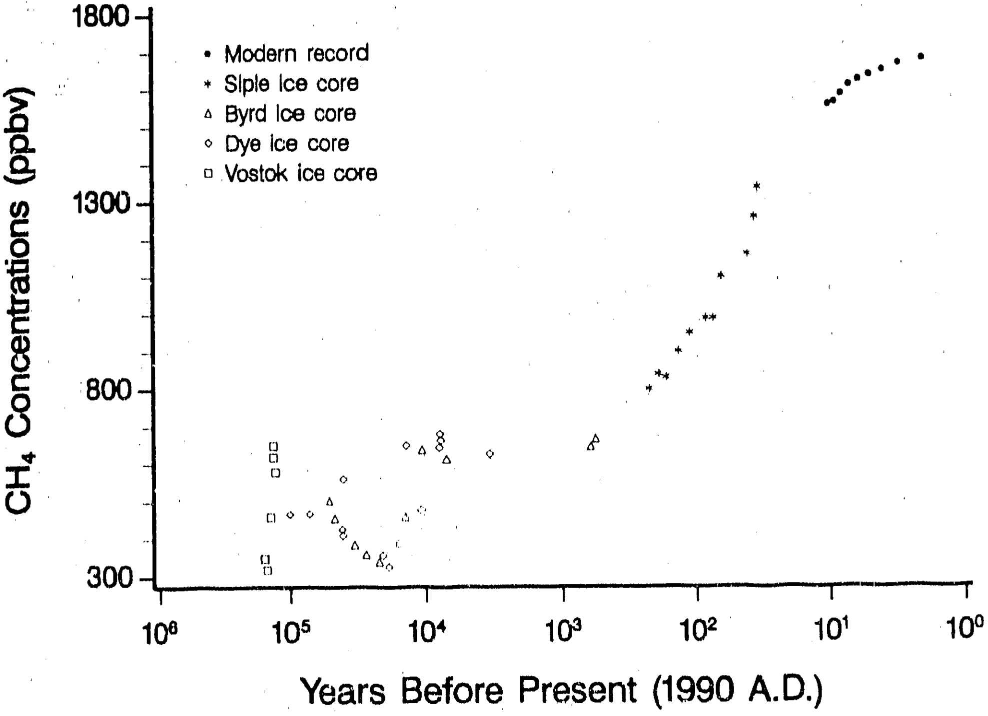
Introduction

Methane (CH_4) is recognized as one of the most important radiatively active trace gases with significant potential to contribute to climatic change within the next century. The most important methane sources are enteric fermentation in ruminants; anaerobic decay of organic matter in rice paddies, natural wetlands, and landfills; coal mining; natural gas production and distribution; oil exploration and production; and biomass burning. There is compelling evidence that the concentration of CH_4 in the atmosphere is rising rapidly and that present levels are approximately double those of a few hundred years ago (see figure to right). Precise records of past and present CH_4 concentrations are critical to studies attempting to determine the potential effects that greenhouse gases would have on climate.

Past concentrations of atmospheric CH_4 have been determined by analyzing air bubbles trapped in ice from both Greenland and Antarctica. Since 1978, when the modern CH_4 record begins, several systematic investigations have found on average a 1–2% increase in CH_4 concentrations per year. Most of these measurements have been made in the troposphere by using the method of gas chromatography with a flame ionization detector. Other measurements have relied upon an optical absorption technique that uses the sun as a source of infrared radiation and yields an average atmospheric abundance along the entire path length traversed through the atmosphere.

The following pages provide CH_4 concentrations derived from ice cores, global monthly averages derived from 7 monitoring sites, and monthly atmospheric CH_4 concentration records from 21 globally distributed sites (see figure on facing page). These latter data were collected as part of the National Oceanic and Atmospheric Administration's Climate Monitoring and Diagnostics Laboratory (NOAA/CMDL) program.

We urge readers to credit the principal investigators and their organizations when using these data. In addition, users are encouraged to contact CDIAC before applying the data in specific model or research exercises. Some of the data that are presented are considered preliminary and are subject to change by several parts per billion. All the data presented here are available in digitized form from CDIAC.



Annual atmospheric CH_4 concentrations during the past 160,000 years (derived from ice cores and the NOAA/CMDL flask sampling network).

Vostok

BACKGROUND

Principal investigators

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France

Y. S. Korotkevich
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Leningrad 199226, U.S.S.R.

Sponsoring agencies

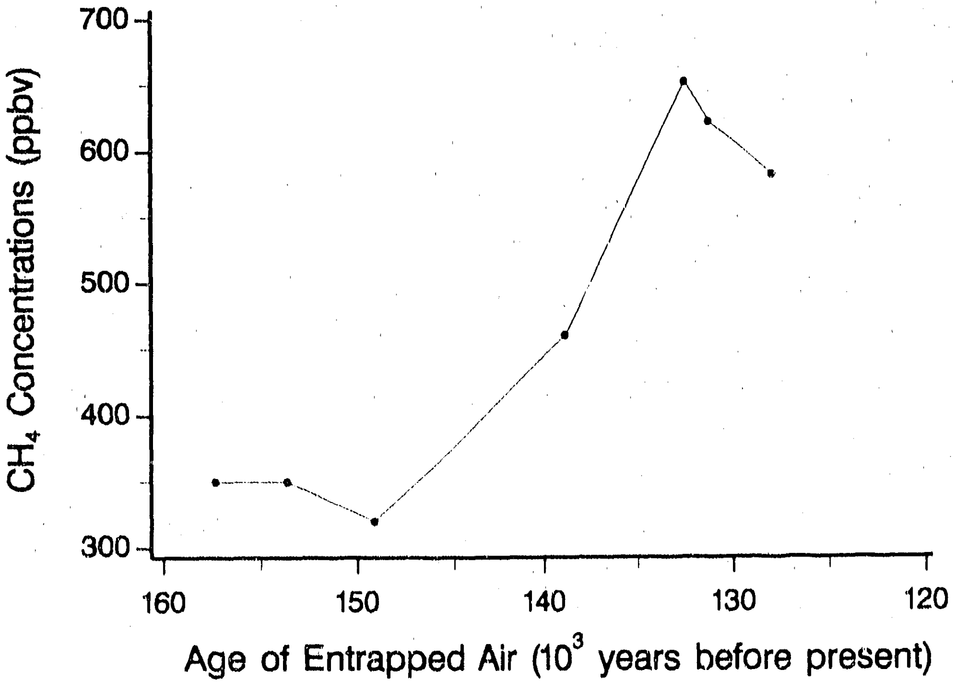
Commission of the European Communities
CNRS/PIREN
TAAF
Soviet Antarctic Expeditions

Period of record — 157,300–127,800 years BP.

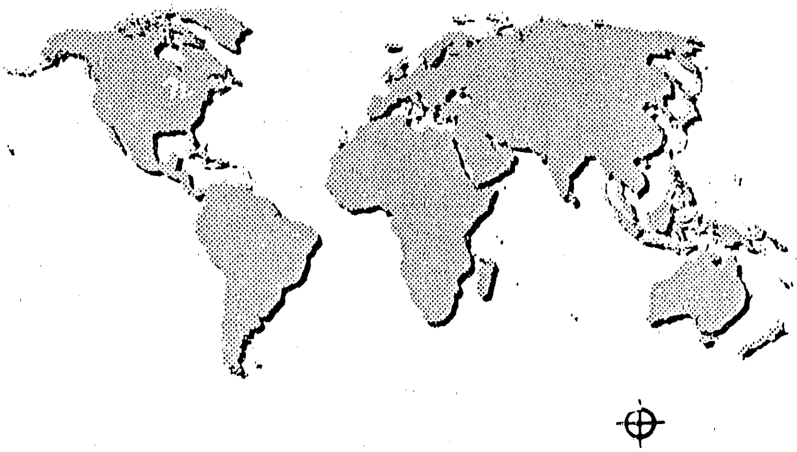
Method — Each ice sample (~40 g) is taken from the center of the core and placed in a glass vessel sealed with vacuum silicon grease. The air surrounding the sample is evacuated, and the ice is melted. The meltwater is then slowly refrozen from the bottom to push out the dissolved air at the water- ice interface. The gas is expanded in an extraction line, and the water is refrozen and injected into a gas chromatograph (flame ionization detector). Three successive injections from the same extracted air are performed. For details, see Raynaud et al. (1988) and Lorius et al. (1985).

Calibration gases used — 1.2 ± 0.1 ppmv of CH_4 in a mixture of N_2, O_2, and CO_2.

Data availability — These data are available from CDIAC and have been published in Raynaud et al. (1988).



Concentrations of atmospheric CH_4 from ice cores.



Vostok
Antarctica
78° 28'S, 106°48'E

Atmospheric CH_4 from Ice Cores

TRENDS

Using a 2083-m-long ice core recovered by the Soviet Antarctic Expeditions at Vostok (East Antarctica), the investigators have determined atmospheric CH_4 concentrations for the past 160,000 years.

On the basis of an analysis of the Vostok ice core, Raynaud et al. (1988) reported that CH_4 concentrations increased from 0.34 to 0.62 ppmv between the end of the penultimate ice age and the following interglacial, about 160×10^3 to 120×10^3 years BP. The mean CH_4 concentration from the Vostok core is in good agreement with results published for comparable periods from other cores.

Atmospheric Methane from Ice Cores

Depth (m)	Age of the ice (yr BP)	Mean age of the gas (yr BP)	CH_4 concentration (ppmv)*	Mean CH_4 concentration ($\pm 2\ \sigma$)† (ppmv)
1789.2	130,080	127,800	0.58, 0.60, 0.57 0.58, 0.59, 0.58	0.68 (0.04)
1834.7	133,360	131,100	0.64, 0.60, 0.62	0.62 (0.02)
1852.3	134,650	132,400	0.67, 0.64, 0.64	0.65 (0.04)
1932.1	141,600	138,800	0.44, 0.46, 0.47	0.46 (0.03)
2016.4	153,420	149,100	0.30, 0.32, 0.33	0.32 (0.03)
2042.5	157,790	153,600	0.35, 0.34, 0.35	0.35 (0.01)
2063.7	161,350	157,300	0.37, 0.34, 0.34 0.35, 0.38, 0.34	0.35 (0.04)

---

*Three concentrations are given because three successive injections into the gas chromatograph from the same extracted air are performed.

†This symbol σ signifies standard deviation.

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Lorius, C., J. Jouzel, C. Ritz, L. Merlivat, N.I. Barkov, Y.S. Korotkevich, and V.M. Kotlyakov. 1985. A 150,000-year climatic record from Antarctic ice. *Nature* 316:591–96.

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Schwander, J., and B. Stauffer. 1984. Age difference between polar ice and air trapped in its bubbles. *Nature* 311:45–47.

Stauffer, B., E. Lochbronner, H. Oeschger, and J. Schwander. 1988. Methane concentration in the glacial atmosphere was only half that of the preindustrial Holocene. *Nature* 332:812–14.

Byrd Station

BACKGROUND

Principal investigators
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CH-3012 Bern, Switzerland

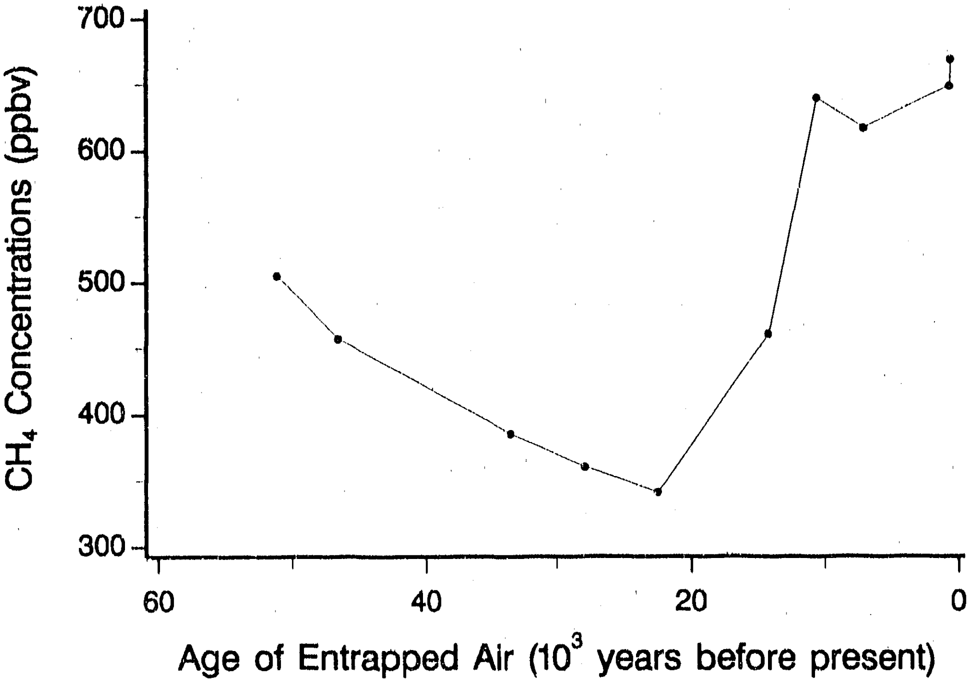
Sponsoring agencies
Swiss National Science Foundation
University of Bern

Period of record – 3,400–100,000 years BP.

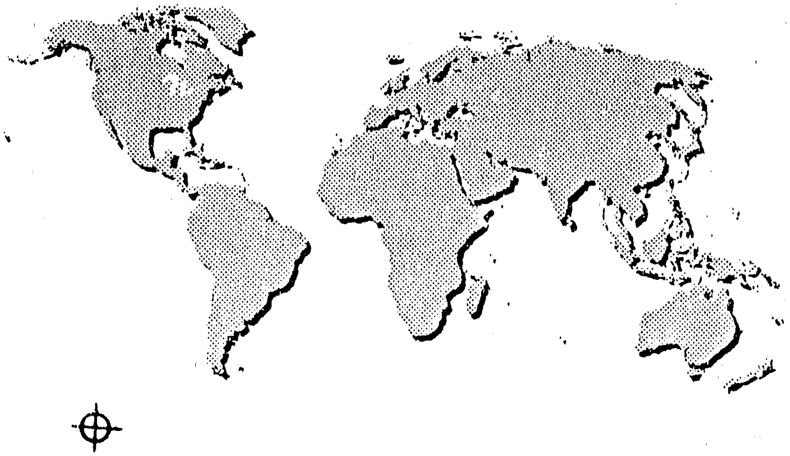
Method – For extracting the air from an ice sample, a 500- to 800-g sample of ice is placed in a glass cylinder. The cylinder is evacuated for 20 min to further clean the sample surface, and the ice sample is melted in 30–40 min. The air released during melting is dried and collected continuously by condensation at 15–20° K. The air collected is then analyzed for CH_4 concentration by using a gas chromatograph equipped with a flame ionization detector. For details on the gas extraction and ice core dating techniques, see Stauffer et al. (1988) and Hammer et al. (1985), respectively.

Calibration gases used – A standard gas mixture of N_2, O_2, Ar, and CO_2 with a CH_4 concentration of 980 ± 30 ppbv is used.

Data availability – These data are available from CDIAC and have been published in Stauffer et al. (1988).



Concentrations of atmospheric CH_4 from ice cores.



Byrd Station
Antarctica
79° 59'S, 120° 01'W

TRENDS

The 2184-m core from Byrd Station was drilled in 1967--1968 by the U.S. Cold Regions Research and Engineering Laboratory. Schwander and Stauffer (1984) reported a difference of 240 years between the age of the ice core from Byrd Station and the mean age of the air trapped in its bubbles.

Stauffer et al. (1988) reported that measurements on ice cores from Byrd Station (Antarctica) and Dye 3 (Greenland) show that the atmospheric CH_4 concentration was only ~350 ppbv during the last glaciation, in comparison with a mean preindustrial level of ~650 ppbv and a present value of 1650 ppbv.

Atmospheric Methane from Ice Cores

Depth (m)	Air enclosed (yr BP)	CH_4 concentration in extracted air (ppbv)*
147.22	550	667 ± 25
153.82	600	647 ± 25
750.04	7,100	615 ± 25
999.63	10,600	638 ± 25
1200.6	14,300	460 ± 25
1395.9	22,400	341 ± 27
1501.3	27,900	360 ± 25
1601.1	33,500	385 ± 25
1795.7	46,600	457 ± 27
1853.3	51,100	505 ± 31

---

*For a 500-g sample, the CH_4 concentration rose 40 ± 10 ppbv because of CH_4 contamination (Stauffer et al. 1988). These results have been corrected accordingly. The precision of their analyses, including extraction, is within ±25 ppbv; the accuracy is further limited by the standard gas, which gives an additional uncertainty of 3% in the methane concentration.

REFERENCES

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Stauffer, B., E. Lochbronner, H. Oeschger, and J. Schwander. 1988. Methane concentration in the glacial atmosphere was only half that of the preindustrial Holocene. *Nature* 332:812–14.

Dye 3

BACKGROUND

Principal investigators
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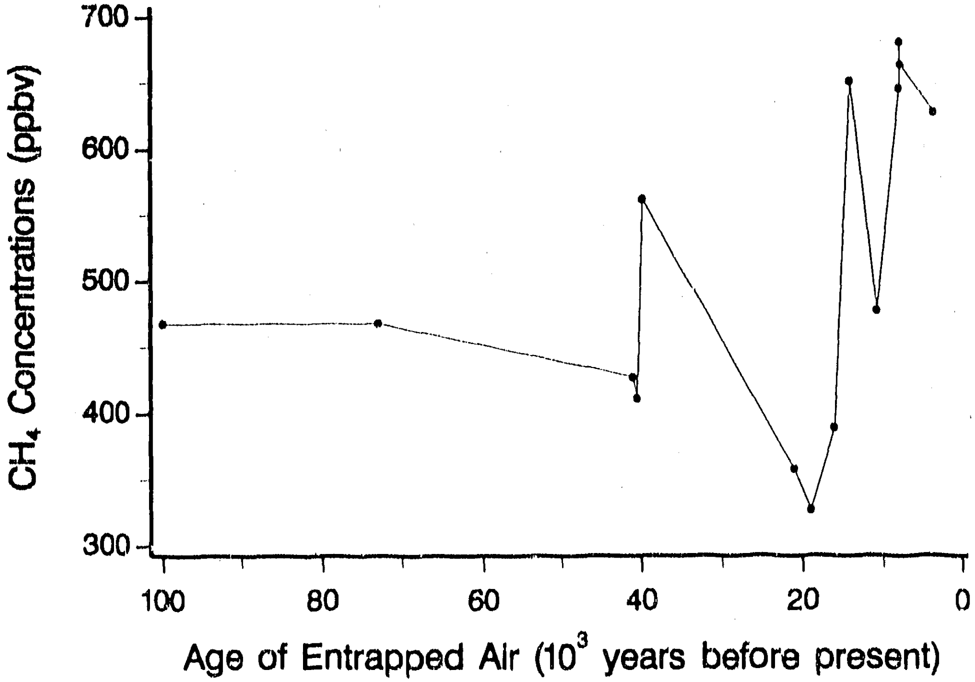
Sponsoring agencies
Swiss National Science Foundation
University of Bern

Period of record – 3,400–100,000 years BP.

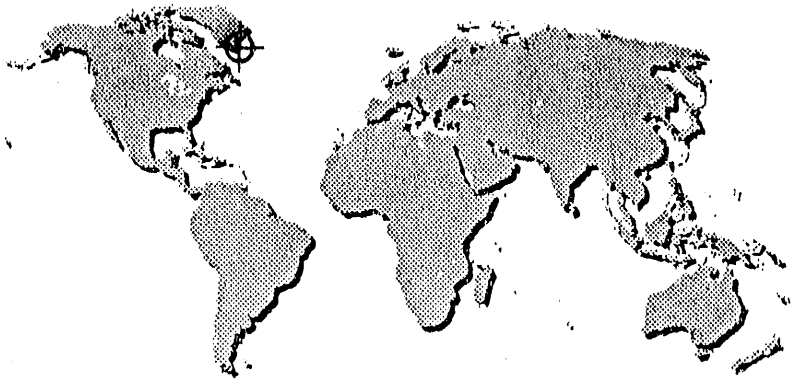
Method – For extracting the air from an ice sample, a 500- to 800-g sample of ice is placed in a glass cylinder. The cylinder is evacuated for 20 min to further clean the sample surface, and then the ice sample is melted in 30–40 min. The air released during melting is dried and collected continuously by condensation at 15–20° K. The air collected is analyzed for CH_4 concentration by using a gas chromatograph equipped with a flame ionization detector. For details on the gas extraction and ice core dating techniques, see Stauffer et al. (1988) and Dansgaard et al. (1982), respectively.

Calibration gases used – A standard gas mixture of N_2, O_2, Ar, and CO_2 with a CH_4 concentration of 980 ± 30 ppbv is used.

Data availability – These data are available from CDIAC and have been published in Stauffer et al. (1988).



Concentrations of atmospheric CH_4 from ice cores.



Dye 3
Greenland
65° 11'N, 43° 50'W

Atmospheric CH_4 from Ice Cores

TRENDS

The Greenland core was drilled at Dye 3 during the summer months 1979–1981 as part of an international collaboration between the United States, Denmark, and Switzerland (i.e., the Greenland Ice Sheet Program). Fourteen samples were measured from the 2037-m core. Schwander and Stauffer (1984) determined that the difference between the mean age of the ice and the mean age of the air trapped in its bubbles was 90 years.

On the basis of analyses of the ice core from Dye 3, Stauffer et al. (1988) reported a decline in the CH_4 concentration from 500 ppbv around 60,000 yearrs BP to 350 ppbv around 20,000 yearrs BP followed by a rapid increase to the Holocene value of 650 ppbv. Present values are now ~1650 ppbv.

Dye 3

Atmospheric Methane from Ice Cores

Depth (m)	Air enclosed (yr BP)	CH_4 concentration in extracted air (ppbv)*
1185.03	3,400	627 ± 25
1670.91	7,700	663 ± 30
1675.26	7,800	680 ± 27
1681.40	7,900	645 ± 37
1789.00	10,800	477 ± 25
1808.39	14,000	650 ± 32
1818.90	16,000	389 ± 32
1828.90	19,000	327 ± 30
1836.81	21,000	358 ± 41
1896.83	39,800	561 ± 31
1898.33	40,500	411 ± 32
1899.33	41,000	427 ± 33
1951.77	73,000	468 ± 25
1990.22	100,000	468 ± 25

---

*For a 500-g sample, the CH_4 concentration rose 40 ± 10 ppbv because of CH_4 contamination (Stauffer et al. 1988). These results have been corrected accordingly. The precision of their analyses, including extraction, is within ±25 ppbv; the accuracy is further limited by the standard gas, which gives an additional uncertainty of 3% in the methane concentration.

Atmospheric Methane from Ice Cores

Depth (m)	Air enclosed (yr BP)	CH_4 concentration in extracted air (ppbv)*
1185.03	3,400	627 ± 25
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1896.83	39,800	561 ± 31
1898.33	40,500	411 ± 32
1899.33	41,000	427 ± 33
1951.77	73,000	468 ± 25
1990.22	100,000	468 ± 25

---

*For a 500-g sample, the CH_4 concentration rose 40 ± 10 ppbv because of CH_4 contamination (Stauffer et al. 1988). These results have been corrected accordingly. The precision of their analyses, including extraction, is within ±25 ppbv; the accuracy is further limited by the standard gas, which gives an additional uncertainty of 3% in the methane concentration.

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Barnola, J.M., D. Raynaud, A. Neftel, and H. Oeschger. 1983. Comparison of CO_2 measurements by two laboratories on air bubbles in polar ice. *Nature* 303:410–13.

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Lorius, C., J. Jouzel, C. Ritz, L. Merlivat, N.I. Barkov, Y.S. Korotkevich, and V.M. Kotlyakov. 1985. A 150,000-year climatic record from Antarctic ice. *Nature* 316:591–96.

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Stauffer, B., G. Fischer, A. Neftel, and H. Oeschger. 1985. Increase of atmospheric methane recorded in Antarctic ice core. *Science* 229:1386–88.

Stauffer, B., E. Lochbronner, H. Oeschger, and J. Schwander. 1988. Methane concentration in the glacial atmosphere was only half that of the preindustrial Holocene. *Nature* 332:812–14.

Siple Station

BACKGROUND

Principal investigators

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Sponsoring agencies

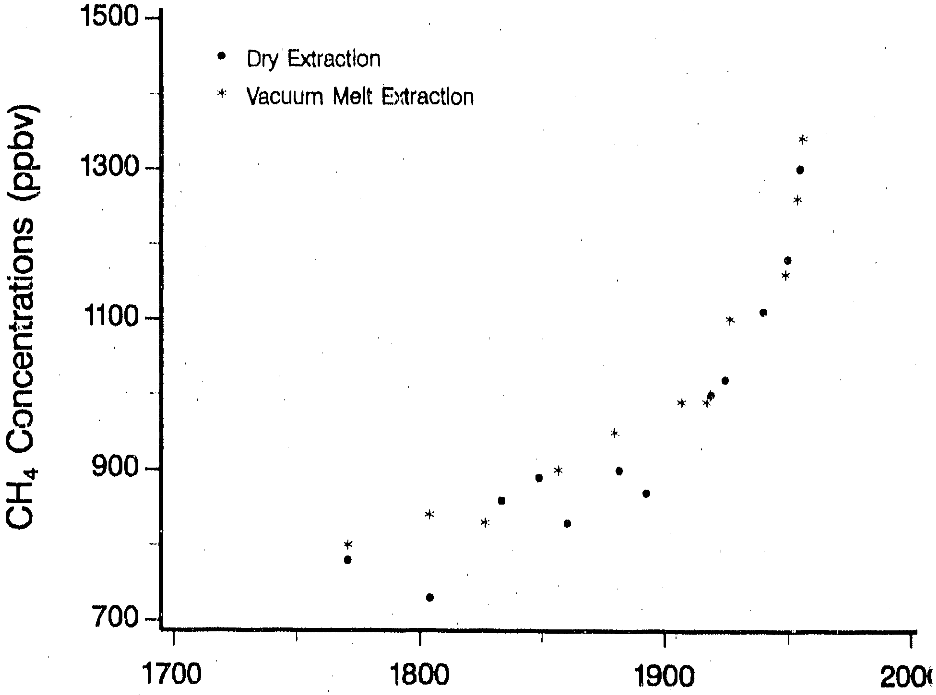
Swiss National Science Foundation
University of Bern

Period of record – 1771–1956.

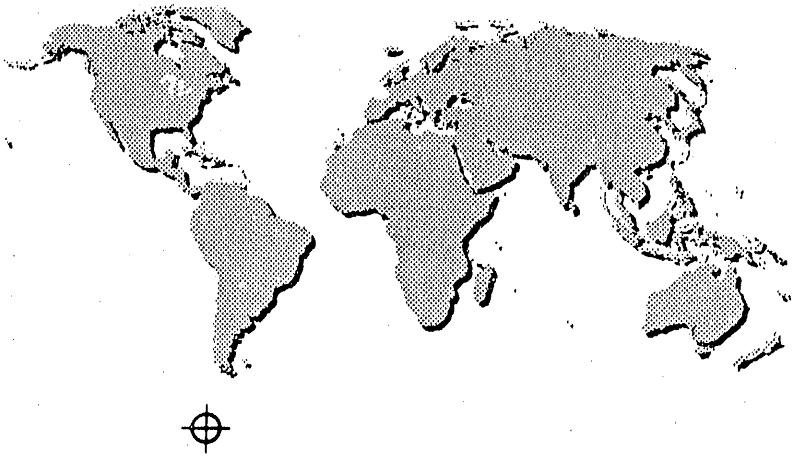
Method – Air is extracted from the bubbles of ice samples by a melt extraction and dry extraction, technique. For the vacuum melt extraction, ~400-g ice samples containing about 10 vol % of air are melted in an evacuated glass container. The escaping gas is collected continuously during the melting process with a Toepler pump in a small glass bulb. For the dry extraction method, ~600-g ice samples are ground in an evacuated steel container with a milling cutter. The air escaping from the mechanically opened bubbles is collected by condensation at 14°K. The extracted gas from both techniques is measured with the flame ionization detector of a gas chromatograph. For details on the gas extraction and ice core dating, see Stauffer et al. (1985) and Lorius et al. (1985), respectively.

Calibration gases used – Two mixtures of N_2, O_2, Ar, and CO_2 with a CH_4 concentration of 980 ± 30 ppbv or 3120 ± 90 ppbv.

Data availability – These data are available from CDIAC and have been published in Stauffer et al. (1985).



Concentrations of atmospheric CH_4 from ice cores.



Siple Station
Antarctica
75° 55′S, 83° 55′W

Atmospheric CH_4 from Ice Cores

TRENDS

The ice core from Siple Station was drilled in the Antarctic summer of 1983–1984 to a depth of 200 m by the Polar Ice Coring Office (Nebraska) and the Physics Institute at the University of Bern. Schwander and Stauffer (1984) reported a difference of 95 years between the mean age of the ice and the air trapped in its bubbles. Samples from Siple Station in western Antarctica are well suited for investigating changes of atmospheric composition in the recent past, having an excellent time resolution because of the high rates of accumulation (Stauffer et al. 1985).

Measurements of the CH_4 concentrations in air extracted by two different methods from ice samples from Siple Station allow the reconstruction of the history of the increase of atmospheric CH_4 during the past 200 years. Determinations of CH_4 concentrations on the 12 ice samples measured by dry extraction show that atmospheric CH_4 concentrations increased from 0.78 ± 0.09 ppmv in 1771 to 1.30 ± 0.07 ppmv in 1955. Determinations on the 11 ice samples measured by vacuum melt extraction show increases from 0.80 ± 0.06 ppmv in 1771 to 1.34 ± 0.08 ppmv in 1956.

Atmospheric Methane from Ice Cores

Depth (m)	Gas age (yr A.D.)	CH_4 concentration in extracted air (ppmv)*
	Dry extraction	
78.6	1955	1.30 ± 0.07
82.6	1950	1.18 ± 0.07
88.0	1940	1.11 ± 0.07
96.4	1925	1.02 ± 0.06
100	1919	1.00 ± 0.07
113	1893	0.87 ± 0.07
119	1882	0.90 ± 0.08
130	1861	0.83 ± 0.07
136	1849	0.89 ± 0.08
144	1834	0.86 ± 0.07
160	1804	0.73 ± 0.08
177	1771	0.78 ± 0.09
	Vacuum melt extraction	
78.0	1956	1.34 ± 0.08
80.0	1954	1.26 ± 0.08
83.0	1949	1.16 ± 0.08
96.0	1927	1.10 ± 0.07
101	1917	0.99 ± 0.06
107	1907	0.99 ± 0.06
120	1880	0.95 ± 0.06
132	1857	0.90 ± 0.06
147	1827	0.83 ± 0.06
160	1804	0.84 ± 0.06
177	1771	0.80 ± 0.06

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*The error limits are the estimated precisions of the measurements.

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Barnola, J.M., D. Raynaud, A. Neftel, and H. Oeschger. 1983. Comparison of CO_2 measurements by two laboratories on air bubbles in polar ice. *Nature* 303:410–13.

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Lorius, C., J. Jouzel, C. Ritz, L. Merlivat, N.I. Barkov, Y.S. Korotkevich, and V.M. Kotlyakov. 1985. A 150,000-year climatic record from Antarctic ice. *Nature* 316:591–96.

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Schwander, J., and B. Stauffer. 1984. Age difference between polar ice and the air trapped in its bubbles. *Nature* 311:45–47.

Stauffer, B., G. Fischer, A. Neftel, and H. Oeschger. 1985. Increase of atmospheric methane recorded in Antarctic ice core. *Science* 229:1386–88.

Stauffer, B., E. Lochbronner, H. Oeschger, and J. Schwander. 1988. Methane concentration in the glacial atmosphere was only half that of the preindustrial Holocene. *Nature* 332:812–14.

BACKGROUND

Principal investigators
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Oregon Institute of Science & Technology
Beaverton, Oregon 97006, U.S.A.

Sponsoring agencies
National Science Foundation
Department of Energy
Biospherics Research Corporation
Andarz Company

Period of record – 1980–1988.

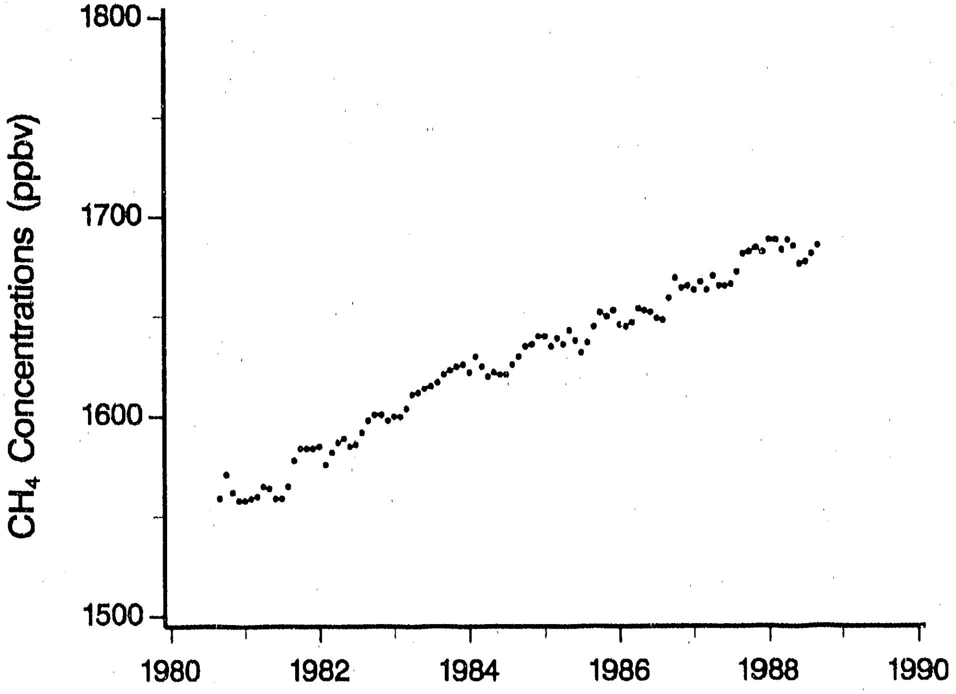
Methods – Flask samples collected in triplicate every week at Barrow, Alaska; Cape Meares, Oregon; Cape Kumukahi and Mauna Loa, Hawaii; Samoa; Cape Grim, Tasmania; and in Antarctica (mostly at the South Pole) were used to calculate average monthly concentrations at each site. Sometimes there were insufficient data to obtain a monthly average at one site or another. These gaps were filled by interpolation. Global averages were then formed as in the following equation:

$$C = \frac{1}{2} \int_{-90}^{90} C(\Phi) \cos(\Phi)\, d\Phi ,$$

where Φ is the latitude. Data from some sites required special treatment before inclusion in the global average. For further details, see Khalil and Rasmussen (1990).

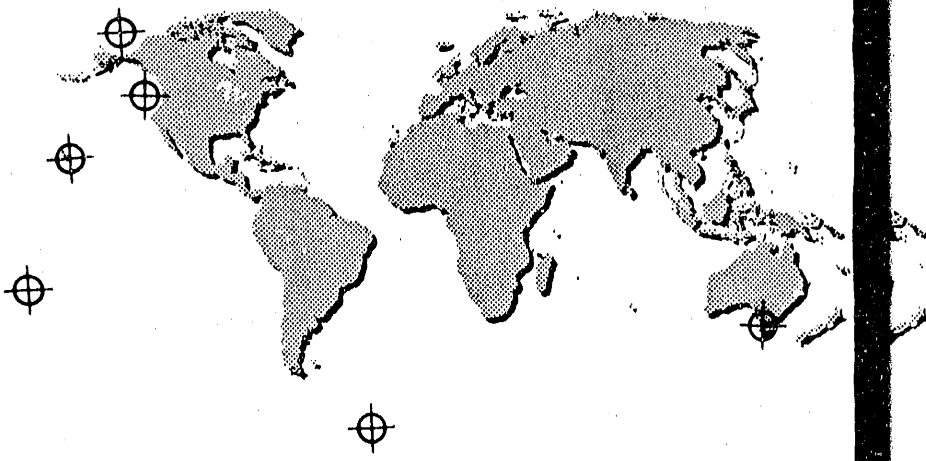
Calibration gases used – All atmospheric measurements of CH_4 from the seven sites were referenced against a single primary calibration standard.

Data availability – These data are available from CDIAC, the principal investigators, and have been published in Khalil and Rasmussen (1990).



Monthly concentrations of atmospheric CH_4.

Barrow
Alaska, U.S.A.
Cape Grim
Tasmania, Australia
Cape Kumukahi
Hawaii, U.S.A.
Cape Matatula
American Samoa
Cape Meares
Oregon, U.S.A.
Mauna Loa
Hawaii, U.S.A.
South Pole
Antarctica



TRENDS

According to Khalil and Rasmussen (1990), “this record shows that methane concentration increased at an average rate of 16.6 ± 0.4 ppbv/year or ~1.02 ± 0.02%/year over 8 years. This trend has not been constant according to our record but has varied between 12 ± 2 and 23 ± 2 ppbv/year over 2-year periods after seasonal variations are removed.”

Earlier work by Rasmussen and Khalil (1981) and Khalil and Rasmussen (1983) reported annual global increases of nearly 2% and 1.3% per year, respectively. Blake and Rowland (1988) showed trends of 1% per year, and Steele et al. (1987) reported even slower increases, slightly less than 0.8% per year.

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1980									1559	1571	1562	1558
1981	1558	1559	1560	1565	1564	1559	1559	1565	1578	1584	1584	1584
1982	1585	1576	1582	1587	1589	1585	1586	1592	1598	1601	1601	1598
1983	1600	1600	1604	1611	1612	1614	1615	1617	1621	1623	1625	1626
1984	1622	1630	1625	1620	1622	1621	1621	1626	1630	1635	1636	1640
1985	1640	1635	1639	1636	1643	1638	1632	1637	1645	1652	1650	1653
1986	1646	1645	1647	1654	1653	1652	1649	1648	1659	1669	1664	1665
1987	1663	1667	1663	1670	1665	1665	1666	1672	1681	1682	1684	1682
1988	1688	1688	1683	1688	1685	1676	1677	1681	1685			

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*Methane concentrations expressed in parts per billion by volume (ppbv).

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Rasmussen, R.A. and M.A.K. Khalil. 1981. Atmospheric methane (CH_4): trends and seasonal cycles. *Journal of Geophysical Research* 86:9826–32.

Steele, L.P., P.J. Fraser, R.A. Rasmussen, M.A.K. Khalil, T.J. Conway, A.J. Crawford, R.H. Gammon, K.A. Masarie, and K.W. Thoning. 1987. The global distribution of methane in the troposphere. *Journal of Atmospheric Chemistry* 5:125–71.

Amsterdam Island

BACKGROUND

Principal investigators

*L. Paul Steele** *Russell C. Martin*
Pieter P. Tans *Ken A. Masarie*
Patricia M. Lang
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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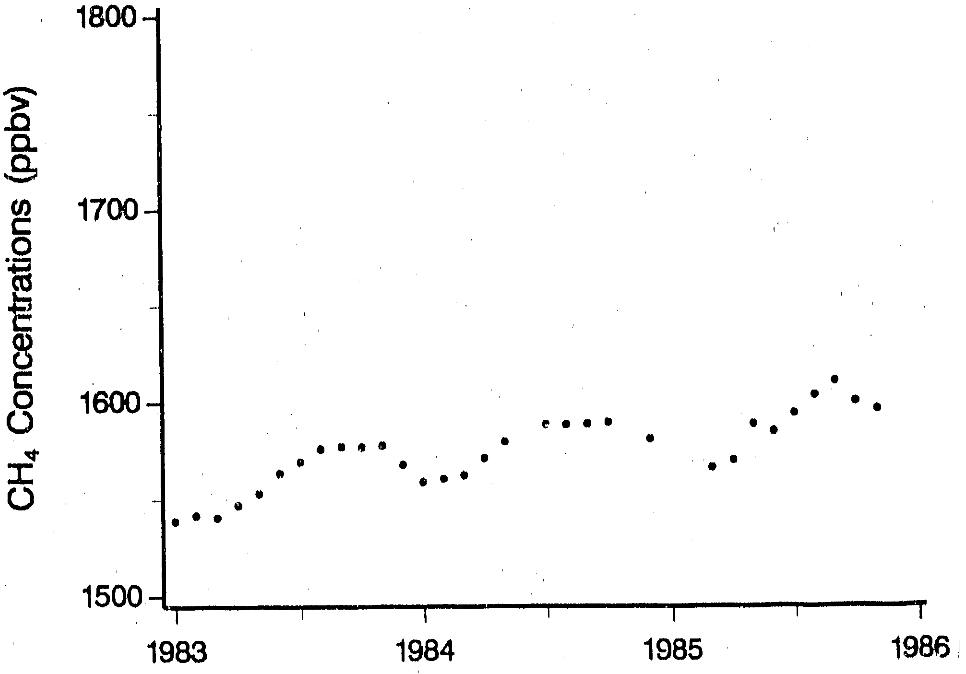
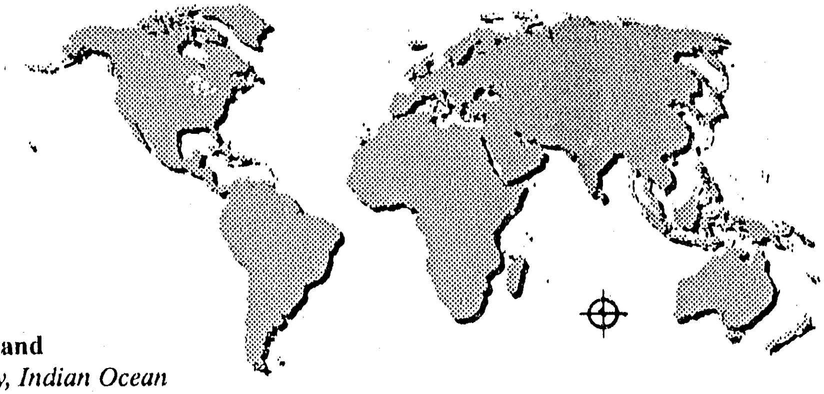
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Amsterdam Island
French Territory, Indian Ocean
Island seashore
37° 57′S, 77° 32′E
150 m above MSL

TREND

The sampling site on Amsterdam Island is operated in cooperation with the French Centre des Faibles Radioactivities. The annual concentration of CH_4 at Amsterdam Island rose from 1561.1 ppbv in 1983 to 1590.5 ppbv in 1985. Steele et al. (1987) found that even with only 2 years of data, a pattern of unmistakable growth in CH_4 concentration was seen at four sites (not including Amsterdam Island) in the Southern Hemisphere. The seasonal pattern seen at Amsterdam Island is typical for the Southern Hemisphere and repeats from year to year.

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983	1539.3	1542.1	1540.9	1547.4	1553.4	1563.9	1569.6	1576.3	1577.4	1577.2	1578.0	1568.1	1561.1
1984	1559.2	1560.7	1562.6	1571.3	1579.7		1588.7	1588.7	1588.9	1589.8		1581.0	1586.0
1985			1566.3	1570.1	1588.8	1584.8	1594.1	1603.6	1610.7	1600.1	1596.2		1590.5

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

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Amundsen Scott (South Pole)

BACKGROUND

Principal investigators

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Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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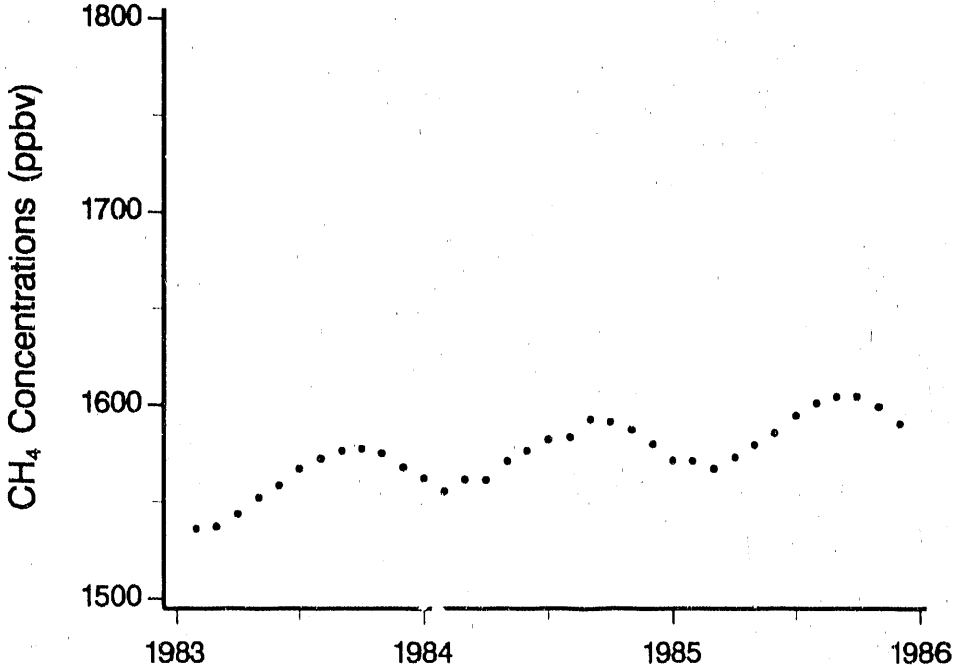
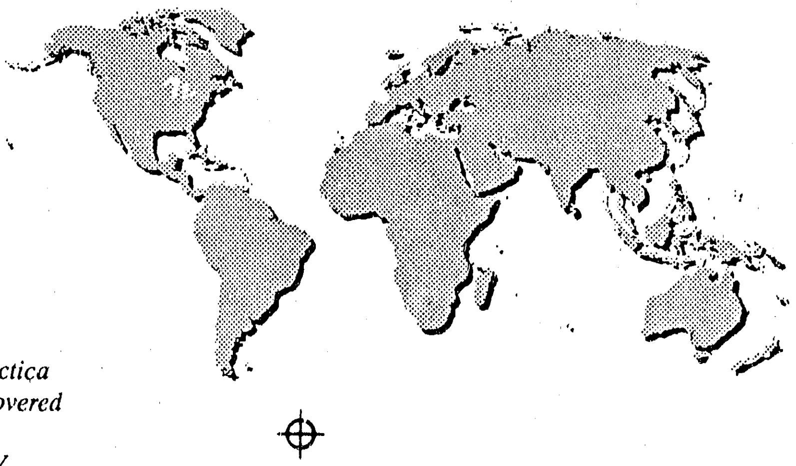
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Amundsen Scott
South Pole, Antarctica
Ice and snow covered plateau
89° 59′ S, 24° 48′ W
2810 m above MSL

TREND

The average annual CH_4 concentration at the South Pole increased from 1560.3 ppbv in 1983 to 1586.7 ppbv in 1985. Steele et al. (1987) reported an average growth rate of 23.1 ppbv per year at the South Pole on the basis of a 12-month running means fitted to a quadratic function. The NOAA/CMDL CH_4 data record from Amundsen Scott is remarkably similar to the CH_4 data records from the other southernmost sites in the CMDL network, except for Kaitorete Spit. Steele et al. (1987) reported that within the limits of the measurement precision, both the absolute concentration and the phase and amplitude of the seasonal cycle are indistinguishable at these Southern Hemisphere sites.

Amundsen Scott (South Pole)

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983		1536.1	1537.1	1543.7	1552.1	1558.4	1566.9	1572.3	1576.4	1577.4	1575.1	1567.8	1560.3
1984	1562.1	1555.4	1561.5	1561.4	1571.1	1576.5	1582.1	1583.5	1592.7	1591.2	1587.2	1579.9	1575.4
1985	1571.3	1571.1	1567.0	1572.9	1579.3	1585.4	1594.4	1600.9	1604.1	1604.3	1599.0	1590.2	1586.7

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

Fraser, P.J., M.A.K. Khalil, R.A. Rasmussen, and A.J. Crawford. 1981. Trends of atmospheric methane in the Southern Hemisphere. *Geophysical Research Letters* 8:1063–66.

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Ascension Island

BACKGROUND

Principal investigators

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Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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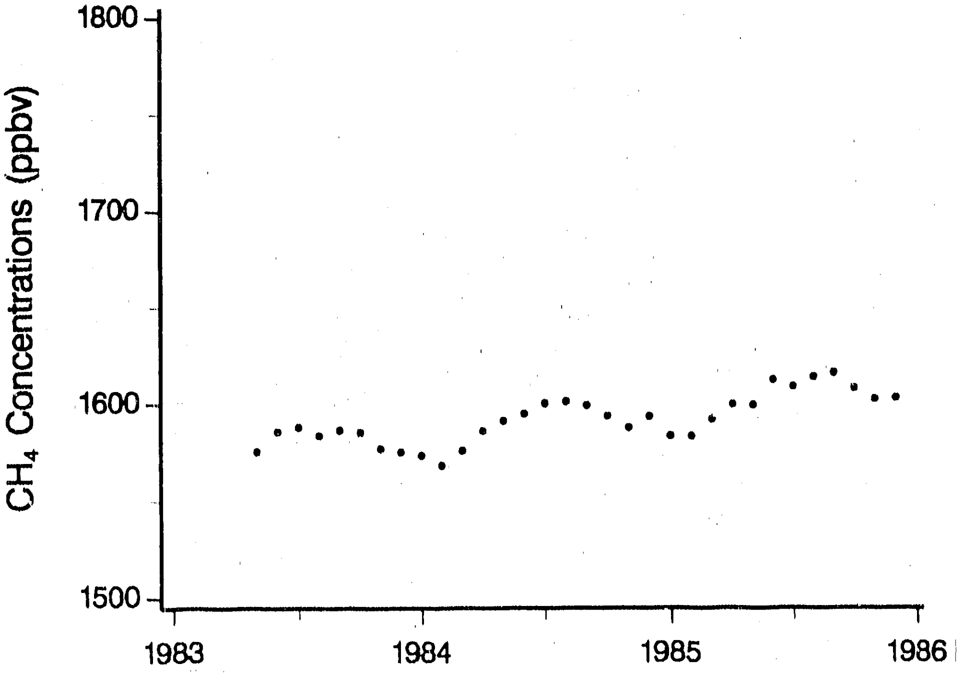
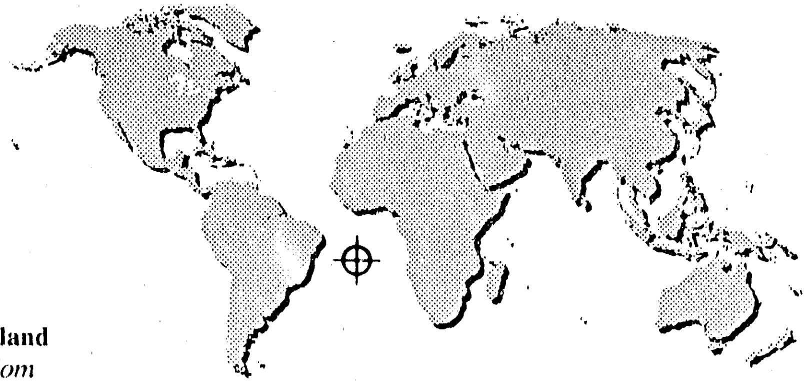
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Ascension Island
United Kingdom
Island seashore
7° 55′S, 14° 25′W
54 m above MSL

TREND

The sampling site on Ascension Island is operated in cooperation with the U.S. Air Force and Pan American World Airways.

The average annual CH_4 concentration at Ascension Island rose from 1582.3 ppbv in 1983 to 1601.9 ppbv in 1985. Steele et al. (1987) calculated an average growth rate of 14.1 ppbv for Ascension Island by fitting a linear regression to 12-month running means. With respect to latitude, this site is located between the sites at American Samoa and the Seychelles. According to Steele et al. (1987), the CH_4 concentration data from Ascension Island show a clear seasonal cycle, but the phase of the cycle is different from that observed at sites in mid and polar latitudes of the Southern Hemisphere. Steele et al. (1987) also reported that this site does not appear to be influenced during any season by air originating north of the Intertropical Convergence Zone.

Ascension Island

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983					1575.6	1586.0	1588.2	1584.0	1586.7	1585.6	1577.2	1575.4	1582.3
1984	1573.6	1568.4	15[illegible]6.0	1586.2	1591.5	1595.0	1600.5	1601.5	1599.3	1593.9	1587.8	1593.6	1588.9
1985	1583.5	1583.4	1592.1	1599.6	1599.4	1612.4	1608.9	1613.9	1616.0	1607.9	1602.3	1603.0	1601.9

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

Fraser, P.J., M.A.K. Khalil, R.A. Rasmussen, and A.J. Crawford. 1981. Trends of atmospheric methane in the Southern Hemisphere. *Geophysical Research Letters* 8:1063–66.

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Cape Grim

BACKGROUND

Principal investigators

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Pieter P. Tans　*Ken A. Masarie*
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Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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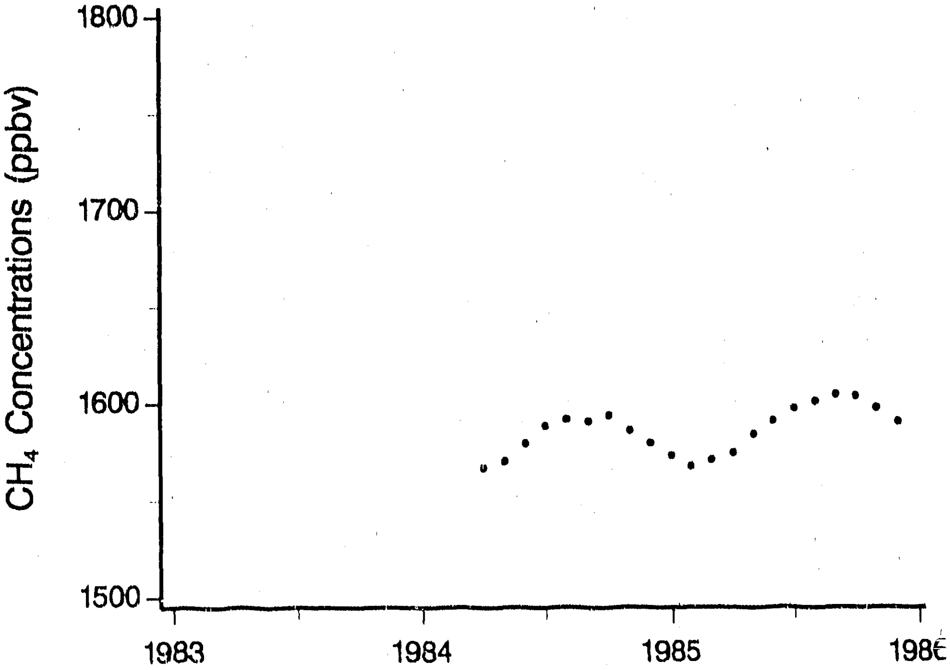
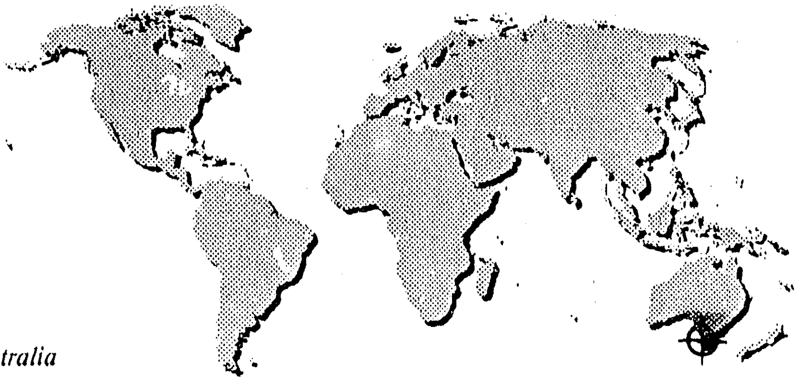
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Cape Grim
Tasmania, Australia
Promontory seashore
40° 41′S, 144° 41′E
94 m above MSL

TREND

The sampling site at Cape Grim, Tasmania, is operated in cooperation with the Commonwealth Scientific and Industrial Research Organization (CSIRO), which has been making CH_4 measurements at Cape Grim since 1978. Fraser et al. (1986) reported an average growth rate of 18.2 ppbv per year at Cape Grim for the 7-year period 1978–1984. NOAA/CMDL has been making CH_4 measurements at Cape Grim since 1984. The NOAA/CMDL data show that the average annual concentration at Cape Grim rose from 1583.1 ppbv in 1984 to 1588.1 in 1985.

The CH_4 record from Cape Grim is comparable to those from other Southern Hemisphere sites. Fraser et al. (1986) found no significant difference in either the seasonal cycle or the long-term growth in concentration for CSIRO CH_4 measurements taken from flask samples collected at Cape Grim and Mawson, Antarctica, for the period 1980–1984. Steele et al. (1987) found that the NOAA/CMDL CH_4 data record from Cape Grim is remarkably similar to four of the five southernmost GMCC sites. The exception to this finding is the monitoring site at Kaitorete Spit, New Zealand.

1986

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1984				1566.9	1570.3	1579.5	1588.8	1591.8	1591.1	1594.0	1585.9	1579.7	1583.1
1985	1573.2	1567.5	1570.9	1574.6	1584.2	1591.1	1597.4	1601.3	1604.4	1603.8	1597.6	1590.6	1588.1

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

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Cape Kumukahi

BACKGROUND

Principal investigators

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Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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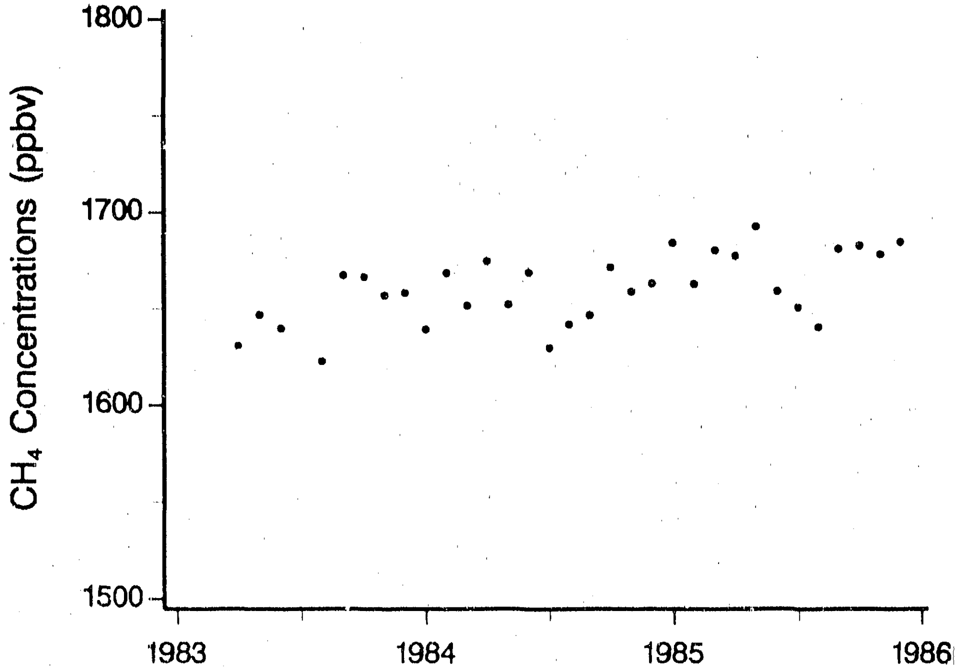
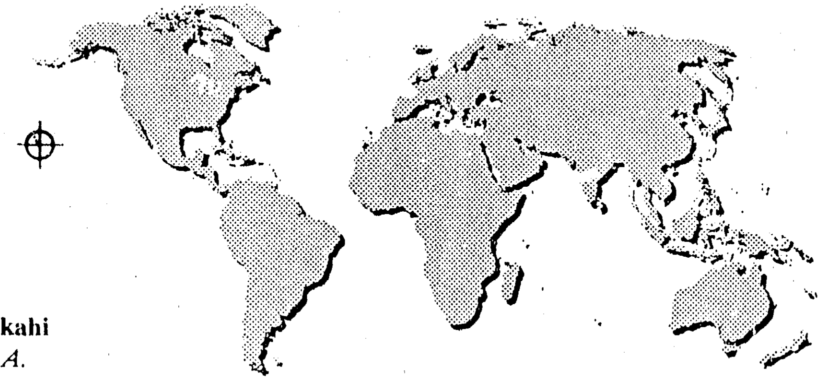
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Cape Kumukahi
Hawaii, U.S.A.
Island seashore
19° 31′N, 154° 49′W
3 m above MSL

TREND

The average annual CH_4 concentration from Cape Kumukahi, Hawaii, rose from 1648.6 ppbv in 1983 to 1672.8 ppbv in 1985. Steele et al. (1987) fitted a linear regression to the 12-month running means from Cape Kumukahi and calculated an average annual growth rate of 7.9 ppbv. Steele et al. (1987) also compared the CH_4 data from Cape Kumukahi with those from Mauna Loa and found a significant vertical gradient in CH_4 concentration, with the long-term average concentrations from Mauna Loa being lower than those at Cape Kumukahi. Steele et al. (1987) found that (1) both sites exhibited a major seasonal minimum in the northern summer of 1984 (2) that the fitted cubic spline functions for both sites show evidence that two minimums and two maximums occur each year at times consistent with those reported by Khalil and Rasmussen (1983).

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983				1630.9	1647.0	1640.0		1623.0	1667.5	1666.6	1657.2	1658.4	1648.6
1984	1639.5	1668.7	1651.9	1674.9	1652.3	1669.0	1630.0	1642.0	1646.7	1671.5	1658.8	1663.1	1655.7
1985	1684.2	1662.9	1680.3	1677.3	1692.5	1658.9	1650.7	1640.4	1680.9	1682.5	1678.1	1684.5	1672.8

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

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Cape Meares

BACKGROUND

Principal investigators

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National Oceanic and Atmospheric Administration
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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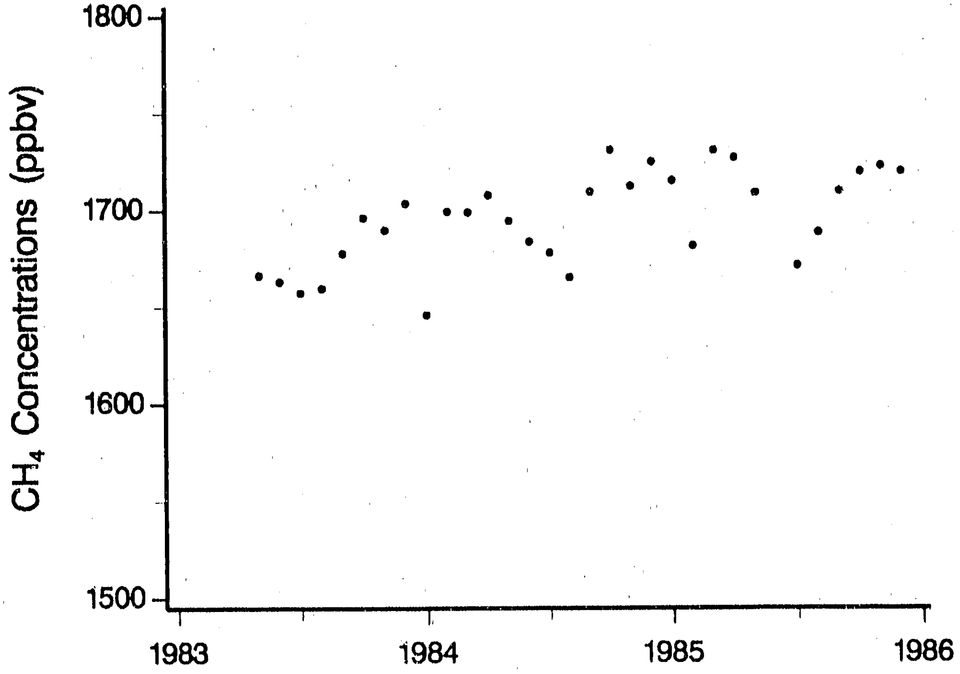
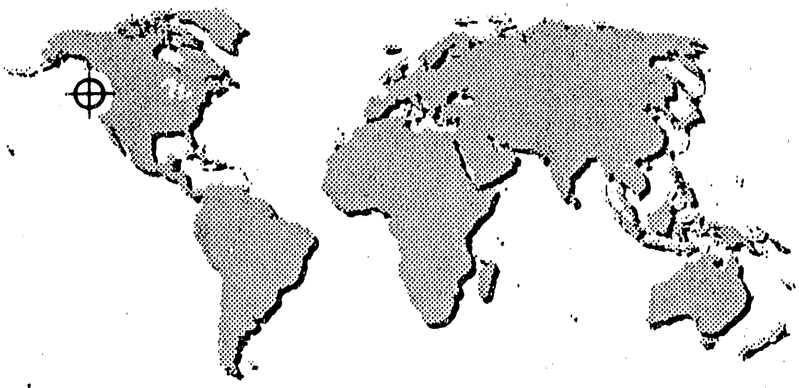
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Cape Meares
Oregon, U.S.A.
Promontory seashore
45° 00′N, 124° 00′W
30 m above MSL

TREND

The sampling site at Cape Meares, Oregon, is operated in cooperation with the Oregon Graduate Institute of Science and Technology. The annual average concentration of CH_4 at Cape Meares rose from 1676.7 ppbv in 1983 to 1708.3 ppbv in 1985. Steele et al. (1987) reported an annual average growth rate of 24.8 ppbv for Cape Meares, which was calculated by fitting a linear regression to 12-month running mean values. Khalil and Rasmussen (1983), on the basis of in situ measurements of CH_4 over a 3-year period at Cape Meares, found that 2 minimums and 2 maximums may occur each year, with the major minimum in the northern summer and the maximum concentrations in spring and fall. Steele et al. (1987) reported that all five of the northernmost CMDL stations, including Cape Meares, exhibited major seasonal minimums during the northern summer of both 1983 and 1984.

Cape Meares

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983					1666.4	1663.2	1657.4	1659.7	1677.7	1696.1	1689.7	1703.5	1676.7
1984	1646.0	1699.3	1698.9	1707.8	1694.5	1683.7	1678.0	1665.3	1709.3	1730.9	1712.3	1724.8	1695.9
1985	1715.1	1681.4	1730.5	1726.7	1708.5		1671.0	1688.1	1709.3	1719.3	1722.3	1719.5	1708.3

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

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Christmas Island

BACKGROUND

Principal investigators

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Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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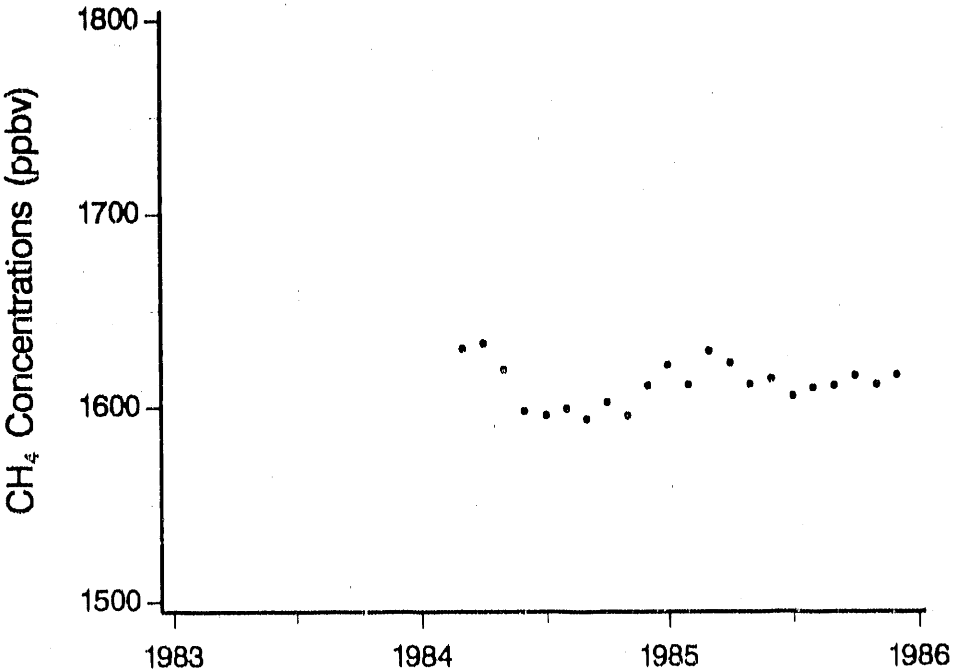
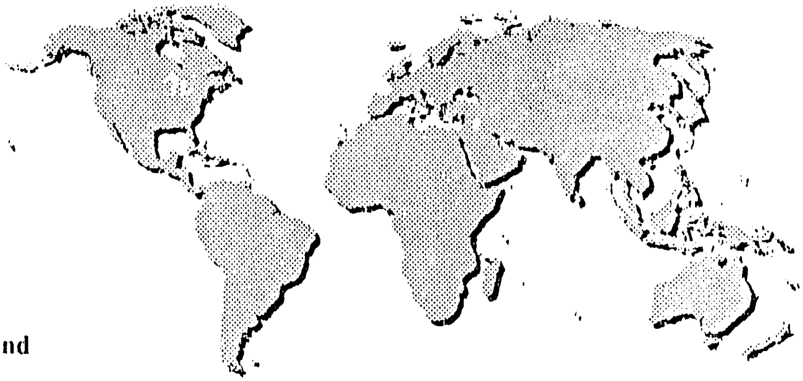
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Christmas Island
Kiribati
Island seashore
2° 00′N, 157° 19′W
3 m above MSL

TREND

The sampling site at Christmas Island is operated in cooperation with Scripps Institution of Oceanography. The annual average concentration of CH_4 at Christmas Island rose from 1607.9 ppbv in 1984 to 1615.2 ppbv in 1985. Because of the climatology of the convergence zone of surface winds in the central Pacific Ocean, atmospheric CH_4 concentrations from Christmas Island should be typical of those found in southern tropical latitudes. Steele et al. (1987) reported that the CH_4 concentrations from Christmas Island during the austral winter and spring of 1984 were strongly consistent with measurements made at similar times at several locations in the Southern Hemisphere. The elevated concentrations during March and April 1984 were almost certainly caused by the influence of air from north of the Intertropical Convergence Zone, and the elevated concentrations in the first few months of 1985 may be caused by the southward movement of the convergence zone or by an irregular intrusion of northern air (Steele et al. 1987).

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1984			1630.3	1633.0	1619.4	1598.1	1595.9	1599.3	1594.0	1602.6	1595.7	1611.1	1607.9
1985	1621.6	1611.5	1628.8	1622.7	1611.8	1614.5	1605.7	1609.9	1611.1	1616.2	1611.6	1616.6	1615.2

---

*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

Fraser, P.J., M.A.K. Khalil, R.A. Rasmussen, and A.J. Crawford. 1981. Trends of atmospheric methane in the Southern Hemisphere. *Geophysical Research Letters* 8:1063–66.

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Cold Bay

BACKGROUND

Principal investigators

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Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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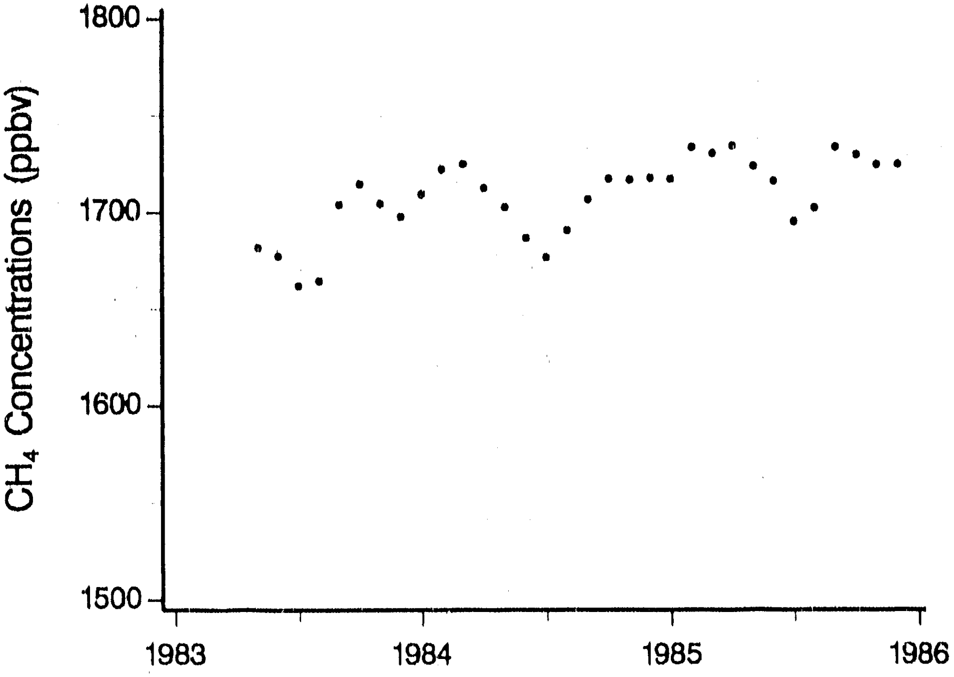
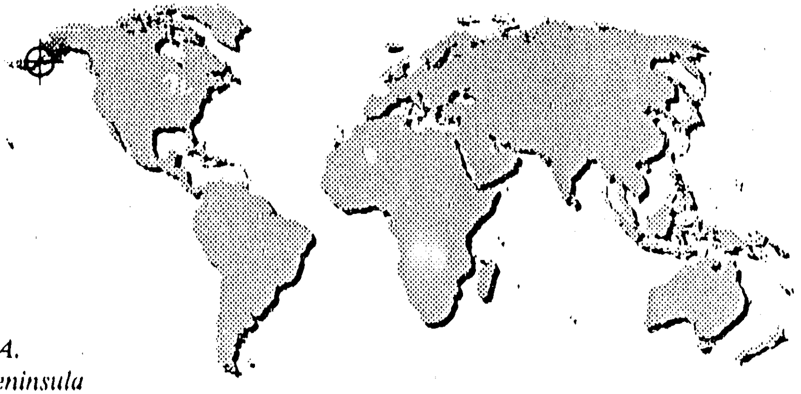
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Cold Bay
Alaska, U.S.A.
Treeless peninsula
55° 12′N, 162° 43′W
25 m above MSL

TREND

The sampling site at Cold Bay, Alaska, is operated in cooperation with the National Weather Service. The average annual CH_4 concentration at Cold Bay rose from 1688.3 ppbv in 1983 to 1721.9 ppbv in 1985. Steele et al. (1987) reported the average annual growth rate for Cold Bay to be 13.0 ppbv. Steele et al. (1987) also found that the CH_4 data from the five northernmost CDML sites, including Cold Bay, exhibited major seasonal minimums during the northern summers of both 1983 and 1984. Secondary minimums were also apparent but not as well defined.

Cold Bay

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983					1681.7	1677.5	1662.0	1664.5	1704.0	1714.7	1704.5	1697.8	1688.3
1984	1709.5	1722.3	1725.0	1712.5	1702.7	1686.6	1676.7	1690.6	1706.5	1717.2	1716.7	1717.7	1707.0
1985	1717.1	1733.4	1730.3	1734.2	1723.5	1715.8	1695.0	1701.9	1733.4	1729.4	1724.4	1724.5	1721.9

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

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Halley Bay

BACKGROUND

Principal investigators

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Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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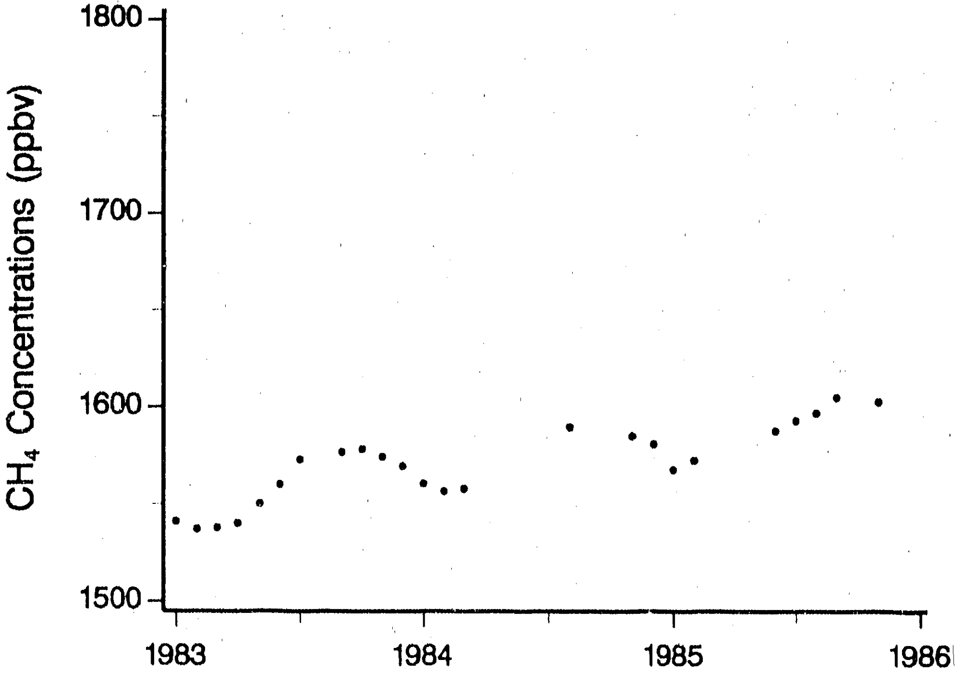
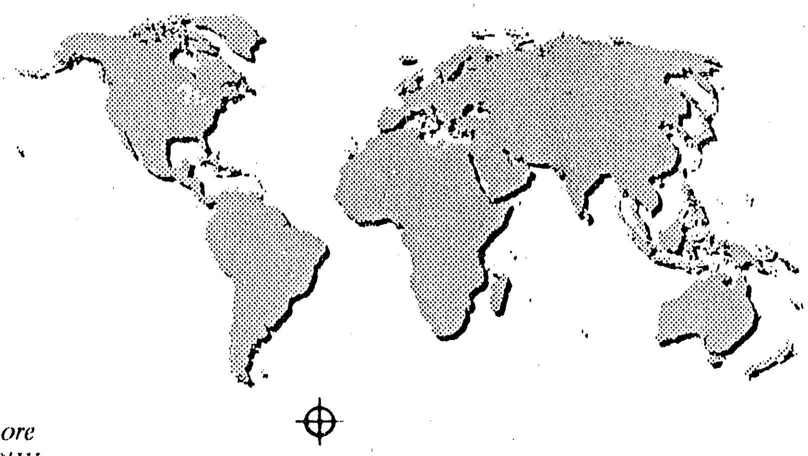
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Halley Bay
Antarctica
Barren seashore
75° 40′S, 25° 30′W
3 m above MSL

TREND

The sampling site at Halley Bay is operated in cooperation with the British Antarctic Survey. The average annual CH_4 concentration at Halley Bay rose from 1558.1 ppbv in 1983 to 1589.3 ppbv in 1985. Steele et al. (1987) reported the CH_4 data from Halley Bay were similar to the data from the other CMDL sites in the Southern Hemisphere, except for Kaitorete Spit, New Zealand. Furthermore, the CH_4 data from Halley Bay exhibit the same phase and amplitude of the seasonal cycle observed at the other Southern Hemisphere sites.

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983	1541.1	1537.2	1537.9	1540.2	1550.2	1560.2	1573.1		1576.8	1578.4	1574.4	1569.6	1558.1
1984	1560.7	1556.7	1558.0					1589.7			1585.0	1580.9	1571.8
1985	1567.7	1572.5				1587.7	1592.9	1596.7	1604.9		1602.6		1589.3

---

*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

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Key Biscayne

BACKGROUND

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Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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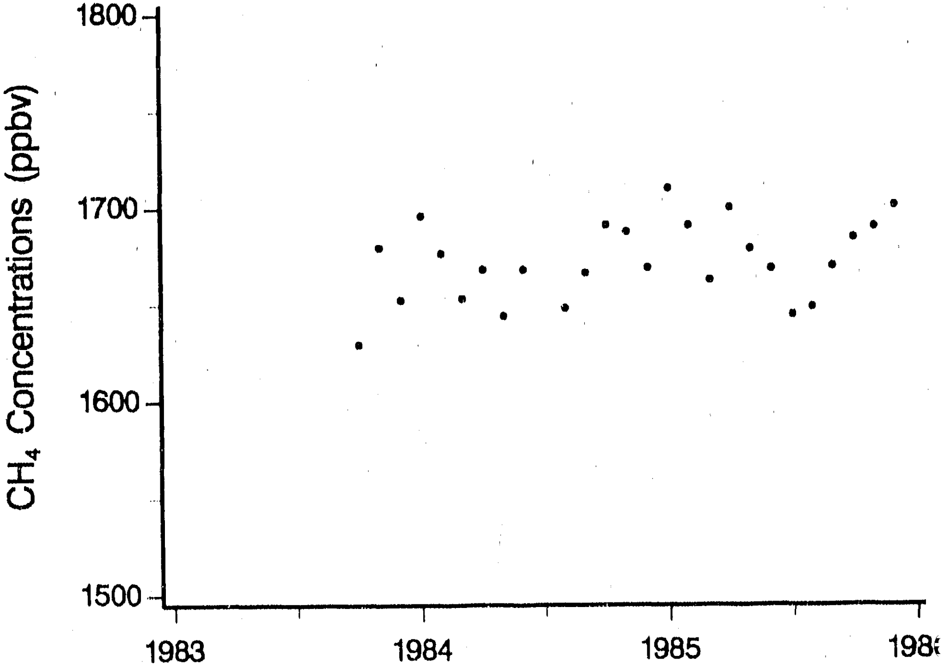
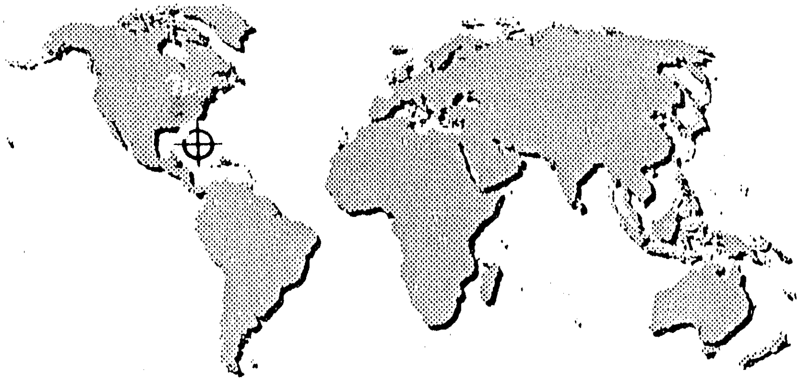
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Key Biscayne
Florida, U.S.A.
Coastal island seashore
25° 40'N, 80° 12'W
3 m above MSL

TREND

The average annual CH_4 concentration at Key Biscayne rose from 1653.9 ppbv in 1983 to 1678.8 ppbv in 1985. Steel et al. (1987) reported that it is difficult to interpret the CH_4 data from Key Biscayne because of changes in sampling frequency, the proximity of the station to urban Miami, and the large degree of scatter shown by the Key Biscayne record. Steele et al. (1987) reported that despite these difficulties, the CH_4 data from Key Biscayne do indicate a seasonal minimum in the northern summer of 1984 and that the annual mean concentration calculated for 1984 fits neatly into the latitudinal gradient with other northern CMDL sites. However, because of these difficulties and questions concerning the suitability of the site for monitoring background measurements, NOAA/CMDL replaced the southern Florida site and began monitoring at Midway Island in 1985. The site at Midway Island is at a comparable latitude (28°N, 177°W) to the Key Biscayne site and is believed to be suitable for obtaining background measurements.

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983										1629.5	1679.7	1652.5	1653.9
1984	1696.0	1676.5	1653.2	1668.0	1644.0	1668.0		1648.0	1666.2	1690.8	1687.3	1668.6	1669.7
1985	1709.8	1690.7	1662.3	1699.6	1678.5	1668.1	1644.3	1648.4	1669.4	1684.0	1689.7	1700.8	1678.8

---

*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

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Kitt Peak

BACKGROUND

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Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

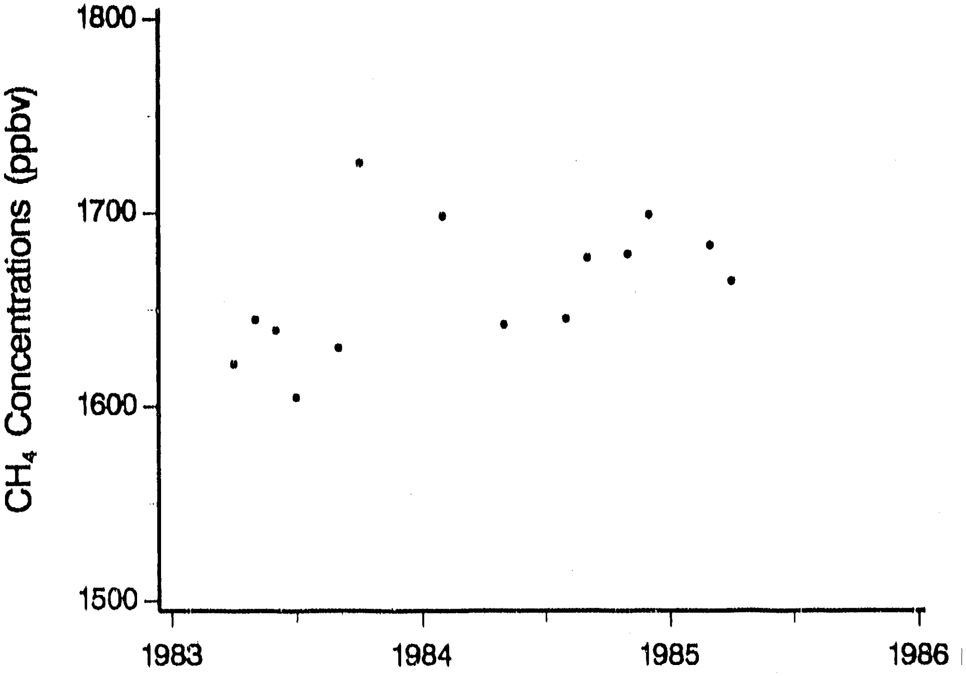
Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

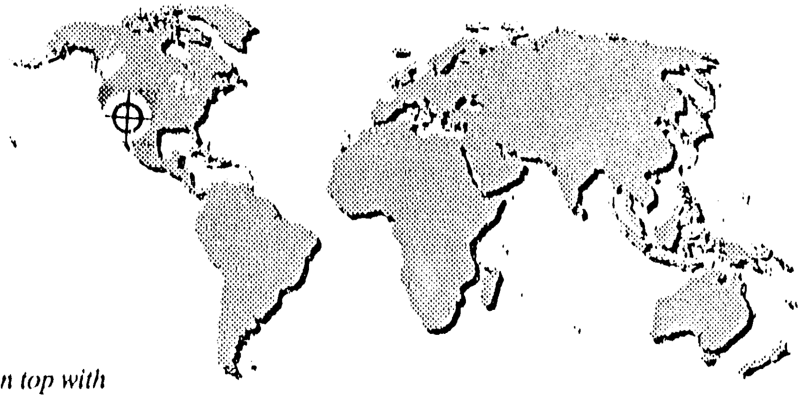
Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

---

*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Kitt Peak,
Arizona, U.S.A.
Arid mountain top with scattered vegetation
32° 00'N, 112° 00'W
2083 m above MSL

TREND

Sampling at Kitt Peak is conducted with the cooperation of the Kitt Peak Observatory. Sampling is done only when a group from Battelle Pacific Northwest Laboratory is making determinations of total column CH_4. Consequently, sampling at Kitt Peak has been sparse in comparison with other sampling at CMDL stations (Steele et al. 1987). Based on a limited number of samples, the average annual CH_4 concentration at Kitt Peak has risen from 1644.6 ppbv in 1983 to 1674.2 ppbv in 1985.

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983				1622.0	1644.9	1639.4	1604.9		1630.5	1726.0			1644.6
1984		1698.5			1642.5			1645.5	1677.0		1678.9	1699.3	1673.6
1985			1683.4	1664.9									1674.2

---

*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

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Mahé Island (Seychelles)

BACKGROUND

Principal investigators

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Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

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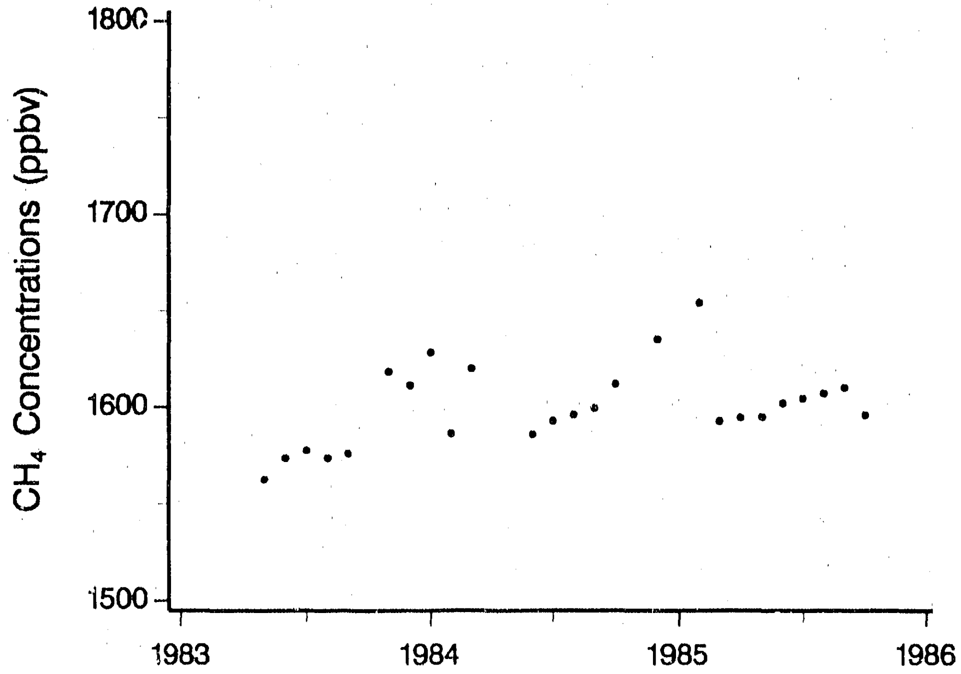
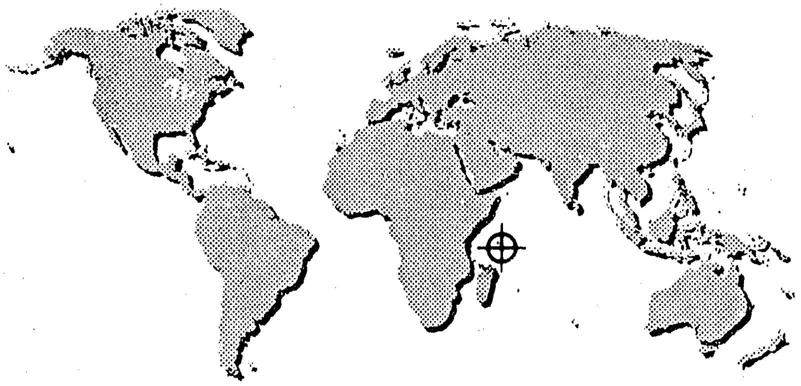
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Mahé Island
Seychelles
Island seashore
4° 40'S, 55° 10'E
3 m above MSL

TREND

The monitoring station at Mahé Island in the Indian Ocean is operated in cooperation with the Physical Science Laboratory of New Mexico State University. The annual average CH_4 concentration at Mahe Island increased from 1584.9 ppbv in 1983 to 1606.0 ppbv in 1985. Steele et al. (1987) also reported that the NOAA/CMDL CH_4 and CO_2 records from the Seychelles show parallel seasonality.

The Seychelles and the corresponding CH_4 measurements are influenced by monsoons and the seasonal migration of the surface wind convergence zone. Steele et al. (1987) reported that during the austral winter this convergence zone is normally found to the north of Mahé Island, bringing southeast monsoon winds and typically Southern Hemisphere CH_4 concentrations to the Mahé Island site. During the austral summer, however, the convergence zone has migrated far to the south of the Seychelles, bringing the site under the predominant influence of the northwest monsoon winds and higher CH_4 concentrations (Steele et al. 1987).

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983					1562.7	1573.8	1577.7	1573.8	1576.1		1618.5	1611.4	1584.9
1984	1628.4	1586.5	1620.0			1586.0	1593.0	1596.1	1599.4	1611.9		1635.1	1606.3
1985		1653.9	1592.6	1594.4	1594.8	1601.8	1604.3	1606.9	1609.9	1595.8			1606.0

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

Fraser, P.J., M.A.K. Khalil, R.A. Rasmussen, and A.J. Crawford. 1981. Trends of atmospheric methane in the Southern Hemisphere. *Geophysical Research Letters* 8:1063–66.

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Khalil, M.A.K., and R.A. Rasmussen. 1990. Atmospheric methane: recent global trends. *Environmental Science and Technology* 24:549–53.

Komhyr, W.D., R.H. Gammon, T.B. Harris, L.S. Waterman, T.J. Conway, W.R. Taylor, and K.W. Thoning. 1985. Global atmospheric CO_2 distributions and variations from 1968–82 NOAA/GMCC CO_2 flask sample data. *Journal of Geophysical Research* 90:5567–96.

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Mariana Islands (Guam)

BACKGROUND

Principal investigators

*L. Paul Steele** *Russell C. Martin*
Pieter P. Tans *Ken A. Masarie*
Patricia M. Lang
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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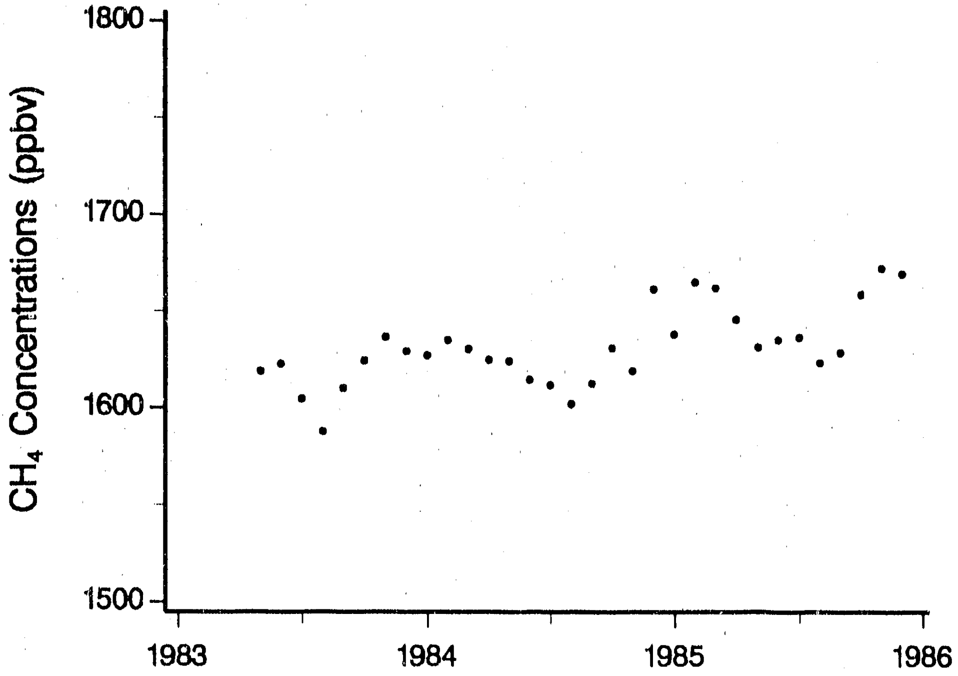
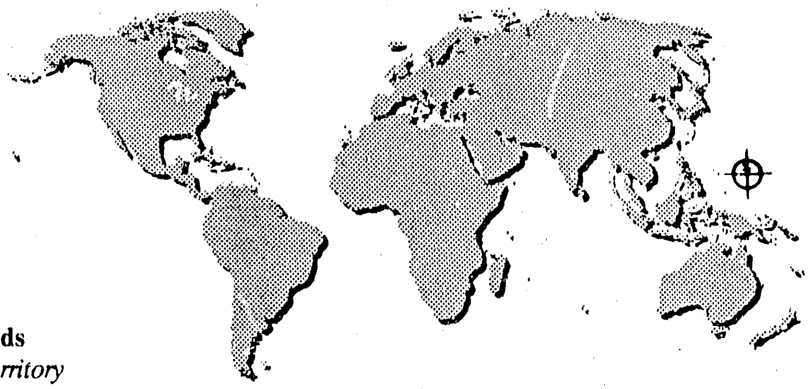
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Mariana Islands
Guam, U.S. Territory
Island seashore
13° 26′N, 144° 47′E
2 m above MSL

TREND

The sampling site at the Mariana Islands is operated in cooperation with the University of Guam. Annual atmospheric CH_4 concentrations at the Guam site rose from 1616.8 ppbv in 1983 to 1646.9 ppbv in 1985. Steele et al. (1987) fitted a linear regression to the 12-month running means from the Mariana Islands site and calculated an annual average growth rate of 11.4 ppbv. Steele et al. (1987) also found a pronounced minimum in the methane concentrations for Guam in the late northern summer of both 1983 and 1984 but found no evidence of a secondary minimum in either year.

Mariana Islands (Guam)

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983					1618.9	1622.8	1604.7	1587.8	1610.2	1624.3	1636.5	1629.2	1616.8
1984	1627.1	1635.0	1630.4	1624.8	1624.1	1614.5	1611.7	1601.9	1612.5	1630.9	1618.9	1661.1	1624.4
1985	1637.9	1664.7	1661.7	1645.5	1631.1	1634.9	1636.2	1623.0	1628.4	1658.2	1671.8	1668.9	1646.9

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

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Matatula Point (American Samoa)

BACKGROUND

Principal investigators

*L. Paul Steele** *Russell C. Martin*
Pieter P. Tans *Ken A. Masarie*
Patricia M. Lang
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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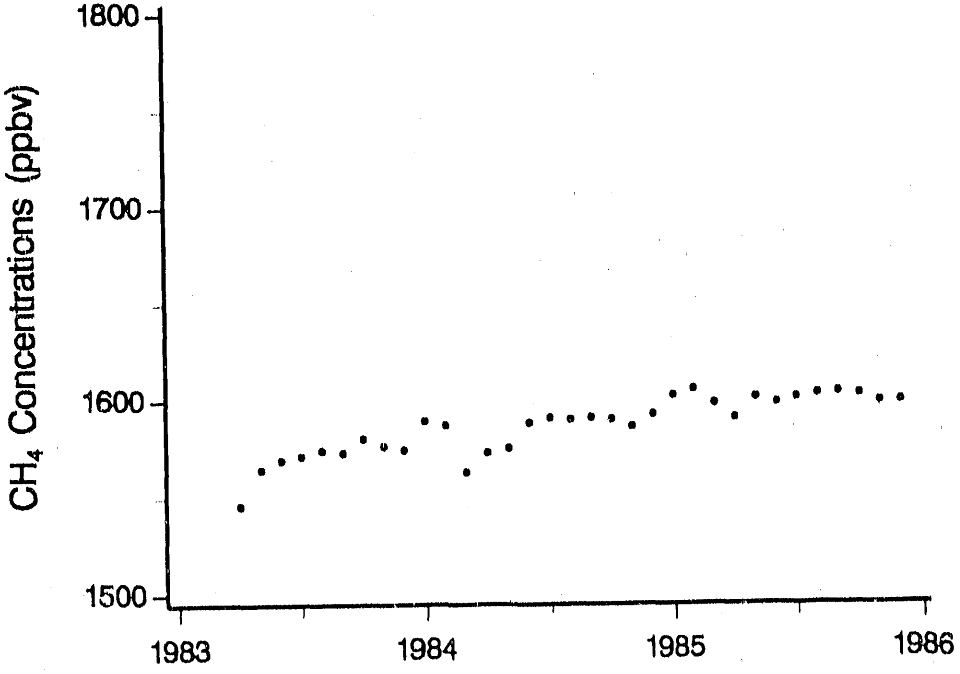
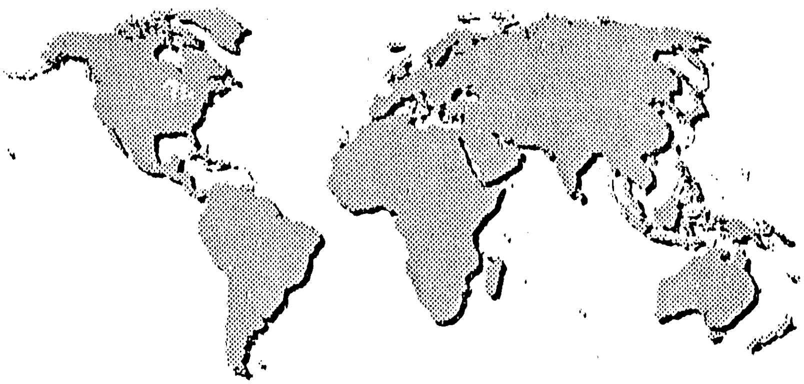
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Matatula Point
American Samoa, U.S. Territory
Island rocky promontory
14° 15'S, 170° 34'W
42 m above MSL

TREND

The average annual CH_4 concentration from American Samoa has increased from 1570.1 ppbv in 1983 to 1600.2 ppbv in 1985. Steele et al. (1987) reported that the CH_4 concentrations from American Samoa showed a long-term increase in CH_4 but no apparent seasonal variation. Steele et al. (1987), using 12-month running means (to remove seasonal variations) fitted to a linear regression, calculated the average growth rate for American Samoa to be 14.0 ppbv per year. Halter et al. (1988) found compelling evidence to support the idea that American Samoa is influenced by significant intrusions of air from the Northern Hemisphere and that these intrusions occur more frequently during the austral summer and autumn. Steele et al. (1987) suggested that since CH_4 concentrations north of the Intertropical Convergence Zone (ITCZ) are always higher than those in the Southern Hemisphere, intrusions of air reaching American Samoa from north of the ITCZ will always have the effect of increasing the CH_4 concentrations observed at American Samoa. The absence of any clear seasonal variation in concentration at American Samoa is probably due to the opposing effects of seasonal transport of CH_4-rich air from north of the ITCZ during those times when the seasonal minimum in CH_4 concentration normally occurs in the Southern Hemisphere (Steele et al. 1987).

Matatula Point (American Samoa)

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983				1546.1	1564.6	1569.4	1571.6	1574.3	1573.1	1580.5	1576.7	1574.6	1570.1
1984	1589.5	1587.2	1563.1	1573.1	1575.4	1588.5	1591.0	1590.1	1591.0	1590.0	1586.3	1592.3	1584.8
1985	1602.2	1605.4	1597.9	1590.5	1601.0	1598.1	1601.0	1602.6	1603.5	1602.3	1598.7	1599.0	1600.2

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

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Mauna Loa

BACKGROUND

Principal investigators

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Patricia M. Lang
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

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Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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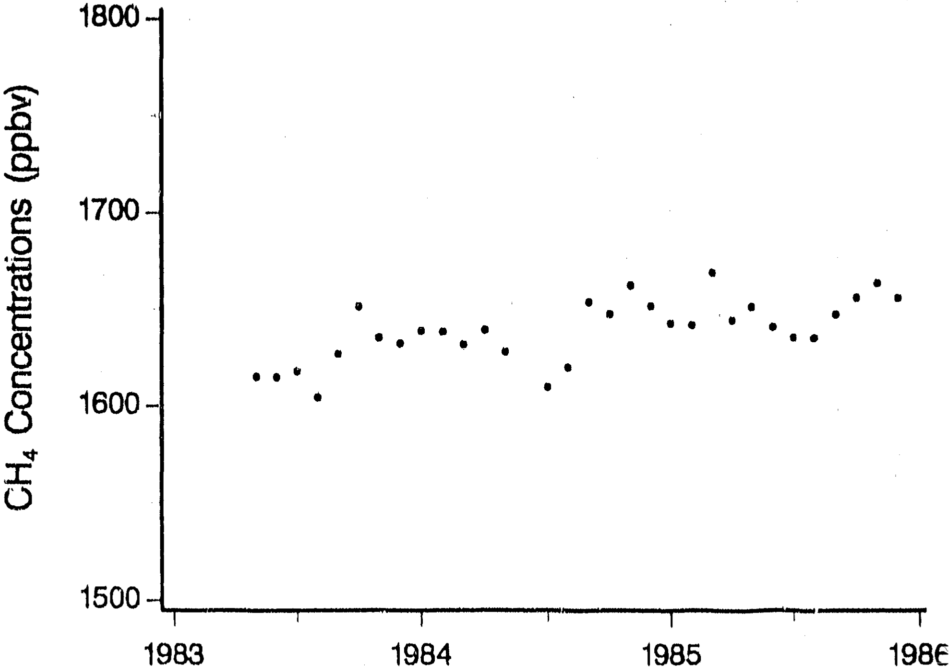
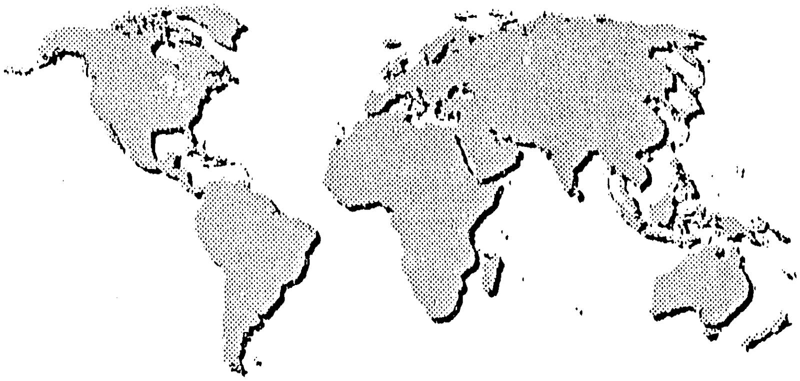
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Mauna Loa
Hawaii, USA
Barren volcanic mountain slope
19° 32′N, 155° 35′W
3397 m above MSL

TREND

The average annual CH_4 concentration at Mauna Loa increased from 1620.3 ppbv in 1983 to 1648.5 ppbv in 1985. By fitting the 12-month running means to a linear regression to remove seasonal variation, Steele et al. (1987) found the annual average growth rate for Mauna Loa to be 12.0 ppbv per year. Steele et al. (1987) also compared the CH_4 data from Mauna Loa with those from Cape Kumukahi and found a significant vertical gradient in CH_4 concentration, with the long-term average concentrations from Mauna Loa being lower than those at Cape Kumukahi. Steele et al. (1987) found that (1) both sites exhibited a major seasonal minimum in the northern summer of 1984 and (2) the fitted cubic spline functions for both sites show evidence that two minimums and two maximums occur each year at times consistent with those reported by Khalil and Rasmussen (1990).

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983					1615.3	1614.9	1618.0	1604.5	1626.9	1651.4	1635.3	1632.4	1620.3
1984	1638.8	1638.4	1631.8	1639.2	1628.0		1609.8	1619.9	1653.7	1647.4	1662.2	1651.5	1638.2
1985	1642.7	1641.7	1668.8	1644.3	1651.2	1640.6	1635.1	1635.1	1647.1	1655.9	1663.4	1655.8	1648.5

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

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Mould Bay

BACKGROUND

Principal investigators

*L. Paul Steele** *Russell C. Martin*
Pieter P. Tans *Ken A. Masarie*
Patricia M. Lang
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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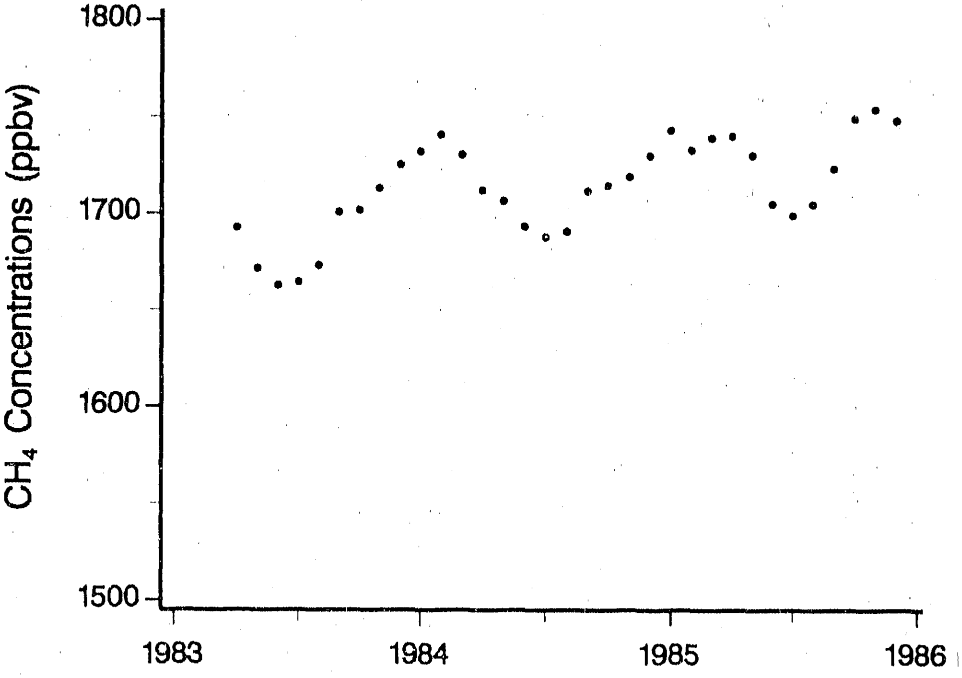
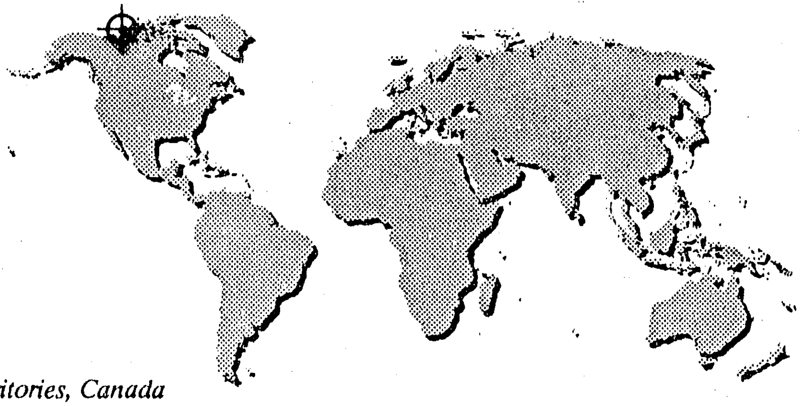
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Mould Bay
Northwest Territories, Canada
Island seashore
76° 14′N, 119° 20′W
15 m above MSL

TREND

The sampling site at Mould Bay is operated in cooperation with the Canadian Atmospheric Environment Service. The annual CH_4 concentrations at Mould Bay have risen from 1689.4 ppbv in 1983 to 1730.2 ppbv in 1985. After fitting a linear regression to the 12-month running means to remove the seasonal variations, Steele et al. (1987) calculated the average annual growth rate for Mould Bay to be 12.2 ppbv. Steele et al. (1987) also reported that the five northernmost CMDL stations, including Mould Bay, exhibit major seasonal minimums during the northern summer months of both 1983 and 1984. Steele et al. (1987) found the degree of scatter for the CH_4 data from Mould Bay was much less than the other four northernmost sites and suggested that this reduced scatter may be a reflection of greater distances between the Mould Bay site and significant sources of CH_4.

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983				1692.5	1671.4	1662.7	1664.3	1673.0	1700.6	1701.6	1713.0	1725.1	1689.4
1984	1732.0	1740.5	1730.1	1711.8	1706.3	1693.0	1687.5	1690.3	1711.3	1714.1	1718.5	1729.5	1713.7
1985	1742.7	1732.4	1738.6	1739.5	1729.7	1704.4	1698.4	1704.3	1722.7	1748.5	1753.5	1747.7	1730.2

---

*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

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Niwot Ridge

BACKGROUND

Principal investigators

*L. Paul Steele** *Russell C. Martin*
Pieter P. Tans *Ken A. Masarie*
Patricia M. Lang
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

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Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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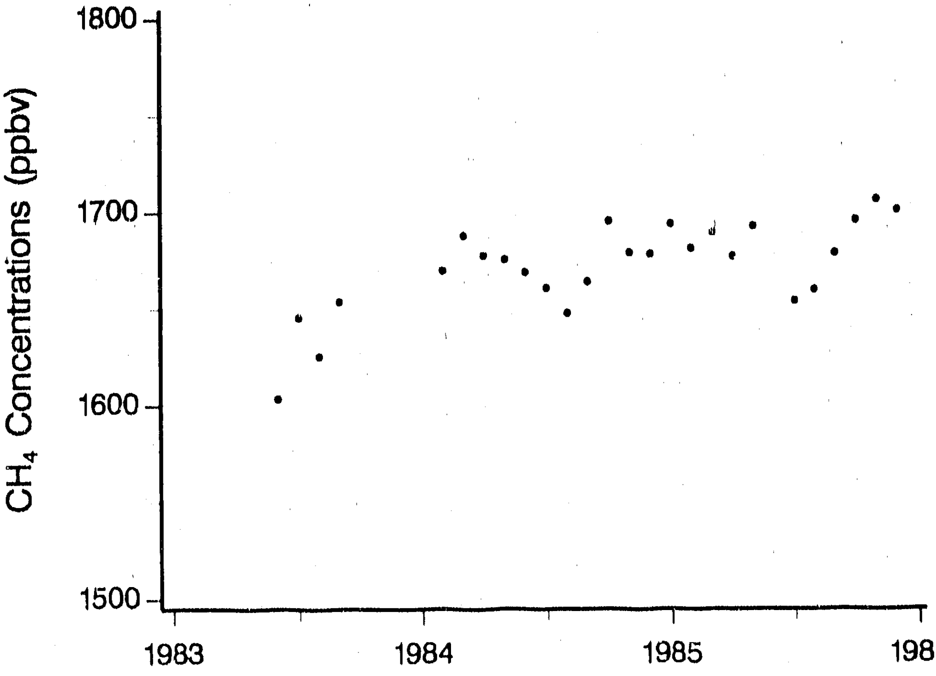
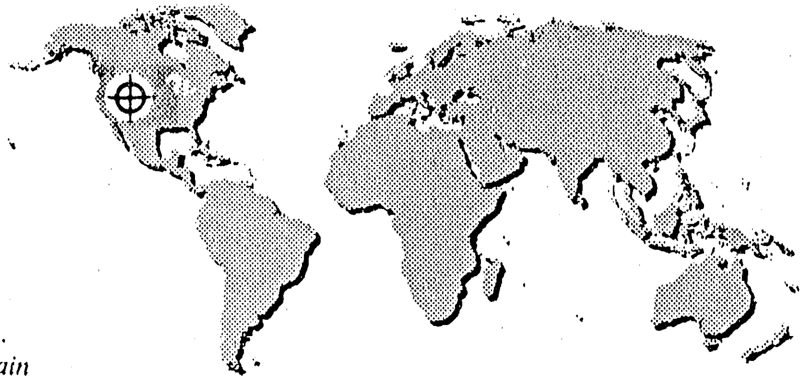
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Niwot Ridge
Colorado, U.S.A.
Alpine mountain
40° 03′N, 105° 38′W
3749 m above MSL

TREND

The Niwot Ridge station is operated in cooperation with the University of Colorado's INSTAAR. The average annual CH_4 concentration at Niwot Ridge has risen from 1632.2 ppbv in 1983 to 1684.3 ppbv in 1985. Steele et al. (1987) compared the CH_4 data from Niwot Ridge and the Azores site, because both have similar latitudes, and found that for extended periods of time the CH_4 concentrations at the high-altitude site of Niwot Ridge are lower than those at the Azores site. Steele et al. (1987) also found a difference of 17 ppbv when comparing the 1984 annual mean values for the two sites.

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Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983						1603.5	1645.6	1625.7	1653.8				1632.2
1984		1669.8	1688.0	1677.8	1675.6	1669.0	1660.9	1647.8	1664.1	1695.3	1679.1	1678.4	1673.3
1985	1693.6	1681.2	1689.3	1676.9	1692.4		1653.8	1659.5	1678.3	1695.3	1706.0	1700.5	1684.3

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

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Palmer Station (Anvers Island)

BACKGROUND

Principal investigators

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Patricia M. Lang
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Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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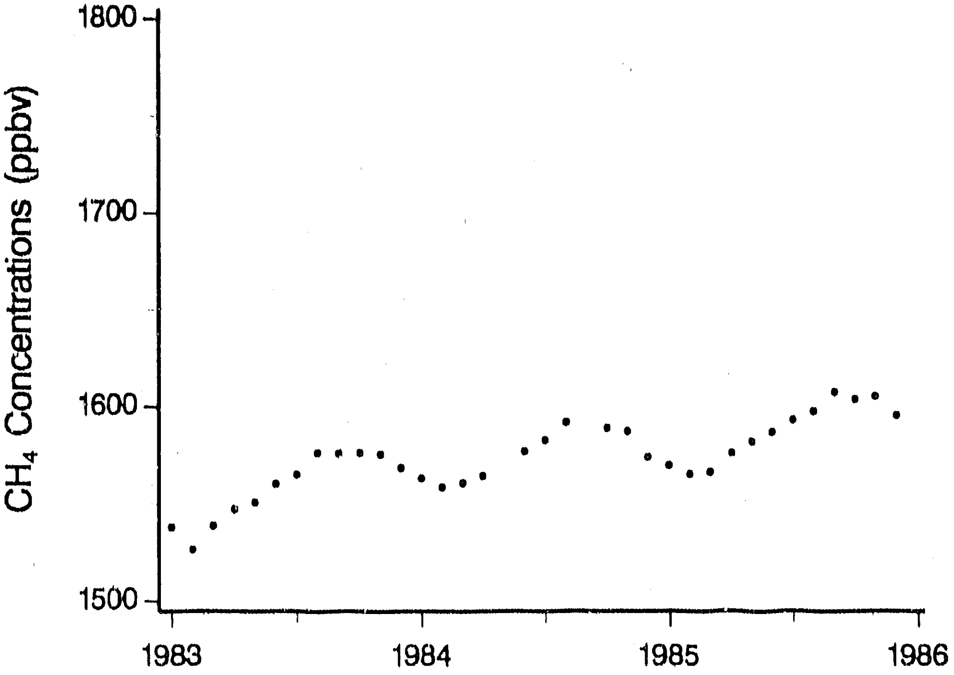
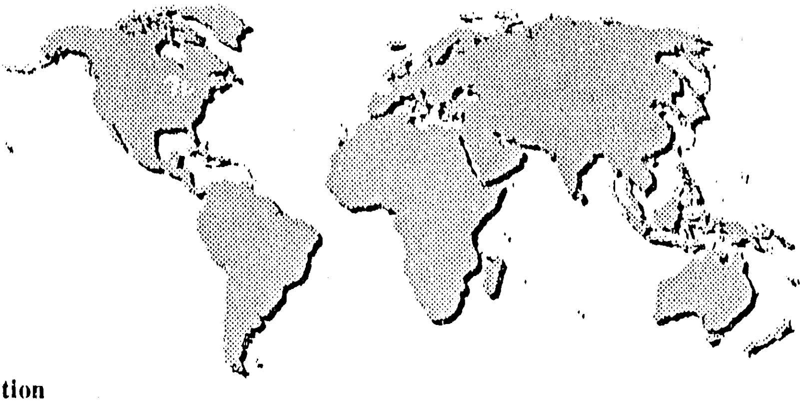
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Palmer Station
Anvers Island, Antarctica
Barren island seashore
64° 55'S, 64° 00'W
33 m above MSL

TREND

The Palmer Station site is operated in cooperation with the Laboratory for Atmospheric Research at Washington State University. The annual average CH_4 concentration from Palmer Station increased from 1558.4 ppbv in 1983 to 1587.5 ppbv in 1985. Using 12-month running means (to remove seasonal variations) fitted to a quadratic function, Steele et al. (1987) found the average growth rate at Palmer Station to be 26.0 ppbv per year.

Steele et al. (1987) made direct comparisons of the NOAA/CMDL CH_4 data with in situ measurements of CH_4 at Palmer Station made by Robinson et al. (1984) during 1982–1983 and found that the 1983 data from both records exhibit a seasonal cycle that is similar in phase and amplitude. However, the concentrations reported by Robinson et al. (1984) were ~30 ppbv lower than those reported by Steele et al. (1987). Robinson et al. (1984) also reported no increasing trend in CH_4 at Palmer Station. This finding differs from the findings of Fraser et al. (1984) and Steele et al. (1987).

Palmer Station (Anvers Island)

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983	1538.1	1526.6	1538.9	1547.4	1550.9	1560.4	1565.2	1576.5	1576.1	1576.4	1575.7	1568.7	1558.4
1984	1563.3	1558.7	1560.9	1564.4		1577.1	1582.9	1592.1		1589.1	1587.3	1574.2	1570.0
1985	1569.8	1565.4	1566.5	1576.1	1582.2	1587.0	1593.1	1597.7	1607.6	1603.8	1605.3	1595.5	1587.5

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

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Fraser, P.J., M.A.K. Khalil, R.A. Rasmussen, and L.P. Steele. 1984. Tropospheric methane in the mid-latitudes of the Southern Hemisphere. *Journal of Atmospheric Chemistry* 1:125–35.

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Point Barrow

BACKGROUND

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Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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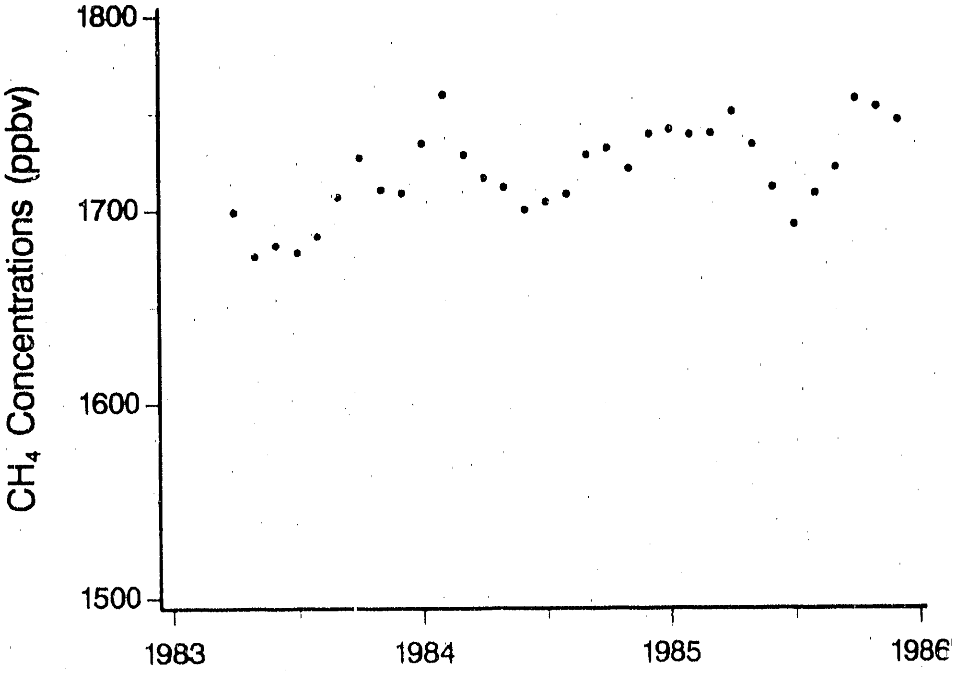
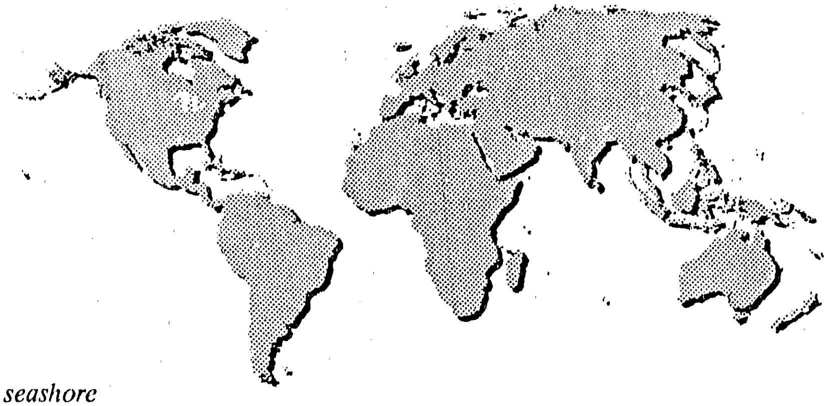
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Point Barrow
Alaska, U.S.A.
Arctic coastal seashore
71° 19′ N, 156° 36′ W
11 m above MSL

TREND

The sampling site at Point Barrow was established as a CMDL station in 1973 for the purpose of measuring atmospheric CO_2 concentrations. Analyses of flask samples for CH_4 concentrations began in 1983. The average annual CH_4 concentration at Point Barrow rose from 1697.5 ppbv in 1983 to 1733.0 ppbv in 1985. Steele et al. (1987) reported an average annual growth rate of 15.7 ppbv for Point Barrow and observed that all of the northernmost CMDL sites (Cape Meares, Oregon; Cold Bay, Alaska; Ocean Station "M," North Atlantic; Point Barrow, Alaska; and Mould Bay, Canada) exhibited major seasonal minimums during the northern summers of both 1983 and 1984.

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983				1699.2	1676.4	1682.1	1678.4	1686.9	1707.0	1727.5	1710.8	1709.1	1697.5
1984	1734.7	1759.9	1728.7	1716.9	1711.9	1700.3	1704.4	1708.3	1728.6	1732.1	1721.4	1739.3	1723.9
1985	1741.6	1738.9	1739.7	1750.7	1733.8	1711.7	1692.4	1708.5	1721.7	1757.3	1753.0	1746.2	1733.0

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

Fraser, P.J., M.A.K. Khalil, R.A. Rasmussen, and A.J. Crawford. 1981. Trends of atmospheric methane in the Southern Semisphere. *Geophysical Research Letters* 8:1063–66.

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St. Croix

BACKGROUND

Principal investigators

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325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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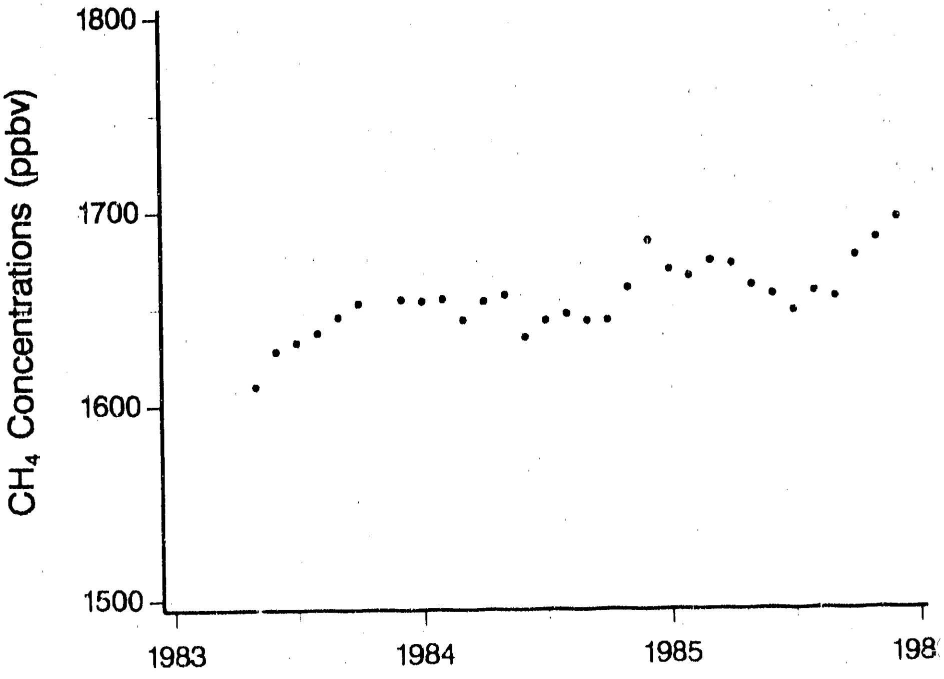
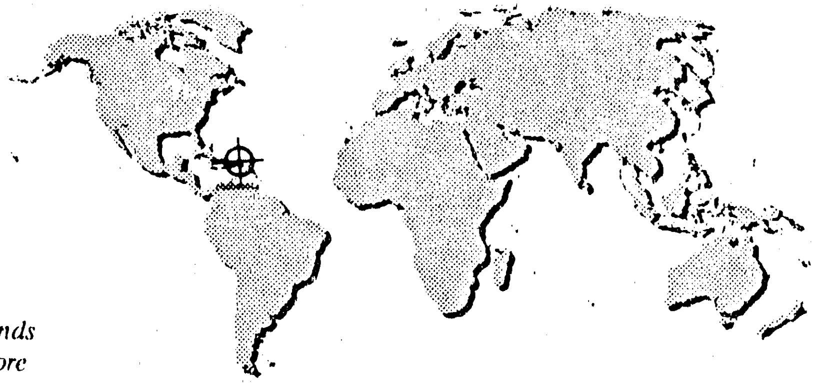
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



St. Croix
U.S. Virgin Islands
Island seashore
17° 45′N, 64° 45′W
3 m above MSL

TREND

The sampling site at St. Croix is operated in cooperation with Fairleigh Dickinson University. The annual average CH_4 concentration at St. Croix rose from 1637.2 ppbv in 1983 to 1667.9 ppbv in 1985. By fitting a linear regression to the 12-month running mean values, Steele et al. (1987) calculated an average growth rate of 11.7 ppbv per year at St. Croix.

1986

St. Croix

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983					1609.9	1628.0	1632.5	1637.4	1645.5	1652.5		1654.5	1637.2
1984	1653.6	1654.5	1643.8	1653.5	1656.5	1635.0	1643.5	1646.8	1643.4	1643.4	1660.0	1684.1	1651.5
1985	1669.2	1665.9	1673.6	1672.1	1661.1	1656.2	1647.9	1657.8	1654.8	1676.2	1685.0	1695.5	1667.9

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

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Terceira Island (Azores)

BACKGROUND

Principal investigators

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Environmental Research Laboratories
325 Broadway
Boulder, Colorado 80303-3328, U.S.A.

Air sample collection – Whole air samples are collected weekly in 0.5-L glass flasks exposed in pairs by means of a portable, battery-powered sampler. Flasks are flushed with air at the time of sampling and pressurized to 1.25–1.5 times ambient atmospheric pressure. See Steele et al. (1987) and Lang et al. (1990).

Measurement apparatus – The flask samples are analyzed for CH_4 at the CMDL laboratory in Boulder by using gas chromatographs fitted with a flame ionization detector. During 1983–1985, four gas chromatographic stystems have been used to analyze samples for CH_4.

Data selection procedures – See Steele et al. (1987), Lang et al. (1990), and Komhyr et al. (1985).

Calibration gases used – CH_4-in-air [1653.0 ppbv (27 Apr. 1983–10 June 1985) and 1676.0 ppbv (11 June 1985–24 Mar. 1987)].

Data availability – The complete set of NOAA/CMDL CH_4 data (including weekly flask samples) is available from the principal investigators. Monthly and annual CH_4 concentrations for all the CMDL flask sampling sites are available from CDIAC.

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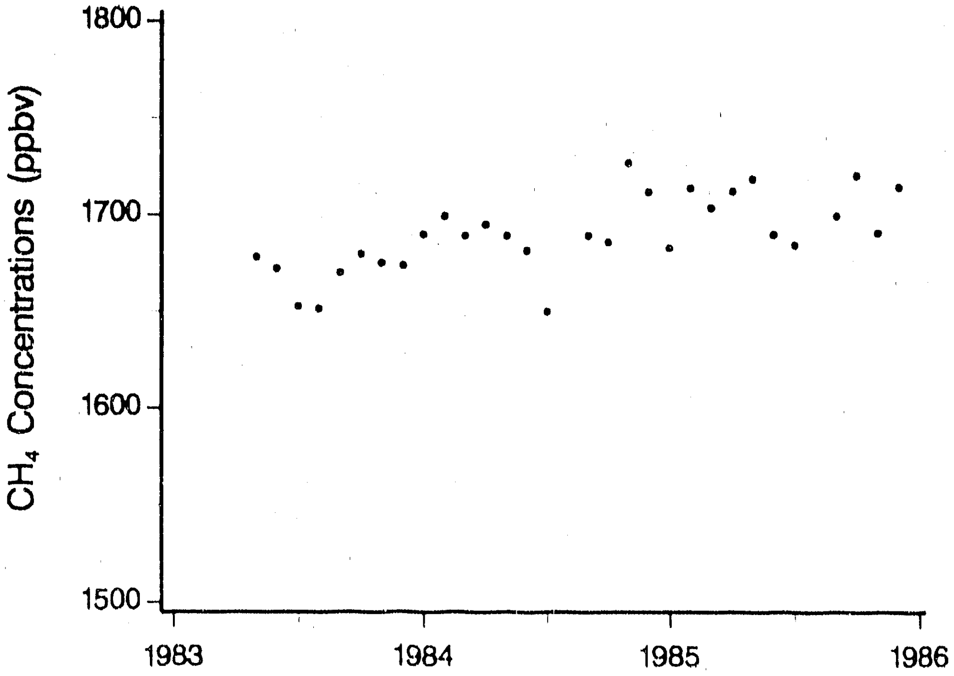
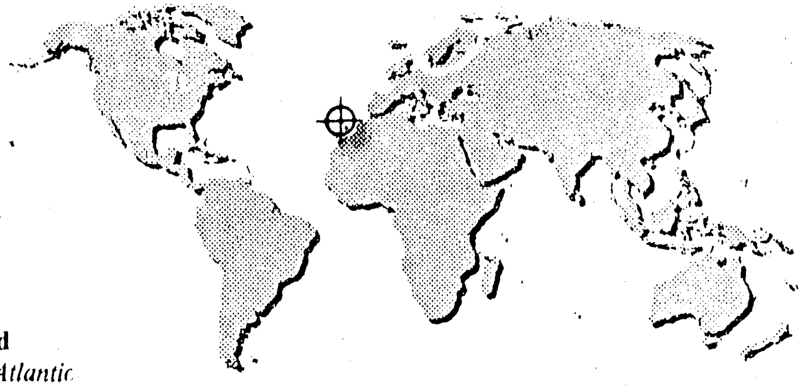
*Now at CSIRO.



Monthly concentrations of atmospheric CH_4.



Terceira Island
Azores, North Atlantic
Island seashore
38° 45′N, 27° 05′W
30 m above MSL

TREND

The average annual CH_4 concentration at the Azores rose from 1669.0 ppbv in 1983 to 1702.3 ppbv in 1985. By fitting a linear regression to the 12-month running means, Steele et al. (1987) reported an average annual CH_4 growth rate of 17.0 ppbv for the Azores. Steele et al. (1987) also compared the methane data from the Azores and Niwot Ridge sites and found that the long-term averages for concentrations at the high-altitude site of Niwot Ridge were lower than those at the Azores. When comparing the annual mean values for 1984, Steele et al. (1987) found the difference between the two sites to be 17 ppbv.

The Azores sampling site is operated in cooperation with the 7th Weather Wing of the United States Air Force.

Terceira Island (Azores)

Concentrations of Atmospheric Methane*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann
1983					1678.0	1672.0	1652.5	1651.3	1670.0	1679.5	1675.0	1673.5	1669.0
1984	1689.9	1699.2	1689.1	1695.0	1689.0	1681.5	1649.8		1689.1	1685.7	1726.5	1711.5	1691.5
1985	1682.7	1713.4	1703.2	1711.7	1718.1	1689.4	1683.9		1698.9	1719.9	1690.2	1713.9	1702.3

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*Methane concentrations expressed in parts per billion by volume (ppbv). Monthly averages calculated as arithmetic means of individual flask concentrations that are indicative of background conditions. Annual averages based on monthly means.

REFERENCES

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Temperature Records

Introduction

During the past 20 years, much attention has been given to the potential climatic effects of increasing concentrations of atmospheric greenhouse gases. This is not surprising because these potential climatic effects could have far-reaching environmental, economic, and social consequences. Much of the work that has been performed during this period has involved (1) climate modeling or empirical analyses attempting to attribute climatic changes to various astronomical and atmospheric factors and (2) assembly and examination of new geological, historical, and instrumental data. From these studies, researchers have gained important new insights into the possible climatic response to the increasing concentrations of CO_2 and other trace gases, together with a better understanding of the sensitivity of the overall climate system to both human and natural perturbations.

In order to isolate the "greenhouse signal," or that part of the climate change that is indicative of increased concentrations of greenhouse gases, it is imperative that we have long-term observational records that can be used to identify the climate changes that have already occurred. Fortunately, for the past century many climatic variables (e.g., surface air temperature) have been measured at a large number of meteorological stations, mostly at land locations in the Northern Hemisphere. It is also imperative that these observational records have sufficient spatial coverage. Although local and regional variations in temperature are important in assessing the impacts of climate and climate change on society, large-scale averages are most likely to indicate detectable changes in climate that result from changes in atmospheric trace gas concentrations. Researchers have compiled and analyzed several time series of large-scale average surface air temperatures largely on the basis of land-based data and data from a few fixed-position weather ships. To determine large-scale tropospheric and stratospheric temperatures, radiosonde and rocketsonde data have typically been used. Many of these series show warming trends in the troposphere, particularly in the 1980s, but it remains unclear whether these trends are the result of a buildup of greenhouse gases or due to other factors [e.g., greater frequency of El Niño/Southern Oscillation (ENSO) events in the Pacific Ocean] (see figure).

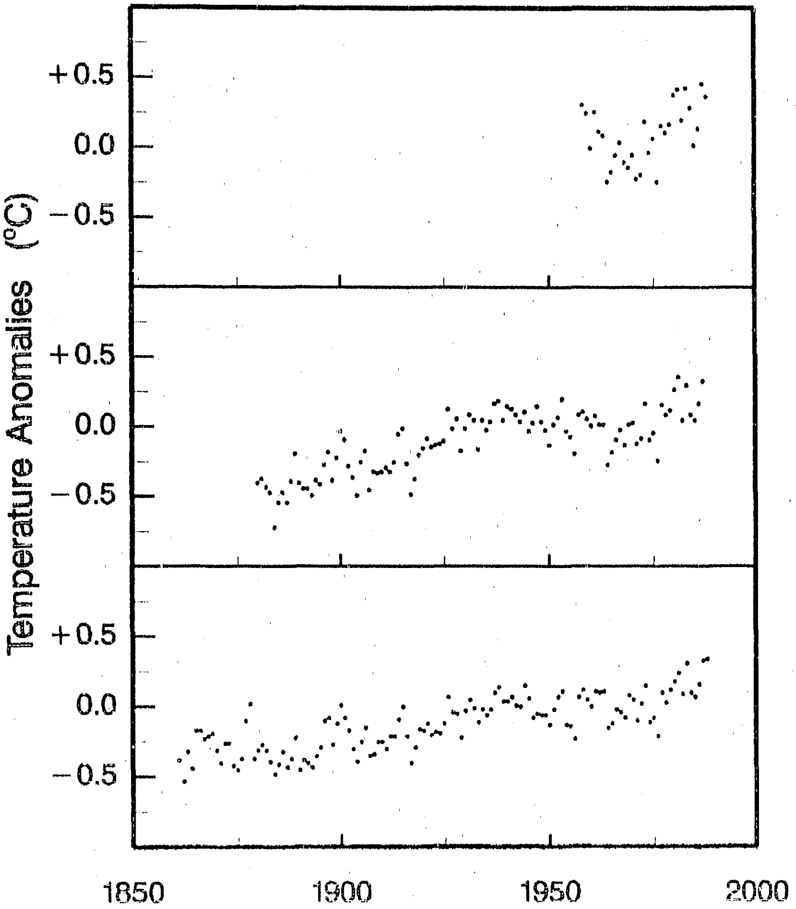
The following pages provide several long-term records of temperatures and temperature anomalies. Their spatial coverage ranges from the globe to U.S. regions and from the Earth's surface to the low stratosphere. The first two records are global and hemispheric temperature anomalies. These records are followed by annual and seasonal temperature anomalies for the surface, troposphere, tropopause, and low stratosphere. Global anomaly estimates are presented first followed by northern and southern zonal averages and averages for each hemisphere. Finally, seasonal and annual temperatures for the United States are presented with national estimates first followed by estimates for the sub-regions that comprise the aggregated West, Central, and Eastern regions. These records represent only a fraction of the long-term records available; however, they are frequently referenced in studies addressing potential greenhouse gas–induced climate changes. All the data presented in this section were made available to the CDIAC by the principal investigator(s) listed for each data record. We urge readers to credit the principal investigators and their organizations when using these data. Users are cautioned to pay close attention to table footnotes concerning the nature of each data record and are encouraged to contact CDIAC before applying the data in specific model or research exercises.

Introduction

During the past 20 years, much attention has been given to the potential climatic effects of increasing concentrations of atmospheric greenhouse gases. This is not surprising because these potential climatic effects could have far-reaching environmental, economic, and social consequences. Much of the work that has been performed during this period has involved (1) climate modeling or empirical analyses attempting to attribute climatic changes to various astronomical and atmospheric factors and (2) assembly and examination of new geological, historical, and instrumental data. From these studies, researchers have gained important new insights into the possible climatic response to the increasing concentrations of CO_2 and other trace gases, together with a better understanding of the sensitivity of the overall climate system to both human and natural perturbations.

In order to isolate the "greenhouse signal," or that part of the climate change that is indicative of increased concentrations of greenhouse gases, it is imperative that we have long-term observational records that can be used to identify the climate changes that have already occurred. Fortunately, for the past century many climatic variables (e.g., surface air temperature) have been measured at a large number of meteorological stations, mostly at land locations in the Northern Hemisphere. It is also imperative that these observational records have sufficient spatial coverage. Although local and regional variations in temperature are important in assessing the impacts of climate and climate change on society, large-scale averages are most likely to indicate detectable changes in climate that result from changes in atmospheric trace gas concentrations. Researchers have compiled and analyzed several time series of large-scale average surface air temperatures largely on the basis of land-based data and data from a few fixed-position weather ships. To determine large-scale tropospheric and stratospheric temperatures, radiosonde and rocketsonde data have typically been used. Many of these series show warming trends in the troposphere, particularly in the 1980s, but it remains unclear whether these trends are the result of a buildup of greenhouse gases or due to other factors [e.g., greater frequency of El Niño/Southern Oscillation (ENSO) events in the Pacific Ocean] (see figure).

The following pages provide several long-term records of temperatures and temperature anomalies. Their spatial coverage ranges from the globe to U.S. regions and from the Earth's surface to the low stratosphere. The first two records are global and hemispheric temperature anomalies. These records are followed by annual and seasonal temperature anomalies for the surface, troposphere, tropopause, and low stratosphere. Global anomaly estimates are presented first followed by northern and southern zonal averages and averages for each hemisphere. Finally, seasonal and annual temperatures for the United States are presented with national estimates first followed by estimates for the sub-regions that comprise the aggregated West, Central, and Eastern regions. These records represent only a fraction of the long-term records available; however, they are frequently referenced in studies addressing potential greenhouse gas–induced climate changes. All the data presented in this section were made available to the CDIAC by the principal investigator(s) listed for each data record. We urge readers to credit the principal investigators and their organizations when using these data. Users are cautioned to pay close attention to table footnotes concerning the nature of each data record and are encouraged to contact CDIAC before applying the data in specific model or research exercises.



Annual global temperature anomalies (Angell's surface data [see pg. 199] are shown in the upper box; Hansen and Lebedeff's data [see pg. 197] are shown in the middle box; and Jones, Wigley, and Wright's data [see pg. 195] are shown in the lower box).

Global and Hemispheric

BACKGROUND

Principal investigators

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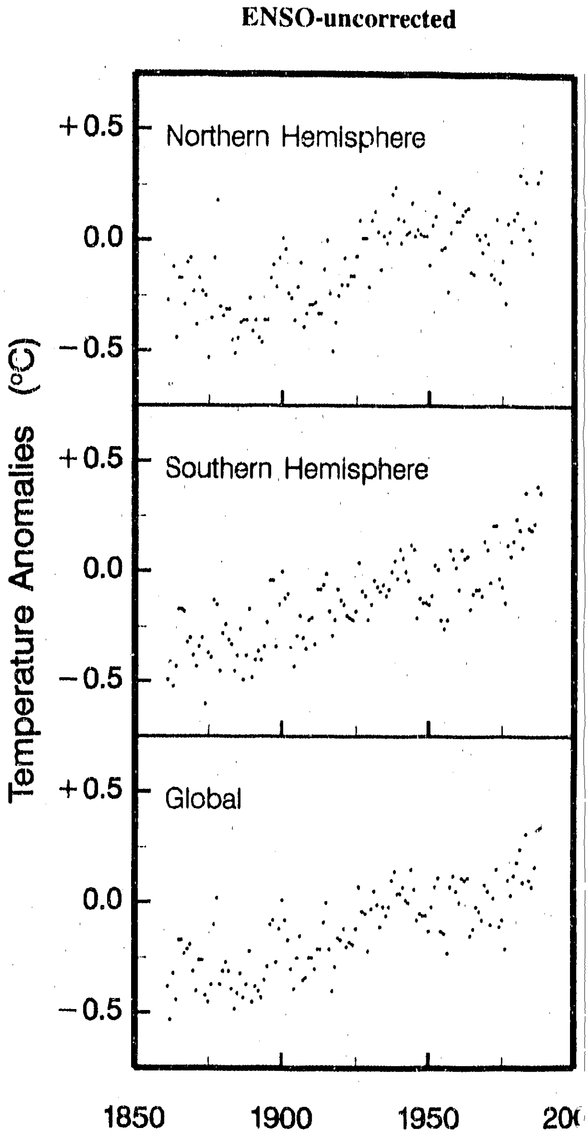
Sponsoring agency

U.S. Department of Energy
Carbon Dioxide Research Program

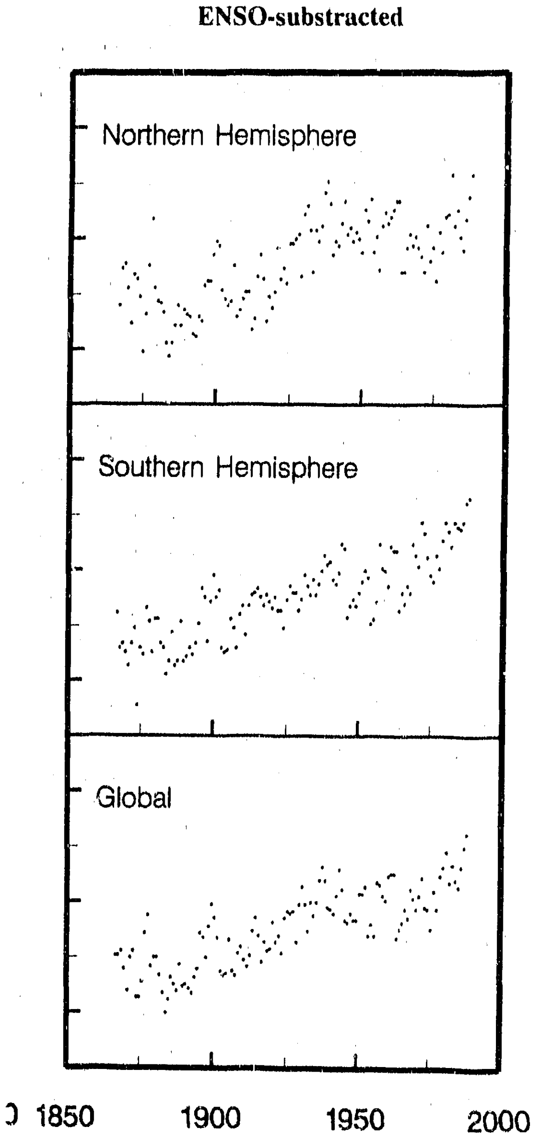
Period of record – 1861–1988 (relative to a 1950–1979 reference period).

Method – These estimates were compiled by Jones et al. (1986a, b, c) and Jones (1988) and are based on corrected land and marine data. Land data were derived from meteorological data and fixed-position weather ship data that were corrected for nonclimatic errors, such as station shifts and/or instrument changes. The marine data were from the Comprehensive Ocean-Atmosphere Data Set (COADS) compilation, which extends (with updates) to 1986. Updates to 1988 were based on hemispheric sea surface temperature (SST) estimates produced by the United Kingdom Meteorological Office. Both SSTs and marine air temperatures were corrected, but only SST data were used in the combined land-marine data set.

Data availability – These data are available from the Climatic Research Unit at the University of East Anglia and are also documented and available from CDIAC (Jones et al. 1990).



Annual global and hemisphe



c temperature anomalies.

TRENDS

These global and hemispheric annual variations show little trend during the nineteenth century, marked warming to 1940, relatively steady conditions to the mid-1970s, followed by a rapid warming during the 1980s. Globally, in 1988 the mean temperature variation was 0.34°C above the mean for the 1950–1979 reference period and 0.01°C warmer than that of 1987. Factoring out ENSO-related events from the global temperature anomaly series, 1988 was considerably warmer than 1987. Statistically, the decade of the 1980s over the globe has been significantly warmer (*t* value 1.90) than the mean of the 1950–1979 reference period (Jones 1988).

Global and Hemispheric

Annual Temperature Anomalies (rela

Year	Northern Hem.	Southern Hem.	Global	ENSO-subtracted† Northern Hem.	ENSO-subtracted† Southern Hem.	ENSO-subtracted† Global
1861	–0.27	–0.49	–0.38			
1862	–0.65	–0.41	–0.53			
1863	–0.12	–0.52	–0.32			
1864	–0.44	–0.43	–0.44			
1865	–0.17	–0.17	–0.17			
1866	–0.17	–0.17	–0.17			
1867	–0.29	–0.18	–0.23	–0.30	–0.19	–0.24
1868	–0.10	–0.32	–0.21	–0.13	–0.35	–0.24
1869	–0.08	–0.30	–0.19	–0.11	–0.33	–0.22
1870	–0.23	–0.38	–0.31	–0.22	–0.37	–0.30
1871	–0.38	–0.43	–0.40	–0.38	–0.43	–0.40
1872	–0.17	–0.34	–0.26	–0.16	–0.33	–0.25
1873	–0.23	–0.30	–0.26	–0.18	–0.26	–0.22
1874	–0.25	–0.60	–0.42	–0.26	–0.61	–0.43
1875	–0.53	–0.37	–0.45	–0.51	–0.35	–0.43
1876	–0.35	–0.39	–0.37	–0.34	–0.38	–0.36
1877	–0.08	–0.13	–0.10	–0.12	–0.17	–0.14
1878	0.18	–0.15	0.02	0.09	0.23	–0.06
1879	–0.30	–0.45	–0.37	–0.22	–0.37	–0.29
1880	–0.34	–0.28	–0.31	–0.28	–0.22	–0.25
1881	–0.31	–0.24	–0.27	–0.29	–0.22	–0.25
1882	–0.31	–0.31	–0.31	–0.33	–0.33	–0.33
1883	–0.45	–0.33	–0.39	–0.47	–0.35	–0.41
1884	–0.51	–0.45	–0.48	–0.53	–0.47	–0.50
1885	–0.44	–0.38	–0.41	–0.47	–0.41	–0.44
1886	–0.37	–0.26	–0.32	–0.39	–0.28	–0.34
1887	–0.36	–0.49	–0.43	–0.30	–0.43	–0.37
1888	–0.36	–0.38	–0.37	–0.39	–0.41	–0.40
1889	–0.26	–0.17	–0.22	–0.32	–0.23	–0.28
1890	–0.41	–0.48	–0.45	–0.34	–0.41	–0.38
1891	–0.36	–0.40	–0.38	–0.35	–0.39	–0.37
1892	–0.44	–0.36	–0.40	–0.43	–0.35	–0.39
1893	–0.46	–0.40	–0.43	–0.44	–0.38	–0.41
1894	–0.36	–0.34	–0.35	–0.35	–0.33	–0.34
1895	–0.36	–0.23	–0.29	–0.37	–0.24	–0.30
1896	–0.17	–0.04	–0.10	–0.21	–0.08	–0.14
1897	–0.11	–0.04	–0.08	–0.19	–0.12	–0.16
1898	–0.21	–0.34	–0.27	–0.19	–0.32	–0.25
1899	–0.08	–0.15	–0.12	–0.07	–0.14	–0.11
1900	0.01	0.00	0.01	–0.01	–0.02	–0.01
1901	–0.04	–0.12	–0.08	–0.03	–0.12	–0.07
1902	–0.24	–0.10	–0.17	–0.23	–0.09	–0.16
1903	–0.26	–0.34	–0.30	–0.27	–0.35	–0.31
1904	–0.36	–0.43	–0.39	–0.30	–0.37	–0.33
1905	–0.21	–0.29	–0.25	–0.28	–0.36	–0.32
1906	–0.10	–0.20	–0.15	–0.12	–0.22	–0.17
1907	–0.39	–0.30	–0.35	–0.35	–0.26	–0.31
1908	–0.33	–0.35	–0.34	–0.32	–0.35	–0.33
1909	–0.29	–0.22	–0.25	–0.27	–0.20	–0.23
1910	–0.29	–0.21	–0.25	–0.24	–0.16	–0.20
1911	–0.28	–0.33	–0.30	–0.24	–0.29	–0.26
1912	–0.33	–0.08	–0.21	–0.41	–0.16	–0.29
1913	–0.33	–0.08	–0.21	–0.36	–0.11	–0.24
1914	–0.13	–0.06	–0.09	–0.17	–0.10	–0.13
1915	0.00	–0.01	0.00	–0.07	0.08	–0.07
1916	–0.24	–0.18	–0.21	–0.18	–0.12	–0.15
1917	–0.50	–0.29	–0.40	–0.37	–0.16	–0.27
1918	–0.37	–0.22	–0.29	–0.26	–0.11	–0.18
1919	–0.25	–0.08	–0.16	–0.31	–0.14	–0.22
1920	–0.20	–0.13	–0.17	–0.24	–0.17	–0.21
1921	–0.08	–0.15	–0.12	–0.04	–0.12	–0.09
1922	–0.20	–0.20	–0.20	–0.18	–0.18	–0.18
1923	–0.16	–0.21	–0.18	–0.13	–0.18	–0.15
1924	–0.16	–0.22	–0.19	–0.20	–0.26	–0.23
1925	–0.07	–0.18	–0.12	–0.02	–0.13	–0.07
1926	0.09	0.04	0.07	–0.02	–0.07	–0.04
1927	0.01	–0.09	–0.04	0.00	–0.10	–0.05
1928	0.01	–0.11	–0.05	0.02	–0.10	–0.04
1929	–0.21	–0.22	–0.22	–0.17	–0.18	–0.18
1930	0.09	–0.15	–0.03	0.11	–0.13	–0.01
1931	0.13	–0.04	0.05	0.15	–0.02	0.07
1932	0.04	–0.07	–0.01	0.04	–0.07	–0.01
1933	–0.13	–0.09	–0.11	–0.15	–0.11	–0.13
1934	0.02	–0.06	–0.02	0.04	–0.04	0.00
1935	–0.01	–0.11	–0.06	–0.01	–0.11	–0.06
1936	0.04	–0.08	–0.02	0.06	–0.06	0.00
1937	0.21	0.00	0.10	0.21	0.00	0.10
1938	0.24	0.05	0.14	0.26	0.07	0.16
1939	0.10	–0.03	0.04	0.16	0.03	0.10
1940	–0.01	0.10	0.04	–0.07	0.04	–0.02
1941	0.09	0.06	0.07	–0.01	–0.04	–0.03
1942	0.03	0.00	0.01	–0.03	–0.06	–0.05
1943	0.04	–0.04	0.00	0.07	–0.01	0.03
1944	0.17	0.12	0.15	0.17	0.12	0.15
1945	0.02	0.10	0.06	0.02	0.10	0.06
1946	0.05	–0.21	–0.08	0.05	–0.21	–0.08

ive to a 1950–79 reference period mean)*

Year	Northern Hem.	Southern Hem.	Global	ENSO-subtracted† Northern Hem.	ENSO-subtracted† Southern Hem.	ENSO-subtracted† Global
1947	0.03	–0.12	–0.05	–0.01	–0.16	–0.09
1948	0.02	–0.14	–0.06	0.03	–0.13	–0.05
1949	0.02	–0.14	–0.06	0.00	–0.16	–0.08
1950	–0.11	–0.15	–0.13	–0.06	–0.10	–0.08
1951	0.07	–0.11	–0.02	0.13	–0.05	0.04
1952	0.11	0.03	0.07	0.08	0.00	0.04
1953	0.22	0.01	0.11	0.18	–0.03	0.07
1954	–0.04	–0.22	–0.13	–0.06	–0.24	–0.15
1955	–0.03	–0.26	–0.14	0.01	–0.22	–0.10
1956	–0.23	–0.22	–0.23	–0.14	–0.14	–0.15
1957	0.04	0.10	0.07	0.06	0.12	0.09
1958	0.17	0.06	0.12	0.12	0.01	0.08
1959	0.09	0.02	0.05	0.07	0.00	0.03
1960	0.09	–0.08	0.00	0.10	–0.07	0.01
1961	0.12	0.10	0.11	0.13	0.11	0.12
1962	0.14	0.06	0.10	0.17	0.09	0.13
1963	0.15	0.07	0.11	0.17	0.09	0.13
1964	–0.14	–0.17	–0.15	–0.15	–0.18	–0.16
1965	–0.15	–0.10	–0.12	–0.15	–0.10	–0.12
1966	0.03	–0.08	–0.02	–0.04	–0.15	–0.09
1967	0.01	–0.08	–0.04	0.02	–0.07	–0.03
1968	–0.05	–0.11	–0.08	–0.03	–0.10	–0.07
1969	0.03	0.14	0.08	0.01	0.12	0.06
1970	–0.01	0.10	0.05	–0.04	0.07	0.02
1971	–0.15	–0.05	–0.10	–0.08	0.02	–0.03
1972	–0.17	0.21	0.02	–0.15	0.22	0.03
1973	0.10	0.21	0.15	0.06	0.17	0.11
1974	–0.19	–0.03	–0.11	–0.10	0.06	–0.02
1975	–0.09	–0.07	–0.08	–0.04	–0.02	–0.03
1976	–0.28	–0.14	–0.21	–0.19	–0.05	–0.12
1977	0.08	0.12	0.10	0.03	0.07	0.05
1978	0.00	0.07	0.03	–0.06	0.01	–0.03
1979	0.10	0.14	0.12	0.10	0.14	0.12
1980	0.13	0.24	0.18	0.11	0.22	0.16
1981	0.30	0.19	0.24	0.29	0.18	0.23
1982	0.06	0.11	0.09	0.06	0.11	0.09
1983	0.27	0.36	0.31	0.13	0.22	0.17
1984	0.01	0.20	0.10	0.01	0.20	0.10
1985	–0.05	0.19	0.07	–0.05	0.19	0.07
1986	0.09	0.22	0.16	0.09	0.22	0.16
1987	0.27	0.39	0.33	0.19	0.31	0.25
1988	0.32	0.36	0.34	0.29	0.33	0.31

*Degrees Celsius.

†Data corrected for the influences of El Niño/Southern Oscillation (ENSO).

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Global and Hemispheric

BACKGROUND

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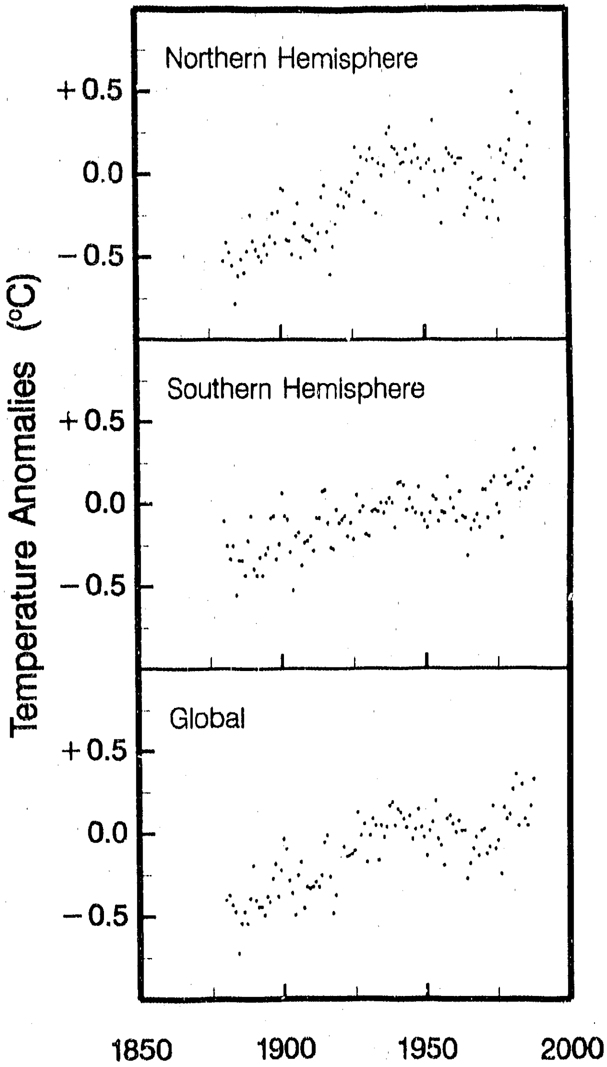
Sponsoring agencies

NASA Climate Program
Environmental Protection Agency

Period of record – 1880–1987 (relative to a 1951–1980 reference period).

Method – Temperature differences between stations were calculated on the basis of (1) surface air temperature data for meteorological stations published in the World Weather Records and Monthly Climatic Data for the World and (2) data provided by the National Center for Atmospheric Research (Jenne 1975; Spangler and Jenne 1980). Starting with temperature differences between neighboring stations, temperature differences are combined to ultimately provide estimates of temperature change for grid boxes, latitudinal zones, hemispheres, and the globe. Further details about the methods of calculating these annual temperature differences are provided in Hansen and Lebedeff (1987).

Data availability – These data are available from CDIAC and were presented in Hansen and Lebedeff (1987) and updated in Hansen and Lebedeff (1988).



Annual surface air temperature anomalies.

TRENDS

Hansen and Lebedeff (1987) reported "global temperature increases by about 0.5°C between 1880 and 1940, decreases by about 0.2°C between 1940 and 1965, and increases by about 0.3 °C between 1965 and 1980. The northern hemisphere temperature change is rather similar to the global change, increasing by 0.6°C between 1880 and 1940, decreasing by 0.3°C between 1940 and 1970, and increasing by 0.3°C between 1970 and 1980. The southern hemisphere temperature change is noisier, but, especially if averaged over a 10-year interval or longer, it shows a more steady increase in temperature, with a warming of about 0.6°C between 1880 and 1980. The largest rate of warming is between 1965 and 1980."

Hansen and Lebedeff (1988) also reported that the global surface air temperatures in the 1980s are the warmest in the history of meteorological records and that the four warmest years on record are all in the 1980s, with the warmest years being 1981 and 1987.

Global and Hemispheric

Year	Global	Northern Hem.	Southern Hem.
1880	–0.40	–0.52	–0.10
1881	–0.37	–0.41	–0.25
1882	–0.43	–0.47	–0.33
1883	–0.47	–0.55	–0.25
1884	–0.72	–0.78	–0.55
1885	–0.54	–0.61	–0.34
1886	–0.47	–0.51	–0.34
1887	–0.54	–0.59	–0.43
1888	–0.39	–0.46	–0.22
1889	–0.19	–0.24	–0.07
1890	–0.40	–0.40	–0.39
1891	–0.44	–0.45	–0.43
1892	–0.44	–0.49	–0.32
1893	–0.49	–0.52	–0.43
1894	–0.38	–0.42	–0.30
1895	–0.41	–0.48	–0.26
1896	–0.27	–0.37	–0.08
1897	–0.18	–0.23	–0.07
1898	–0.38	–0.41	–0.33
1899	–0.22	–0.22	–0.24
1900	–0.03	–0.08	0.07
1901	–0.09	–0.09	–0.07
1902	–0.28	–0.39	–0.09
1903	–0.36	–0.40	–0.29
1904	–0.49	–0.48	–0.52
1905	–0.25	–0.29	–0.19
1906	–0.17	–0.17	–0.17
1907	–0.45	–0.50	–0.37
1908	–0.32	–0.37	–0.23
1909	–0.33	–0.39	–0.22
1910	–0.32	–0.40	–0.19
1911	–0.29	–0.30	–0.28
1912	–0.32	–0.45	–0.08
1913	–0.25	–0.35	–0.08
1914	–0.05	–0.13	0.08
1915	–0.01	–0.06	0.09
1916	–0.26	–0.34	–0.11
1917	–0.48	–0.60	–0.26
1918	–0.37	–0.43	–0.27
1919	–0.20	–0.29	–0.03
1920	–0.15	–0.18	–0.11
1921	–0.08	–0.08	–0.09
1922	–0.14	–0.19	–0.07
1923	–0.13	–0.10	–0.19
1924	–0.12	–0.12	–0.11
1925	–0.10	–0.04	–0.21
1926	0.13	0.17	0.06
1927	–0.01	0.01	–0.04
1928	0.06	0.11	–0.01
1929	–0.17	–0.16	–0.18
1930	–0.01	0.09	–0.19
1931	0.09	0.16	–0.04
1932	0.05	0.10	–0.03
1933	–0.16	–0.23	–0.04
1934	0.05	0.07	0.01
1935	–0.02	0.00	–0.05
1936	0.04	0.06	0.01
1937	0.17	0.25	0.04
1938	0.19	0.29	0.01
1939	0.05	0.17	–0.14
1940	0.15	0.16	0.13
1941	0.13	0.13	0.14
1942	0.09	0.07	0.12
1943	0.04	0.08	–0.03
1944	0.11	0.16	0.04
1945	–0.03	–0.04	–0.02
1946	0.03	0.08	–0.05
1947	0.15	0.18	0.11
1948	0.04	0.10	–0.06
1949	–0.02	0.04	–0.10
1950	–0.13	–0.13	–0.14
1951	0.02	0.07	–0.05

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*Anomalies expressed in degrees Celsius.

Annual Temperature Anomalies*

Year	Global	Northern Hem.	Southern Hem.
1952	0.07	0.09	0.05
1953	0.20	0.33	0.03
1954	–0.03	0.02	–0.10
1955	–0.07	–0.09	–0.04
1956	–0.19	–0.29	–0.05
1957	0.09	0.03	0.17
1958	0.11	0.16	0.04
1959	0.06	0.13	–0.02
1960	0.01	0.11	–0.10
1961	0.08	0.07	0.08
1962	0.02	0.10	–0.07
1963	0.02	0.10	–0.08
1964	–0.27	–0.24	–0.31
1965	–0.18	–0.20	–0.15
1966	–0.09	–0.08	–0.10
1967	–0.02	0.01	–0.06
1968	–0.13	–0.12	–0.14
1969	0.02	–0.03	0.09
1970	0.03	–0.02	0.09
1971	–0.12	–0.15	–0.08
1972	–0.08	–0.26	0.14
1973	0.17	0.17	0.17
1974	–0.09	–0.16	0.00
1975	–0.04	–0.03	–0.05
1976	–0.24	–0.27	–0.20
1977	0.16	0.15	0.17
1978	0.09	0.07	0.12
1979	0.12	0.12	0.13
1980	0.27	0.21	0.33
1981	0.36	0.50	0.20
1982	0.05	0.03	0.09
1983	0.30	0.37	0.22
1984	0.09	0.08	0.10
1985	0.05	–0.02	0.13
1986	0.17	0.17	0.17
1987	0.33	0.31	0.34

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Global (90°S–90°N)

BACKGROUND

Principal investigators

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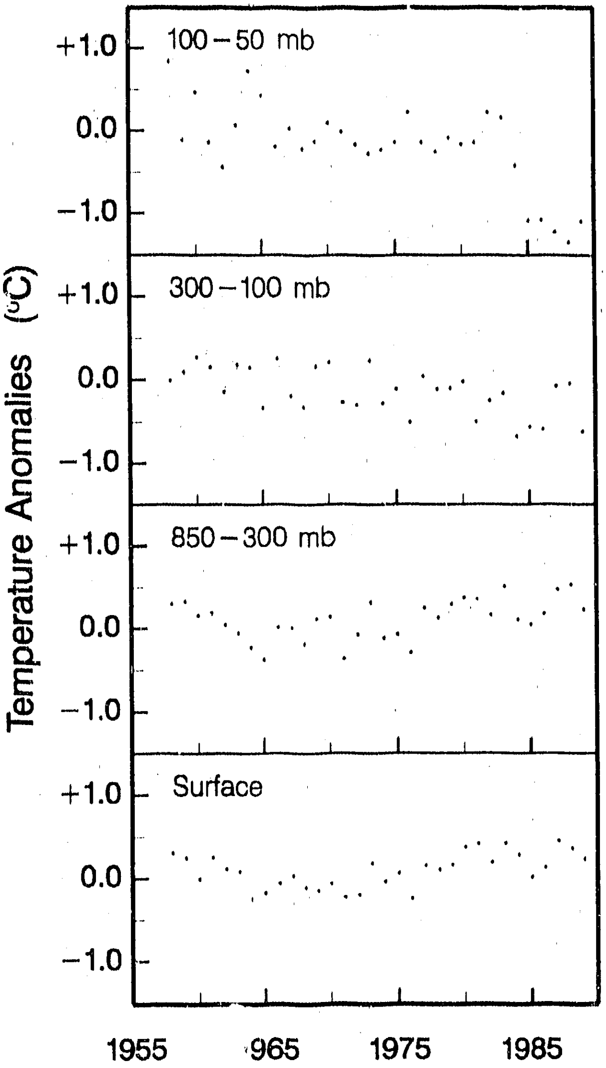
Period of record — 1958–1990 (relative to a 1958–1977 average).

Method — Surface temperatures and thickness-derived temperatures from a 63-station, globally distributed radiosonde network have been used to estimate global and zonal annual and seasonal temperature anomalies. Most of the temperature values used were column-mean temperatures, obtained from the differences in height (thickness) between constant-pressure surfaces at individual radiosonde stations. The pressure height data before 1980 were obtained from published values in *Monthly Climatic Data for the World*. The data are evaluated as deviations from the mean based on the interval 1958–1977.

Data availability — These data are available from the principal investigator and from CDIAC (Angell and Korshover 1987).



Global annual temperature anomalies, 1958–1989 (1989 value is provisional).

TRENDS

Angell (1986) reported that, during the last quarter century, the surface and troposphere have warmed, the tropopause layer and the low stratosphere have cooled, and low-level warming and higher-level cooling have been more pronounced in the Southern Hemisphere than the Northern Hemisphere. For the earth's surface and the troposphere (850-300 mb) Angell (1988) reported a global temperature increase of 0.08°C/10 year and 0.09°C/10 year over the 30-year interval 1958–1987. There was record surface warmth in the north polar and north temperate latitudes during the first half of 1990.

Global (90°S–90°N)

An

	Surface					850–300 mb					300–100 mb					Surface–100 mb				
Year	Win†	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.70	0.26	–0.04	0.33	0.31	0.39	0.21	0.27	0.32	0.30	0.11	–0.26	0.11	0.03	0.00	0.39	–0.02	0.17	0.22	0.19
1959	0.40	0.28	0.26	0.05	0.25	0.25	0.43	0.36	0.29	0.33	–0.05	0.47	0.19	–0.22	0.10	0.22	0.43	0.30	0.16	0.28
1960	0.10	–0.05	0.03	–0.07	0.00	0.28	–0.04	0.27	0.13	0.16	0.46	0.15	0.35	0.15	0.28	0.28	0.01	0.24	0.10	0.1
1961	0.37	0.15	0.10	0.33	0.26	0.29	0.17	0.01	0.27	0.19	0.16	0.59	0.19	–0.32	0.16	0.27	0.30	0.04	0.15	0.19
1962	0.33	0.11	–0.02	0.07	0.12	0.14	–0.01	–0.01	0.07	0.05	–0.43	–0.43	–0.11	0.40	–0.14	0.05	–0.08	–0.03	0.13	0.02
1963	0.11	–0.10	0.02	0.32	0.09	0.07	–0.14	–0.11	–0.03	–0.05	–0.21	0.21	0.38	0.39	0.19	–0.05	–0.10	0.02	0.12	0.00
1964	–0.21	–0.47	–0.06	–0.23	–0.24	–0.07	–0.10	–0.25	–0.45	–0.22	0.09	0.31	0.03	0.19	0.16	0.00	–0.07	–0.16	–0.26	–0.12
1965	–0.21	–0.21	–0.17	–0.09	–0.17	–0.58	–0.47	–0.40	–0.04	–0.37	–0.35	–0.46	–0.35	–0.15	–0.33	–0.47	–0.44	–0.34	–0.09	–0.34
1966	–0.17	0.07	–0.04	–0.07	–0.05	–0.03	0.07	0.05	0.00	0.02	0.42	0.20	0.39	0.04	0.26	0.03	0.10	0.11	–0.01	0.0
1967	–0.08	0.08	0.05	0.10	0.04	–0.13	–0.03	0.06	0.12	0.01	–0.13	–0.33	–0.14	–0.14	–0.19	–0.13	–0.08	0.02	0.05	–0.04
1968	–0.10	0.16	–0.22	–0.23	–0.10	–0.02	–0.07	–0.33	–0.31	–0.18	0.00	–1.07	–0.36	0.16	–0.31	0.02	–0.26	–0.31	–0.19	–0.19
1969	–0.45	–0.12	–0.11	0.11	–0.14	–0.16	0.14	0.32	0.18	0.12	0.42	0.58	0.01	–0.32	0.17	–0.03	0.12	0.18	0.06	0.08
1970	0.20	–0.09	–0.15	–0.15	–0.05	0.11	0.13	0.18	0.13	0.14	0.05	0.28	0.35	0.20	0.22	0.08	0.13	0.18	0.11	0.13
1971	–0.28	–0.20	–0.18	–0.21	–0.22	–0.17	–0.44	–0.39	–0.44	–0.36	–0.02	–0.15	–0.35	–0.53	–0.26	–0.16	–0.35	–0.34	–0.42	–0.32
1972	–0.38	–0.30	0.14	–0.23	–0.19	–0.49	–0.13	0.18	0.16	–0.07	–0.48	–0.54	–0.23	0.10	–0.29	–0.50	–0.30	0.08	0.04	–0.17
1973	0.21	0.28	0.17	0.08	0.19	0.56	0.41	0.25	0.04	0.32	0.45	0.40	0.12	–0.01	0.24	0.49	0.39	0.24	0.05	0.29
1974	–0.14	0.04	–0.02	0.02	–0.03	0.01	–0.12	–0.11	–0.23	–0.11	–0.44	–0.26	–0.30	–0.08	–0.27	–0.14	–0.12	–0.14	–0.15	–0.14
1975	0.08	0.31	0.06	–0.17	0.07	–0.03	0.00	–0.16	–0.10	–0.07	–0.12	0.10	–0.20	–0.17	–0.10	–0.08	0.09	–0.12	–0.12	–0.06
1976	–0.22	–0.42	–0.12	–0.21	–0.24	–0.15	–0.36	–0.27	–0.38	–0.29	–0.54	–0.66	–0.53	–0.25	–0.50	–0.25	–0.44	–0.39	–0.32	–0.35
1977	–0.11	0.33	0.31	0.09	0.16	0.13	0.42	0.28	0.18	0.25	0.22	0.12	–0.03	–0.11	0.05	0.11	0.33	0.22	0.10	0.19
1978	0.10	0.06	0.11	0.15	0.10	–0.03	0.30	0.21	0.03	0.13	0.16	–0.03	–0.27	–0.24	–0.10	0.02	0.21	0.08	–0.01	0.08
1979	–0.02	0.30	0.12	0.28	0.18	0.05	0.53	0.30	0.28	0.29	0.01	0.04	–0.33	–0.06	–0.09	0.03	0.37	0.19	0.23	0.21
1980	0.53	0.56	0.29	0.15	0.38	0.37	0.39	0.52	0.21	0.37	–0.41	0.28	0.22	–0.13	–0.01	0.27	0.46	0.41	0.16	0.33
1981	0.44	0.57	0.39	0.28	0.42	0.44	0.40	0.30	0.26	0.35	–0.61	–0.68	–0.37	–0.30	–0.49	0.20	0.17	0.19	0.14	0.18
1982	0.33	0.10	0.22	0.16	0.20	0.33	–0.05	0.29	0.05	0.16	–0.17	–0.35	–0.08	–0.37	–0.24	0.19	–0.07	0.21	–0.02	0.08
1983	0.57	0.51	0.32	0.32	0.43	0.41	0.87	0.52	0.22	0.51	–0.39	0.18	–0.05	–0.33	–0.15	0.29	0.68	0.36	0.15	0.37
1984	0.35	0.49	0.05	0.27	0.29	0.14	0.26	0.01	0.02	0.11	–1.07	–0.60	–0.36	–0.61	–0.66	–0.10	0.11	–0.06	–0.07	–0.03
1985	–0.11	0.09	0.29	–0.19	0.02	0.15	0.09	0.02	–0.08	0.05	–0.37	–0.20	–0.68	–0.93	–0.55	0.02	0.03	–0.10	–0.28	–0.08
1986	–0.02	0.36	0.14	0.09	0.14	0.33	0.14	0.12	0.12	0.18	–0.97	–0.53	–0.39	–0.44	–0.58	–0.02	0.03	0.03	0.01	0.01
1987	0.30	0.58	0.69	0.26	0.46	0.46	0.44	0.61	0.35	0.47	–0.10	–0.36	0.10	0.11	–0.06	0.33	0.28	0.47	0.29	0.34
1988	0.37	0.51	0.27	0.33	0.37	0.51	0.52	0.73	0.36	0.53	–0.31	–0.14	0.19	0.13	–0.03	0.31	0.38	0.52	0.30	0.38
1989	0.37	0.27	0.21	0.10	0.24	0.15	0.18	0.30	0.30	0.23	–0.78	–0.49	–0.54	–0.61	–0.61	–0.01	0.04	0.10	0.07	0.05
1990	0.47	0.89				0.25	0.60				–0.46	–0.39				0.13	0.43			

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*Temperature anomalies expressed (in relation to a 1958–1977 average) in degrees Celsius.

†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

ual and Seasonal Temperature Anomalies*

100–50 mb					100–30 mb				
Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1.01	0.53	0.58	1.22	0.84	0.68	0.34	0.71	1.50	0.81
–0.30	0.81	–0.33	–0.62	–0.11	0.02	1.42	0.39	–0.55	0.32
1.04	0.51	–0.05	0.36	0.47	1.23	–0.01	–0.78	–0.32	0.03
–1.38	–0.38	0.93	0.26	–0.14	–1.25	–1.07	0.59	–0.35	–0.52
0.07	–0.83	–0.69	–0.30	–0.44	–0.22	–1.23	–1.10	–0.59	–0.79
–0.43	–0.52	0.54	0.70	0.07	–0.63	–1.40	0.76	1.40	0.03
0.49	1.10	0.61	0.71	0.73	0.25	1.14	0.80	0.47	0.67
0.36	0.28	0.30	0.79	0.43	–0.01	0.37	0.19	0.66	0.30
–0.13	–0.66	–0.24	0.28	–0.19	–0.64	–0.41	0.06	0.82	–0.04
0.28	0.08	–0.02	–0.21	0.03	0.18	0.48	–0.04	–0.17	0.11
–0.48	–0.12	–0.11	–0.12	–0.21	–0.81	0.04	0.00	–0.19	–0.24
–0.12	–0.20	–0.36	0.19	–0.12	–0.72	–0.22	[illegible]	0.18	–0.17
0.06	–0.05	0.50	–0.10	0.10	–0.08	0.09	[illegible]	0.47	0.26
0.43	–0.24	–0.22	–0.01	–0.01	0.36	–0.32	–0.31	–0.50	–0.19
0.04	–0.02	–0.22	–0.43	–0.16	0.42	0.28	–0.53	–0.31	–0.04
–0.14	–0.30	–0.36	–0.28	–0.27	–0.12	–0.73	–0.57	–0.43	–0.46
–0.16	0.06	–0.37	–0.39	–0.22	0.09	–0.04	–0.43	–0.75	–0.28
–0.15	0.05	0.15	–0.53	–0.12	–0.29	–0.22	–0.20	–0.38	–0.27
0.18	0.37	–0.05	0.37	0.22	0.26	0.20	0.20	–0.17	0.12
–0.76	–0.01	–0.03	0.26	–0.14	–1.43	–0.33	–0.55	0.28	–0.51
–0.30	0.06	0.02	–0.76	–0.25	–0.79	–0.46	–0.26	–0.61	–0.53
0.22	0.24	–0.24	–0.53	–0.08	–0.13	0.19	–0.29	–0.81	–0.26
–0.09	–0.29	–0.25	–0.01	–0.15	–0.13	–0.83	–0.36	0.05	–0.32
0.15	–0.15	–0.61	0.06	–0.14	0.29	–0.35	–0.48	–0.11	–0.16
0.10	0.17	0.09	0.50	0.22	–0.33	–0.06	–0.03	0.35	–0.02
0.62	0.12	–0.29	0.17	0.16	0.19	–0.13	–0.41	0.01	–0.09
0.10	–0.46	–0.59	–0.70	–0.41	–0.30	–0.43	–0.49	–0.67	–0.47
–0.98	–1.04	–1.35	–0.96	–1.08	–0.78	–0.81	–1.11	–0.95	–0.91
–1.03	–0.74	–1.02	–1.50	–1.07	–0.80	–0.62	–0.78	–1.08	–0.82
–0.90	–1.29	–1.17	–1.53	–1.22	–0.73	–0.92	–1.26	–1.53	–1.11
–1.45	–1.41	–1.17	–1.32	–1.34	–1.15	–0.99	–0.96	–0.86	–0.99
–0.87	–1.08	–1.00	–1.41	–1.09	–0.64	–0.82	–0.92	–1.28	–0.92
–1.53	–1.18				–1.00	–0.97			

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North Polar (60°N–90°N)

	Surface					850–300 mb					300–100 mb				
Year	Win†	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	–0.45	–0.95	0.18	0.16	–0.27	–0.88	–0.14	0.18	0.21	–0.16	0.60	1.12	–0.21	0.56	0.52
1959	0.93	0.41	0.18	0.85	0.59	1.02	0.95	0.42	1.47	0.97	–0.39	1.47	0.04	–0.28	0.21
1960	–0.78	0.00	0.54	–0.51	–0.19	–0.07	0.88	0.84	0.00	0.41	3.47	–0.70	–0.32	0.77	0.81
1961	1.85	–0.56	0.11	1.28	0.67	1.89	–0.42	–0.63	0.49	0.33	0.60	3.05	1.47	0.46	1.40
1962	1.06	0.69	0.21	0.44	0.60	–0.14	0.22	–0.07	–0.32	–0.08	–2.63	–1.68	–0.81	–0.18	–1.33
1963	–0.08	–0.09	–0.39	0.19	–0.09	–0.04	0.25	–0.25	–0.21	–0.06	–0.11	0.28	0.53	–0.53	0.04
1964	0.15	–0.55	–0.18	–0.60	–0.30	0.07	–0.56	–0.70	–0.70	–0.47	–2.91	1.61	0.04	0.74	–0.13
1965	–0.55	0.18	–0.10	0.54	0.02	–0.21	–0.39	–0.88	0.84	–0.16	–1.09	–1.61	0.04	–0.38	–0.76
1966	–3.41	–1.44	0.00	–0.96	–1.45	–1.47	–0.42	0.11	0.21	–0.39	2.49	0.42	0.81	0.49	1.05
1967	–0.28	1.35	–0.66	0.78	0.30	–0.46	0.07	–0.39	0.42	–0.09	–1.40	–3.89	–0.21	–1.47	–1.74
1968	0.00	0.58	–0.25	–0.91	–0.15	–0.18	–0.32	0.00	–0.42	–0.23	1.36	–4.34	–0.49	–0.42	–0.97
1969	–0.70	–0.48	0.01	0.58	–0.15	0.07	0.11	0.49	0.32	0.25	2.98	0.18	0.28	–0.14	0.83
1970	1.31	0.44	–0.36	–0.71	0.17	1.02	–0.21	0.14	–0.18	0.19	2.87	0.28	–0.11	0.18	0.81
1971	–0.82	0.05	0.64	–0.06	–0.05	–0.53	–0.21	–0.11	–1.30	–0.54	0.32	0.53	–0.18	–0.73	–0.02
1972	–0.11	–0.29	–0.20	–0.75	–0.34	–0.25	0.07	0.21	–0.35	–0.08	–3.15	–0.46	–0.49	0.32	–0.95
1973	1.57	–0.25	0.83	–0.14	0.50	0.63	–0.35	0.77	0.11	0.29	0.49	1.26	–0.21	0.32	0.47
1974	0.53	0.14	–0.21	0.14	0.15	0.18	0.74	0.00	–0.28	0.16	–2.63	0.98	–0.28	0.88	–0.26
1975	–0.13	0.91	–0.33	–0.41	0.01	–0.67	0.25	–0.14	–0.21	–0.19	–0.77	1.40	0.04	–0.49	0.05
1976	0.30	0.28	–0.45	–0.93	–0.20	–0.56	–0.21	–0.28	0.48	–0.14	–4.03	–2.24	–1.02	–1.13	–2.11
1977	0.18	–0.79	0.19	–0.55	–0.24	0.78	0.06	0.83	–0.15	0.38	3.27	1.42	–0.88	–0.77	0.76
1978	0.60	0.55	–0.36	–0.18	0.15	0.03	0.54	0.36	–0.38	0.14	–0.65	0.49	–0.14	–1.17	–0.37
1979	–0.46	–0.23	–0.91	–0.18	–0.45	–0.39	0.16	0.25	0.00	0.01	–0.36	0.54	–0.10	0.09	0.04
1980	1.12	0.30	0.00	–0.84	0.15	0.38	0.35	0.17	–0.40	0.13	–2.36	1.15	0.09	–0.23	–0.34
1981	1.85	0.48	–0.45	1.10	0.75	–0.27	0.76	–0.22	0.56	0.21	–1.72	–0.90	–0.02	–0.63	–0.82
1982	0.80	–0.06	–0.19	–1.71	–0.29	0.25	–0.38	0.18	–0.71	–0.17	–0.45	–0.33	–0.12	–1.09	–0.50
1983	0.38	0.52	–0.08	–0.34	0.12	–0.46	0.48	0.56	–0.01	0.14	–4.43	0.23	–0.65	–1.28	–1.53
1984	1.18	0.49	–0.10	0.17	0.44	0.10	0.40	0.07	0.58	0.29	–3.25	1.61	–0.18	–0.93	–0.69
1985	0.13	–0.33	–0.54	–0.51	–0.31	0.43	–0.78	–0.86	–0.04	–0.31	3.75	1.71	–0.02	0.04	1.37
1986	–0.10	–0.19	–0.02	0.81	0.13	0.38	–0.59	–0.01	–0.34	–0.14	–1.43	0.20	–0.89	–1.02	–0.79
1987	–1.21	–0.73	0.00	–0.58	–0.63	–0.47	0.32	–0.02	–0.40	–0.14	1.73	0.26	–0.24	0.61	0.59
1988	0.54	1.06	0.44	–0.45	0.40	0.10	–0.09	0.95	–0.11	0.21	–0.22	–1.35	–0.37	–1.09	–0.76
1989	1.99	1.42	0.69	0.06	1.04	–0.49	0.58	0.27	–0.27	0.02	–3.62	1.09	–0.52	–0.61	–0.92
1990	0.92	3.98				0.02	0.22				–3.87	–5.98			

*Temperature anomalies (in relation to a 1958–1977 average) expressed in degrees Celsius.

†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

Annual and Seasonal Temperature Anomalies*

Surface–100 mb					100–50 mb					100–30 mb				
Win	**Spr**	**Fall**	**Sum**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**
–0.48	0.02	0.09	0.28	–0.02	2.60	–1.60	0.23	2.77	1.00	2.35	–2.47	0.31	3.92	1.03
0.69	0.98	0.30	0.98	0.74	–3.03	6.25	1.08	–1.30	0.75	–2.18	5.95	1.30	–1.27	0.95
0.60	0.38	0.53	0.09	0.40	6.05	4.16	0.28	2.12	3.15	9.25	–0.41	0.09	2.95	2.97
1.60	0.33	–0.04	0.62	0.63	1.32	2.12	–0.21	1.14	1.09	1.17	2.87	0.16	1.18	1.35
–0.49	–0.30	–0.19	–0.16	–0.29	–5.08	–4.23	–1.30	–0.09	–2.68	–6.31	–4.86	–1.67	–0.20	–3.26
–0.06	0.20	–0.10	–0.21	–0.04	–0.19	–3.14	0.97	–1.02	–0.85	1.34	–4.03	0.93	–0.69	–0.61
–0.58	–0.08	–0.45	–0.36	–0.37	–4.29	2.28	0.13	0.35	–0.38	–4.55	3.35	–0.07	0.06	–0.30
–0.46	–0.57	–0.55	0.52	–0.27	–2.68	–2.73	–0.37	–1.02	–1.70	–4.63	–1.78	–0.47	–1.56	–2.11
–0.91	–0.40	0.25	0.08	–0.25	3.18	–0.71	0.33	0.09	0.72	1.49	–0.55	0.06	0.17	0.29
–0.55	–0.60	–0.40	0.06	–0.37	–3.30	–5.61	0.30	–0.99	–2.40	–4.17	–1.94	0.07	–2.15	–2.05
0.19	–1.06	–0.15	–0.50	–0.38	0.25	–4.63	0.10	0.08	–1.05	–3.96	–2.19	0.29	0.41	–1.36
0.59	0.03	0.36	0.26	0.31	1.28	–0.81	–1.76	–0.35	–0.41	–0.59	–0.43	0.02	–0.57	–0.39
1.48	0.01	0.00	–0.19	0.33	2.76	–0.24	0.69	1.62	1.21	3.03	–0.39	0.75	0.02	0.85
–0.39	0.00	0.00	–0.97	–0.34	2.35	–0.84	0.06	–0.33	0.31	0.85	–1.17	–0.12	–0.41	–0.21
–0.87	–0.11	–0.01	–0.27	–0.32	–2.06	0.76	0.06	–0.46	–0.43	–1.91	1.88	–0.11	–0.02	–0.04
0.76	0.02	0.56	0.12	0.37	1.90	–0.65	–0.67	–0.58	0.00	4.09	–1.48	–0.73	–0.35	0.38
–0.39	0.69	–0.10	0.05	0.06	–2.47	2.85	0.02	1.42	0.46	–0.97	3.05	0.01	0.63	0.68
–0.60	0.62	–0.13	–0.31	–0.11	0.57	1.59	–0.11	–0.94	0.28	1.45	0.18	0.26	0.27	0.54
–1.19	–0.58	–0.47	–0.10	–0.59	–4.38	1.40	–0.15	–0.66	–0.95	–1.62	1.26	0.03	–0.49	–0.21
1.23	0.22	0.34	–0.36	0.36	2.94	0.95	1.30	0.95	1.54	0.07	0.74	0.62	0.28	0.43
–0.08	0.52	0.13	–0.52	0.01	–1.10	0.30	–1.09	–2.42	–1.08	–0.91	0.15	–0.91	–0.88	–0.64
–0.39	0.05	–0.03	–0.01	–0.10	2.10	0.49	–0.33	0.23	0.62	0.26	0.48	–0.29	–0.89	–0.11
–0.09	0.52	0.20	–0.24	0.10	–0.12	0.87	0.10	0.41	0.32	1.05	0.83	0.06	0.05	0.50
–0.34	0.28	–0.22	0.34	0.02	–0.13	–1.52	–0.43	–0.18	–0.57	0.47	–2.35	–0.18	–0.21	–0.57
0.17	–0.20	0.03	–0.91	–0.23	1.11	0.42	0.52	–1.08	0.24	0.92	0.96	0.54	–1.90	0.13
–0.98	0.48	0.21	–0.29	–0.15	–4.36	–0.01	–0.81	–0.98	–1.54	–4.00	0.15	–0.90	–1.33	–1.52
–0.47	0.68	–0.01	0.19	0.10	–1.73	1.01	–0.45	–0.76	–0.48	–1.37	0.72	–0.22	–0.42	–0.32
1.12	–0.15	–0.62	–0.10	0.06	3.34	0.22	–0.69	–0.50	0.59	2.13	0.10	–0.43	–0.55	0.31
–0.12	–0.32	–0.24	–0.30	–0.25	–1.54	1.10	–0.62	–1.67	–0.68	–0.79	0.86	–0.41	–1.11	–0.36
–0.11	0.13	–0.06	–0.21	–0.06	3.20	–2.23	–0.34	0.38	0.25	2.27	–1.53	–0.36	0.57	0.24
0.07	–0.18	0.57	–0.39	0.02	–1.48	0.03	–0.81	–1.35	–0.90	–0.72	0.36	–0.58	–0.98	–0.48
–0.77	0.83	0.17	–0.29	–0.02	–0.38	1.11	–0.97	–0.75	–0.25	0.30	0.61	–0.60	–0.43	–0.03
–0.69	–0.53				–3.26	–6.18				–1.54	–3.47			

North Temperate Zone (30°N–60°N)

	Surface					850–300 mb					300–100 mb			
Year	**Win†**	**Spr**	**Sum**	**Fall**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**
1958	1.67	0.03	0.12	0.33	0.54	1.61	0.70	–0.07	0.14	0.60	–0.46	–0.35	0.39	0.98
1959	0.48	0.31	0.55	–0.49	0.21	0.25	0.95	0.42	0.14	0.44	0.35	0.88	0.63	0.28
1960	0.52	–0.88	0.10	–0.34	–0.15	–0.04	–0.70	0.14	–0.07	–0.17	0.84	0.60	0.25	0.53
1961	0.92	0.82	0.25	0.21	0.55	0.42	0.56	0.21	0.67	0.47	0.53	0.42	0.53	–0.28
1962	0.94	0.39	–0.09	–0.31	0.23	0.46	0.56	0.18	0.04	0.31	–0.70	–0.21	–0.28	0.28
1963	0.26	–0.11	0.03	0.97	0.29	0.53	–0.18	0.21	0.81	0.34	–0.53	–0.14	0.56	0.67
1964	0.12	–0.83	–0.19	–0.17	–0.27	–0.04	0.32	0.21	–0.07	0.11	0.14	0.07	–0.07	0.18
1965	–0.47	–0.32	–0.20	–0.60	–0.40	0.18	–0.35	–0.39	–0.49	–0.26	0.56	0.14	–0.39	0.25
1966	0.39	0.37	–0.36	–0.05	0.09	0.00	0.04	0.18	0.56	0.20	–0.25	–0.46	0.77	0.00
1967	–0.47	0.48	0.64	0.85	0.38	–0.35	0.46	0.46	0.60	0.29	–0.07	0.42	–0.88	–0.67
1968	–0.42	1.07	–0.31	–0.16	0.05	0.74	0.42	–0.67	–0.28	0.05	0.00	–0.84	–0.32	–0.04
1969	–2.27	–0.93	–0.10	–0.03	–0.83	–0.98	–0.49	0.07	0.14	–0.32	–0.46	0.25	0.21	–0.32
1970	0.00	–0.29	–0.23	0.21	–0.08	–0.42	–0.35	0.07	0.18	–0.13	–0.39	–0.42	0.32	–0.21
1971	–0.67	–0.35	–0.25	0.65	–0.16	–0.53	–0.60	–0.21	0.14	–0.30	–0.04	0.04	0.07	–0.11
1972	–0.90	–0.25	–0.06	–0.60	–0.45	–0.95	–0.35	–0.28	–0.49	–0.52	0.42	–0.46	–0.53	–0.35
1973	–0.19	–0.02	0.12	–0.43	–0.13	0.00	–0.21	–0.21	–0.67	–0.27	0.14	0.35	0.00	–0.49
1974	–0.02	–0.32	–0.47	–0.24	–0.26	–0.39	–0.81	–0.63	–1.12	–0.74	–0.25	–0.11	–0.53	–0.25
1975	0.52	0.58	0.51	0.00	0.40	–0.42	0.04	0.32	–0.21	–0.07	0.07	–0.21	–0.77	–0.21
1976	0.02	–0.80	–0.05	–0.82	–0.41	–0.25	–1.09	–0.46	–1.03	–0.71	–0.14	–0.46	–1.09	–0.52
1977	–0.96	0.53	–0.08	0.17	–0.09	–0.96	0.44	–0.11	0.14	–0.12	–0.12	0.51	0.05	0.14
1978	–0.20	–0.53	0.07	0.10	–0.14	–0.66	–0.22	–0.05	–0.13	–0.27	0.42	–0.30	0.16	–0.21
1979	–0.54	0.33	0.16	0.01	–0.01	–0.43	0.73	0.22	0.44	0.24	–0.28	–0.25	–0.31	0.10
1980	0.65	–0.14	–0.47	0.03	0.02	0.21	–0.31	0.29	–0.24	–0.01	–0.51	0.92	0.84	0.46
1981	1.06	1.06	0.31	0.40	0.71	0.73	0.71	0.37	–0.03	0.45	–0.76	–0.79	0.01	0.23
1982	0.21	–0.22	–0.05	0.28	0.[illegible]	–0.32	–0.28	–0.01	0.20	–0.10	0.69	0.50	0.09	–0.33
1983	2.92	0.60	0.34	0.57	1.11	0.93	0.98	0.45	0.39	0.69	–0.23	–0.95	–0.11	0.04
1984	1.02	0.03	0.26	–0.19	0.28	0.05	–0.25	0.27	–0.61	–0.14	–0.40	–0.32	0.00	0.43
1985	–1.29	–0.27	–0.20	–0.99	–0.69	–0.51	–0.26	–0.25	–0.46	–0.37	0.22	0.80	0.01	0.32
1986	0.14	0.51	–0.40	–0.45	–0.05	–0.07	0.52	–0.06	0.17	0.14	0.31	–0.31	–0.20	–0.12
1987	0.78	–0.13	0.10	–0.79	–0.01	0.23	0.22	0.38	–0.41	0.11	–0.05	–0.82	0.29	0.90
1988	0.55	0.60	0.39	0.26	0.45	–0.05	0.23	0.97	0.37	0.38	–0.70	0.20	–0.06	–0.05
1989	1.49	0.79	0.47	0.17	0.73	0.36	0.50	0.54	0.33	0.43	0.49	0.02	–0.85	–0.28
1990	1.31	1.77				0.53	1.03				0.35	0.24		

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*Temperature anomalies (in relation to a 1958–1977 average) expressed in degrees Celsius.

†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

Annual and Seasonal Temperature Anomalies*

	Surface–100 mb					100–50 mb					100–30 mb				
Ann	Win	Spr	Fall	Sum	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
0.14	1.16	0.36	0.06	0.36	0.49	1.40	1.22	0.89	1.93	1.36	0.36	0.83	1.37	1.94	1.13
0.54	0.31	0.83	0.49	0.07	0.43	1.48	2.18	1.32	0.64	1.41	0.60	1.48	0.99	1.21	1.07
0.56	0.25	–0.44	0.16	0.02	0.00	1.19	1.33	1.00	0.37	0.97	0.69	1.02	0.77	0.34	0.71
0.30	0.53	0.57	0.29	0.38	0.44	–1.30	0.23	0.78	–1.11	–0.35	–0.15	–0.04	0.74	–0.33	0.06
–0.23	0.28	0.36	0.03	0.06	0.18	0.53	–0.23	–0.80	0.23	–0.07	1.27	–0.53	–1.02	0.11	–0.04
0.14	0.25	–0.16	0.26	0.81	0.29	–1.11	0.01	0.70	1.01	0.15	0.56	–1.25	0.41	0.68	0.10
0.08	0.03	0.07	0.08	–0.03	0.04	–0.09	0.56	–0.16	–0.91	–0.15	0.70	1.40	–0.22	–0.70	0.30
0.14	0.16	–0.24	–0.36	–0.34	–0.20	–0.46	0.07	–0.02	0.19	–0.06	–0.68	1.40	0.14	0.02	0.22
0.02	0.01	–0.02	0.22	0.33	0.14	0.59	–0.85	0.24	0.80	0.20	–0.16	–0.50	0.27	0.90	0.13
–0.30	–0.31	0.45	0.19	0.36	0.17	0.85	0.23	–1.21	–0.28	–0.10	0.09	0.42	–0.44	–0.41	–0.09
–0.30	0.38	0.25	–0.53	–0.21	–0.03	–0.99	–0.74	0.18	–0.10	–0.41	–1.58	–0.91	0.12	–0.35	–0.68
–0.08	–1.08	–0.40	0.07	0.01	–0.35	–1.37	0.03	–0.04	1.15	–0.06	–2.03	–0.43	–0.07	–0.63	–0.79
–0.18	–0.34	–0.36	0.08	0.10	–0.13	0.05	0.37	0.33	–0.27	0.12	–0.28	0.46	0.31	–0.08	0.10
–0.01	–0.44	–0.42	–0.15	0.17	–0.21	0.03	–0.78	0.00	–0.11	–0.22	–0.75	–0.96	0.02	–0.50	–0.55
–0.23	–0.64	–0.36	–0.30	–0.48	–0.45	–0.33	0.12	0.30	0.19	0.07	1.26	0.27	–0.45	0.13	0.30
0.00	0.00	–0.05	–0.11	–0.59	–0.19	0.56	–0.94	–0.60	–0.38	–0.34	0.49	–1.58	–0.58	–0.89	–0.64
–0.29	–0.30	–0.57	–0.56	–0.78	–0.55	–0.09	0.46	–0.07	–0.38	–0.02	0.66	0.54	–0.14	0.11	0.29
–0.28	–0.15	0.07	0.11	–0.29	–0.07	–0.16	–0.09	–0.29	–0.82	–0.34	–0.66	–0.62	–0.12	–0.09	–0.37
–0.55	–0.18	–0.90	–0.53	–0.88	–0.62	0.04	0.38	–0.58	0.27	0.03	0.72	0.43	–0.35	0.29	0.27
0.15	–0.77	0.47	–0.04	0.14	–0.05	–0.17	–0.08	0.42	0.17	0.09	–0.25	–0.30	0.12	–0.13	–0.14
0.02	–0.34	–0.09	0.02	–0.10	–0.13	0.24	–1.35	–0.78	–0.29	–0.55	–0.58	–1.29	–0.56	–0.09	–0.63
–0.19	–0.36	0.45	0.09	0.31	0.12	0.18	0.60	–0.16	0.27	0.22	0.47	0.06	0.00	–0.02	0.13
0.43	0.14	0.04	0.27	–0.07	0.10	–0.21	1.02	0.03	1.08	0.48	–0.93	0.41	0.39	0.79	0.17
–0.33	0.49	0.42	0.28	0.10	0.32	0.52	0.04	–0.09	0.53	0.25	0.45	0.36	0.11	0.83	0.44
0.24	–0.02	–0.09	0.03	0.09	0.00	0.93	0.64	0.91	0.24	0.68	1.78	0.68	0.77	0.36	0.90
–0.31	1.02	0.50	0.28	0.33	0.53	0.28	0.18	–0.39	–0.02	0.01	0.51	0.23	–0.57	0.31	0.12
–0.07	0.11	–0.22	0.21	–0.34	–0.06	0.00	0.59	–0.79	0.40	0.05	0.23	0.34	–0.49	0.26	0.09
0.34	–0.48	–0.03	–0.18	–0.37	–0.27	–0.44	–1.09	–0.65	–0.01	–0.55	–0.26	–0.82	–0.46	–0.04	–0.40
–0.08	0.05	0.34	–0.15	0.00	0.06	1.07	–0.26	–0.39	0.26	0.17	0.80	–0.09	–0.28	0.19	0.16
0.08	0.26	–0.07	0.32	–0.18	0.08	–0.01	–0.68	0.27	0.77	0.09	0.03	–0.40	–0.24	0.63	0.01
–0.15	–0.09	0.29	0.64	0.26	0.28	–1.36	0.68	–0.23	–0.10	–0.25	–0.68	0.47	–0.23	–0.10	–0.14
–0.16	0.58	0.44	0.22	0.17	0.35	0.33	–0.87	–0.80	–0.37	–0.43	0.46	–0.54	–0.71	–0.23	–0.26
	0.62	0.98			–0.78	–0.43				–0.55	–0.40				

North Subtropics (10°N–30°N)

	Surface					850–300 mb					300–100 mb				
Year	Win†	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.22	0.40	0.12	0.30	0.26	0.28	0.77	0.81	0.88	0.69	0.31	0.18	0.56	0.77	0.46
1959	0.05	0.08	–0.02	–0.07	0.01	0.53	0.63	0.42	0.39	0.49	0.67	0.32	0.35	0.70	0.51
1960	0.05	0.00	0.05	–0.47	–0.09	0.49	0.44	0.49	0.18	0.40	0.53	0.11	0.39	–0.21	0.21
1961	–0.07	–0.24	–0.17	–0.38	–0.22	0.18	0.11	0.00	0.04	0.08	0.11	0.28	0.56	0.25	0.30
1962	–0.21	–0.12	–0.12	0.02	–0.11	0.28	–0.14	–0.11	0.18	0.05	0.60	0.35	0.25	0.25	0.36
1963	0.42	0.17	0.10	0.34	0.26	–0.07	–0.25	–0.21	–0.21	–0.19	–0.11	0.18	0.11	0.46	0.16
1964	–0.67	–0.39	–0.14	–0.39	–0.40	0.07	0.07	–0.07	–0.46	–0.10	0.63	0.53	0.14	–0.35	0.24
1965	–0.15	–0.38	–0.18	–0.08	–0.20	–0.91	–0.53	–0.60	–0.25	–0.57	–0.67	–0.49	–0.28	0.07	–0.34
1966	–0.35	0.09	0.06	0.08	–0.03	0.14	0.32	0.25	0.14	0.21	1.02	0.56	0.67	0.24	0.62
1967	–0.31	–0.17	–0.07	–0.47	–0.26	0.25	–0.35	0.14	–0.11	–0.02	0.00	0.11	0.21	0.14	0.12
1968	–0.29	–0.37	0.02	0.01	–0.16	–0.46	–0.60	–0.39	–0.32	–0.44	–0.49	–0.95	–1.02	–0.91	–0.84
1969	0.39	0.42	0.44	0.24	0.37	–0.14	0.11	0.28	0.04	0.07	–0.56	0.39	–0.46	–0.42	–0.26
1970	0.55	0.19	0.28	0.00	0.26	0.11	0.18	0.25	0.07	0.15	–0.21	0.35	0.39	0.28	0.20
1971	–0.11	0.06	–0.27	–0.27	–0.15	–0.25	–0.70	–0.67	–0.60	–0.56	–0.42	–0.74	–1.05	–0.95	–0.79
1972	–0.19	–0.32	0.27	0.30	0.02	–0.67	–0.35	–0.04	–0.11	–0.29	–0.98	–0.77	0.00	0.21	–0.39
1973	0.47	0.62	0.28	0.35	0.43	0.53	0.39	0.07	0.11	0.28	1.05	0.60	0.18	–0.14	0.42
1974	0.12	0.20	–0.32	0.02	0.01	–0.18	–0.21	–0.28	–0.11	–0.20	–0.53	–0.63	–0.53	–0.21	–0.48
1975	0.17	0.12	–0.08	0.09	0.08	–0.25	0.04	–0.32	0.00	–0.13	–0.60	–0.14	–0.11	0.11	–0.19
1976	0.08	–0.23	0.08	0.48	0.10	–0.49	–0.49	–0.49	–0.34	–0.45	–0.35	–0.35	–0.39	–0.40	–0.37
1977	0.09	0.45	0.40	0.71	0.41	0.31	–0.13	–0.20	0.19	0.04	–0.05	–0.15	–0.17	–0.69	–0.27
1978	0.44	–0.14	0.43	0.63	0.34	–0.01	0.08	–0.02	–0.16	–0.03	0.00	–0.64	–0.70	–0.76	–0.53
1979	0.19	0.38	0.16	0.44	0.29	–0.51	–0.02	–0.03	0.08	–0.12	–0.58	0.05	–0.76	–0.88	–0.54
1980	0.71	0.96	0.45	0.56	0.67	0.06	0.14	0.36	0.21	0.19	–0.34	0.12	0.00	–0.24	–0.12
1981	0.54	0.71	0.68	0.33	0.57	0.05	–0.11	0.06	0.18	0.05	–0.56	–0.79	–0.63	–0.74	–0.68
1982	0.57	0.05	0.40	0.45	0.37	–0.17	–0.27	0.10	–0.34	–0.17	–0.53	–0.82	–0.22	–0.67	–0.56
1983	–0.37	–0.13	0.59	0.64	0.18	–0.25	0.12	0.10	0.04	0.00	0.35	0.20	0.21	–0.56	0.05
1984	–0.19	0.48	0.11	0.36	0.19	0.05	0.07	–0.35	–0.19	–0.11	–1.02	–0.87	–0.71	–1.23	–0.96
1985	–0.17	0.02	0.22	0.34	0.10	–0.05	–0.19	–0.28	–0.51	–0.26	–0.74	–0.53	–0.97	–1.03	–0.82
1986	0.07	0.21	0.28	0.27	0.21	0.25	0.07	0.11	0.10	0.13	–0.77	–1.02	–0.60	–0.47	–0.72
1987	0.46	0.42	0.76	1.07	0.68	0.23	–0.15	0.48	0.69	0.31	0.35	–0.35	–0.16	0.22	0.02
1988	0.37	0.47	0.18	0.02	0.26	0.59	0.52	0.81	0.52	0.61	–0.38	–0.21	–0.04	–0.26	–0.22
1989	0.14	0.14	0.30	–0.02	0.14	0.07	0.06	0.24	0.45	0.21	–0.42	–0.92	–0.45	–0.22	–0.50
1990	0.31	0.14				–0.13	0.74				0.76	0.30			

*Temperature anomalies (in relation to a 1958–1977 average) expressed in degrees Celsius.
†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

Annual and Seasonal Temperature Anomalies*

Surface–100 mb					100–50 mb					100–30 mb				
Win	**Spr**	**Fall**	**Sum**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**
0.28	0.58	0.64	0.76	0.57	0.60	0.60	–0.47	0.13	0.22	0.71	1.50	–0.19	0.33	0.59
0.48	0.47	0.33	0.41	0.42	0.01	–0.22	0.14	–0.39	–0.12	0.12	–0.73	–0.11	0.33	–0.10
0.43	0.07	0.39	–0.02	0.22	–0.41	–0.48	0.14	0.71	–0.01	–0.48	–0.21	0.11	0.64	0.02
0.12	0.17	0.10	0.02	0.10	–0.38	–0.64	1.38	1.99	0.59	–1.01	–1.17	1.54	1.37	0.18
0.27	–0.03	–0.03	0.17	0.10	0.63	0.08	–0.49	–0.15	0.02	0.83	0.39	–0.39	0.16	0.25
0.00	–0.08	–0.09	0.03	–0.04	0.05	0.81	1.99	0.86	0.93	–0.33	0.84	1.81	1.12	0.86
0.07	0.10	–0.04	–0.42	–0.07	1.19	0.77	1.47	0.18	0.90	1.28	0.72	1.35	0.74	1.02
–0.73	–0.50	–0.46	–0.15	–0.46	1.15	0.55	1.06	1.39	1.04	1.39	1.34	0.79	1.24	1.19
0.25	0.34	0.31	0.15	0.26	–0.09	–0.08	–0.27	–0.08	–0.13	–0.71	–0.53	–0.34	0.46	–0.28
0.10	–0.22	0.12	–0.11	–0.03	0.09	0.57	–0.49	–1.42	–0.31	0.45	0.73	–0.37	–0.67	0.04
–0.44	–0.64	–0.46	–0.40	–0.49	–0.34	1.16	0.00	–0.11	0.18	–0.03	1.04	–0.02	–0.53	0.12
–0.08	–0.22	0.14	–0.03	–0.05	–0.18	0.11	–0.10	0.67	0.13	–1.16	–0.78	–0.84	0.22	–0.64
0.11	0.22	0.29	0.11	0.18	–0.83	–0.57	–0.06	0.03	–0.36	–0.94	–0.20	0.40	0.42	–0.08
–0.26	–0.58	–0.69	–0.62	–0.54	–0.13	–0.05	–0.17	0.01	–0.09	–0.46	–0.32	0.05	–0.32	–0.26
–0.66	–0.44	0.02	0.03	–0.26	0.56	–0.55	–1.62	–0.48	–0.52	0.20	–0.41	–1.61	–1.10	–0.73
0.64	0.48	0.13	0.09	0.34	–0.48	–0.54	–0.18	–0.15	–0.34	–1.72	–1.26	–0.36	–0.55	–0.97
–0.21	–0.24	–0.34	–0.11	–0.23	0.18	–0.77	–0.58	–0.55	–0.43	0.83	–0.69	–0.48	-1.16	–0.38
–0.26	0.01	–0.23	0.04	–0.11	–0.20	0.39	–0.22	–0.09	–0.03	–0.47	0.02	–0.03	–0.35	–0.21
–0.36	–0.42	–0.37	–0.22	–0.34	1.15	0.49	0.77	–0.13	0.57	1.29	0.05	0.16	–0.39	0.28
0.20	–0.04	–0.11	0.09	0.04	–1.57	1.00	0.30	0.06	–0.05	–1.89	0.53	–1.16	–1.23	–0.94
0.00	–0.12	–0.08	–0.16	–0.09	–0.89	–0.66	–0.76	–0.77	–0.77	–2.17	–1.87	–1.13	–1.33	–1.63
–0.41	0.07	0.22	0.02	–0.03	–0.10	0.13	–0.21	–0.24	–0.11	0.06	0.11	–0.31	–0.86	–0.25
0.07	0.26	0.22	0.19	0.19	0.28	–0.52	–0.27	–0.20	–0.18	–0.14	–1.44	0.07	–0.24	–0.44
–0.01	–0.12	0.12	0.06	0.01	–0.22	–0.78	–0.75	–0.31	–0.52	0.04	–1.00	–0.88	–0.59	–0.61
–0.22	–0.33	0.07	–0.29	–0.19	0.04	0.28	0.71	0.90	0.48	–0.67	0.43	0.89	1.14	0.45
–0.14	0.07	0.18	0.09	0.05	1.14	–0.14	–0.37	0.61	0.31	0.22	–1.13	–0.69	0.56	–0.26
–0.22	–0.07	–0.31	–0.22	–0.21	0.29	–0.99	–0.93	–0.26	–0.47	0.35	–0.75	–0.74	–0.32	–0.37
–0.20	–0.21	–0.32	–0.48	–0.30	–1.07	–0.81	–0.39	0.23	–0.51	–0.92	–0.91	–0.50	–0.13	–0.62
–0.01	–0.18	0.02	0.10	–0.02	–1.26	–0.54	–1.65	–1.33	–1.20	–0.89	–0.80	–1.26	–0.96	–0.98
0.33	–0.11	0.40	0.59	0.30	–1.50	–0.47	–0.55	–0.65	–0.79	–0.99	–0.55	–0.74	–0.76	–0.76
0.34	0.42	0.48	0.25	0.37	–1.66	–1.50	–1.21	–1.81	–1.55	–1.23	–1.09	–0.98	–1.21	–1.13
0.05	–0.19	0.10	0.22	0.05	–0.69	–0.70	–0.05	–0.40	–0.46	–0.39	–0.68	–0.42	–0.42	–0.48
0.14	0.56				0.04	0.91				–0.33	–0.32			

Equatorial (10°S–10°N)

	Surface					850–300 mb					300–100 mb			
Year	**Win†**	**Spr**	**Sum**	**Fall**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**
1958	0.45	–0.30	–0.90	0.30	–0.11	0.25	–0.30	–0.60	–0.22	–0.22	0.68	–1.65	–0.05	0.37
1959	0.15	–0.45	–0.18	0.25	–0.06	–0.04	–0.09	–0.27	–0.27	–0.17	–0.13	–0.19	–0.02	–0.25
1960	–0.07	–0.07	0.00	0.23	0.02	–0.03	–0.11	0.15	0.06	0.02	0.11	–0.19	0.38	0.23
1961	0.12	0.17	0.13	0.02	0.11	–0.11	–0.05	–0.03	–0.35	–0.14	–0.03	–0.12	–0.55	–0.03
1962	–0.02	–0.18	–0.12	–0.13	–0.11	–0.14	–0.25	–0.22	0.20	–0.10	0.32	0.21	–0.06	0.29
1963	–0.22	–0.23	0.07	0.22	–0.04	–0.24	–0.10	0.13	0.19	–0.01	–0.11	0.20	–0.26	–0.07
1964	–0.23	–0.09	–0.11	–0.39	–0.21	0.49	0.28	–0.32	–0.47	–0.01	0.21	0.00	–0.34	–0.78
1965	–0.64	–0.01	–0.31	0.07	–0.22	–0.76	–0.20	–0.32	0.06	–0.31	–1.08	–0.94	–0.40	0.15
1966	–0.10	0.13	0.20	–0.03	0.05	0.30	0.23	0.20	–0.33	0.10	0.35	0.21	0.01	–0.37
1967	–0.08	–0.09	–0.06	–0.38	–0.15	–0.34	–0.39	–0.10	–0.17	–0.25	–0.20	–0.33	0.21	0.00
1968	–0.13	–0.20	0.08	0.09	–0.04	–0.17	–0.35	–0.11	–0.19	–0.21	–0.57	–1.01	0.15	–0.26
1969	0.17	0.36	–0.01	0.32	0.21	0.19	0.68	0.25	0.24	0.34	0.30	0.92	–0.13	0.39
1970	0.38	0.14	–0.11	–0.37	0.01	0.55	0.62	0.38	0.43	0.50	0.41	1.30	[illegible]	0.57
1971	–0.14	–0.20	–0.33	–0.47	–0.29	–0.21	–0.55	–0.43	–0.57	–0.44	0.06	–0.82	–0.60	–0.76
1972	–0.10	–0.24	0.19	0.24	0.02	–0.55	–0.13	0.45	0.64	0.10	–0.85	–0.46	0.18	0.45
1973	0.59	0.37	0.16	0.36	0.37	1.15	0.64	0.39	0.35	0.63	1.13	0.87	0.76	0.37
1974	0.03	–0.30	0.26	0.12	0.03	–0.37	–0.02	0.08	0.16	–0.04	–0.29	–0.02	0.35	–0.20
1975	0.13	0.19	–0.10	–0.27	-0.01	0.18	0.20	–0.02	–0.06	0.08	0.15	0.18	–0.10	0.28
1976	–0.31	0.08	–0.20	0.07	-0.09	–0.18	–0.34	–0.16	0.37	–0.08	–0.02	–0.42	0.15	0.55
1977	–0.02	0.43	0.37	0.33	0.28	0.45	0.32	0.44	0.47	0.42	0.36	0.16	0.26	0.33
1978	0.51	0.26	0.30	0.39	0.37	0.50	0.78	0.11	0.05	0.36	0.10	0.35	–0.29	–0.36
1979	0.54	0.60	0.54	0.61	0.57	0.52	0.22	0.50	0.42	0.42	0.36	0.09	–0.01	–0.51
1980	0.40	0.49	0.06	0.33	0.32	0.35	0.44	0.57	0.50	0.47	–0.84	–0.60	–0.11	–0.44
1981	0.13	0.43	0.15	0.07	0.20	0.31	0.45	0.09	0.37	0.31	–0.89	–0.91	–0.73	–0.54
1982	0.26	0.28	0.62	0.33	0.37	0.53	0.24	0.57	0.21	0.39	–0.56	–0.98	–0.40	–0.86
1983	0.52	0.58	0.61	0.14	0.46	1.21	1.21	0.77	–0.10	0.77	0.06	0.31	0.21	–0.47
1984	0.63	–0.01	–0.32	0.13	0.11	–0.04	0.08	–0.04	–0.07	–0.02	–0.86	–0.89	–0.99	–1.20
1985	0.56	0.06	0.05	0.28	0.24	0.26	0.08	–0.19	0.11	0.07	–1.04	–1.13	–1.34	–1.25
1986	0.35	0.39	0.29	0.22	0.31	0.20	0.02	–0.05	0.37	0.14	–0.90	–0.77	–0.81	–0.64
1987	0.81	1.37	1.41	0.87	1.12	0.77	0.80	0.96	0.91	0.86	–0.02	–0.19	0.23	0.30
1988	1.03	0.74	0.24	0.57	0.65	1.15	0.62	0.77	0.24	0.70	0.22	0.33	0.73	–0.64
1989	0.23	–0.08	0.12	0.56	0.21	–0.26	–0.30	–0.12	0.23	–0.11	–1.45	–1.18	–0.52	–0.28
1990	0.70	0.72				0.17	0.62				–0.96	–0.40		

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*Temperature anomalies (in relation to a 1958–1977 average) expressed in degrees Celsius.

†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

Annual and Seasonal Temperature Anomalies*

	Surface–100 mb					100–50 mb					100–30 mb				
Ann	**Win**	**Spr**	**Fall**	**Sum**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**
–0.16	0.37	–1.43	–0.59	–0.21	–0.47										
–0.15	–0.02	–0.11	–0.20	–0.04	–0.09	–1.87	–2.65	–2.81	1.25	–1.52					
0.13	–0.01	–0.10	0.18	0.13	0.05	0.21	–1.07	–2.00	–1.72	–1.15	–0.14	–1.23	–5.18	–4.66	–2.80
–0.18	–0.06	0.01	–0.28	–0.21	–0.14	–5.23	–2.29	0.83	2.63	–1.02	–4.97	–4.80	–0.56	–1.47	–2.95
0.19	–0.01	–0.13	–0.24	0.05	–0.08	0.59	–0.88	–1.21	–2.17	–0.92	–0.37	–2.04	–3.64	–3.12	–2.29
–0.06	–0.20	–0.05	0.02	0.13	–0.03	–1.45	–2.02	–0.47	1.02	–0.73	–3.99	–3.46	0.72	3.89	–0.71
–0.23	0.37	0.19	–0.28	–0.49	–0.05	1.38	2.27	1.70	1.50	1.71	0.62	1.99	1.49	0.64	1.19
–0.57	–0.81	–0.41	–0.33	0.08	–0.37	0.99	0.51	–0.55	–0.83	0.03	0.57	–0.09	–1.14	–1.37	–0.51
0.05	0.15	0.21	0.12	–0.29	0.05	–1.86	–1.97	–0.48	2.23	–0.52	–2.34	–0.93	1.72	2.30	0.19
–0.08	–0.31	–0.32	–0.01	–0.15	–0.20	1.49	2.12	0.33	0.23	1.04	2.04	2.03	0.88	0.14	1.27
–0.42	–0.25	–0.47	–0.01	–0.15	–0.22	–0.30	1.14	–0.91	–1.16	–0.31	–1.06	0.09	–0.95	–0.48	–0.60
0.37	0.21	0.63	0.09	0.29	0.31	–1.18	–1.59	0.34	0.57	–0.47	–1.25	–0.38	1.22	1.59	0.30
0.74	0.49	0.69	0.37	0.40	0.49	0.28	0.20	0.39	0.69	0.39	–0.70	–0.55	0.10	0.65	–0.13
–0.53	–0.19	–0.56	–0.45	–0.59	–0.45	0.20	–0.63	1.09	1.25	0.48	1.67	1.66	1.14	–0.42	1.01
–0.17	–0.54	–0.22	0.36	0.52	0.03	1.84	1.26	–0.82	–2.22	0.02	1.80	0.54	–1.36	–0.72	0.07
0.78	0.94	0.65	0.43	0.36	0.60	–1.74	–0.79	0.89	0.71	–0.23	–1.80	–0.22	0.51	0.37	–0.29
–0.04	–0.29	–0.16	0.17	0.08	–0.05	1.64	0.46	–1.01	–1.59	–0.13	1.27	–0.72	–2.05	–2.32	–0.96
0.13	0.17	0.19	–0.05	–0.01	0.08	–0.78	–0.53	0.76	1.24	0.17	–0.54	–0.11	0.26	1.44	0.26
0.07	–0.16	–0.29	–0.10	0.36	–0.05	3.31	1.44	0.91	1.29	1.72	2.51	0.50	0.48	–1.53	0.49
0.28	0.35	0.30	0.39	0.41	0.36	–1.34	–0.72	–0.65	–1.21	–0.98	–3.83	–1.59	–1.40	1.22	–1.40
–0.05	0.43	0.58	0.06	0.01	0.27	–0.52	0.52	2.34	1.41	0.94	–0.03	0.80	1.19	0.60	0.64
–0.02	0.49	0.25	0.40	0.31	0.36	0.60	–0.10	–0.96	–2.24	–0.68	–0.42	–0.63	–0.81	–2.08	–0.99
–0.50	0.16	0.34	0.34	0.24	0.27	–0.79	–1.93	0.05	1.60	–0.27	–1.14	–2.53	0.69	1.37	–0.40
–0.77	–0.01	0.14	–0.11	0.08	0.03	1.33	0.55	–0.12	–0.07	0.42	1.44	–0.23	–1.32	–1.11	–0.31
–0.70	0.23	0.03	0.36	0.00	0.16	–0.98	–0.41	–0.32	1.92	0.05	–2.76	–2.23	0.44	2.42	–0.53
0.03	0.89	0.98	0.62	–0.06	0.61	1.55	1.19	0.60	0.76	1.03	0.87	0.55	–0.87	–1.10	–0.14
–0.99	–0.16	–0.17	–0.32	–0.29	–0.24	0.45	–1.10	–2.11	–2.44	–1.30	–0.94	–1.40	–1.49	–1.68	–1.38
–1.19	0.02	–0.19	–0.41	–0.16	–0.19	–2.86	–1.42	–0.05	0.38	–0.99	–1.74	–0.76	0.13	–0.27	–0.66
–0.78	–0.01	–0.10	–0.16	0.12	–0.04	–0.92	–1.16	–1.82	–2.65	–1.64	–1.01	–1.30	–1.62	–2.03	–1.49
0.08	0.68	0.72	0.69	0.88	0.74	–2.55	–3.27	–3.70	–1.43	–2.74	–2.25	–2.46	–2.20	–0.89	–1.95
0.16	0.96	0.58	0.68	0.10	0.58	–1.38	–2.29	–1.49	–2.04	–1.80	–1.08	–1.83	–1.13	–1.65	–1.42
–0.86	–0.44	–0.46	–0.17	0.17	–0.23	–0.68	–1.58	–1.89	–2.31	–1.62	–0.83	–1.27	–1.45	–1.77	–1.33
	0.01	0.41				–2.80	–2.13				–2.02	–1.33			

South Subtropics (30°S–10°S)

	Surface					850–300 mb					300–100 mb				
Year	Win†	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	1.10	1.00	–0.10	0.40	0.60	0.70	0.04	0.56	0.53	0.46	–0.14	0.04	0.00	–1.51	–0.40
1959	0.47	0.50	0.67	0.52	0.54	0.21	0.07	0.32	0.28	0.22	–0.63	–0.21	–0.53	–0.56	–0.48
1960	0.34	0.20	0.01	0.37	0.23	0.46	0.07	0.56	0.32	0.35	0.53	–0.18	0.00	0.18	0.13
1961	0.06	0.15	–0.08	0.26	0.10	–0.04	0.49	0.18	0.11	0.19	–0.18	0.39	–0.11	–0.32	–0.06
1962	0.08	0.04	–0.04	0.26	0.09	0.18	–0.28	–0.04	–0.04	–0.05	–0.07	0.07	0.11	0.28	0.10
1963	–0.13	0.00	–0.16	–0.10	–0.10	–0.18	–0.14	0.07	–0.14	–0.10	–0.56	0.07	0.25	0.07	–0.04
1964	–0.13	–0.01	–0.23	0.05	–0.08	0.00	0.07	–0.42	–0.56	–0.23	0.42	0.04	–0.32	–0.67	–0.13
1965	–0.08	–0.28	–0.09	–0.28	–0.18	–1.16	–0.60	–0.63	–0.28	–0.67	–1.19	–0.60	–0.49	0.04	–0.56
1966	–0.08	–0.25	–0.16	–0.25	–0.19	0.04	–0.18	0.04	–0.18	–0.07	0.25	0.42	0.00	0.11	0.20
1967	0.09	0.09	–0.16	0.10	0.03	–0.28	–0.04	–0.07	–0.18	–0.14	–0.42	–0.42	–0.25	–0.32	–0.35
1968	0.17	–0.72	–0.60	–0.21	–0.34	–0.23	–0.35	–0.14	0.07	–0.16	–0.11	–0.67	0.04	0.14	–0.15
1969	0.12	0.28	0.02	–0.03	0.10	0.28	0.60	0.53	0.32	0.43	0.14	0.98	0.39	0.35	0.47
1970	0.03	–0.14	–0.09	–0.24	–0.11	0.35	0.53	0.49	0.28	0.41	0.49	0.53	0.63	0.77	0.61
1971	–0.16	–0.23	–0.17	–0.25	–0.20	–0.21	–0.63	–0.56	–0.67	–0.52	0.77	–0.42	–0.46	–0.60	–0.18
1972	–0.13	–0.21	0.20	–0.06	–0.05	–0.39	0.00	0.21	0.60	0.11	0.46	–0.46	0.04	0.18	0.06
1973	0.48	0.59	0.51	0.02	0.40	0.95	0.95	0.35	0.28	0.63	0.91	0.35	0.42	0.39	0.52
1974	–0.41	–0.15	0.10	–0.05	–0.13	0.07	0.07	–0.32	–0.14	–0.08	–0.18	–0.25	–0.21	0.04	–0.15
1975	–0.45	0.11	0.15	–0.09	–0.07	–0.25	–0.21	–0.35	–0.25	–0.26	–0.14	0.11	–0.02	–0.11	–0.04
1976	–0.57	–0.32	–0.26	–0.19	–0.34	–0.32	–0.32	–0.46	–0.35	–0.36	–0.70	–0.35	–0.53	0.00	–0.40
1977	0.16	0.36	0.24	0.16	0.23	0.38	0.62	0.80	0.47	0.57	–0.07	0.03	–0.37	0.20	–0.05
1978	–0.09	0.12	–0.02	0.04	0.01	0.33	0.24	0.46	0.26	0.32	0.21	–0.04	0.07	0.13	0.09
1979	–0.24	0.14	0.10	0.03	0.01	0.17	0.51	0.45	0.28	0.35	0.07	0.18	–0.15	–0.03	0.02
1980	0.49	0.97	0.53	0.44	0.61	0.61	0.88	0.75	0.41	0.66	–0.27	–0.09	0.23	0.31	0.05
1981	0.01	0.26	–0.31	0.55	0.13	0.53	0.23	0.28	0.21	0.31	–0.19	–0.22	–0.46	–0.34	–0.30
1982	0.38	0.87	0.51	0.38	0.54	0.62	–0.04	0.33	0.35	0.32	–0.07	–0.01	–0.20	–0.05	–0.08
1983	0.47	0.76	0.58	0.79	0.65	0.78	1.22	0.40	0.03	0.61	0.41	0.59	0.02	–0.10	0.23
1984	0.40	0.71	0.81	0.84	0.69	0.42	0.89	0.26	0.31	0.47	–1.24	–0.88	–0.91	–0.82	–0.96
1985	–0.24	0.29	0.57	0.20	0.21	0.39	0.53	0.12	0.45	0.37	–1.22	–0.79	–0.79	–0.63	–0.86
1986	–0.70	0.49	0.59	0.64	0.26	0.60	0.23	0.04	0.12	0.25	–0.86	–0.10	–0.23	–0.03	–0.31
1987	0.76	1.66	0.70	0.70	0.96	0.79	0.76	0.49	0.64	0.67	–0.13	–0.14	0.83	1.03	0.40
1988	0.39	0.23	0.40	0.73	0.44	0.99	0.99	0.92	0.16	0.77	0.49	0.47	0.66	0.23	0.46
1989	–0.29	0.37	0.22	0.04	0.09	0.05	0.16	0.27	0.14	0.16	–0.58	–0.51	–0.15	0.15	–0.27
1990	–0.07	0.59				0.01	0.57				0.03	0.20			

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*Temperature anomalies (in relation to a 1958–1977 average) expressed in degrees Celsius.

†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

Annual and Seasonal Temperature Anomalies*

Surface–100 mb					100–50 mb					100–30 mb				
Win	Spr	Fall	Sum	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
0.58	0.44	0.33	−0.48	0.22										
0.07	0.08	0.19	0.13	0.12										
0.46	0.04	0.34	0.30	0.29										
0.05	0.41	0.07	0.04	0.12										
0.03	−0.34	−0.01	0.08	−0.08										
0.26	−0.07	0.14	−0.09	−0.07										
0.07	0.05	−0.37	−0.10	−0.09	1.15	1.97	1.30	0.75	1.29	0.27	1.09	1.78	−0.07	0.77
−0.99	−0.55	−0.51	−0.21	−0.57	1.58	0.33	1.20	1.63	1.19	0.43	−0.26	0.78	2.13	0.77
0.18	−0.06	−0.01	−0.13	−0.01	−0.12	0.05	−0.86	0.22	−0.18	−0.12	−0.16	−0.72	0.33	−0.17
−0.25	−0.10	−0.13	−0.02	−0.13	1.00	0.41	0.94	−0.10	0.56	0.39	0.67	0.14	−0.21	0.25
0.15	−0.48	0.11	−0.27	−0.20	−0.81	0.49	0.60	0.72	0.25	−0.62	0.75	0.68	0.32	0.28
0.22	0.71	0.41	0.27	0.40	−0.16	−0.04	−1.20	0.19	−0.30	−0.42	−0.81	−1.41	0.65	−0.50
0.45	0.23	0.42	0.36	0.37	−0.52	−0.29	1.48	0.10	0.19	−0.77	0.24	1.51	1.16	0.54
0.02	−0.52	−0.47	−0.58	−0.39	1.17	0.25	−1.16	−0.33	−0.02	1.46	−0.32	−1.12	−0.62	−0.15
0.27	−0.08	0.25	0.40	0.08	−0.14	−0.56	0.42	−0.35	−0.16	0.05	0.06	−0.74	−1.05	−0.42
0.86	0.76	0.29	0.26	0.54	−0.77	−0.23	−0.59	−0.66	−0.56	−0.67	−0.67	−0.64	−0.49	−0.62
0.07	−0.04	−0.23	−0.09	−0.11	0.40	−0.10	0.50	−0.03	0.19	−0.18	−0.07	1.05	−0.44	0.09
0.26	0.02	−0.20	−0.19	−0.16	−0.38	0.09	−0.35	0.03	−0.15	−0.31	0.35	−1.56	−0.83	−0.59
0.34	−0.33	−0.44	−0.25	−0.34	0.72	−0.06	−0.18	−0.18	0.08	0.27	−0.34	0.91	−0.30	0.14
0.24	0.43	0.45	0.36	0.37	−2.32	−0.63	−0.18	−0.28	−0.85	−2.91	−0.63	−0.08	−0.88	−1.13
0.23	0.23	0.29	0.19	0.24	−0.33	−0.25	−0.38	−1.25	−0.55	−1.45	−1.13	−0.64	−1.54	−1.19
0.05	0.38	0.26	0.17	0.22	−0.82	0.19	0.05	−0.30	−0.22	−1.80	0.41	0.43	−1.03	−0.50
0.53	0.90	0.64	0.46	0.63	−0.37	−1.76	−1.20	−0.06	−0.85	0.19	−2.28	−1.73	−0.56	−1.10
0.18	0.10	0.05	0.17	0.13	−0.41	−0.82	−0.12	0.46	−0.22	−0.22	−0.45	1.23	0.49	0.26
0.43	0.10	0.24	0.26	0.26	−0.58	0.01	1.16	1.16	0.44	−0.78	0.08	0.69	−0.09	−0.03
0.66	1.01	0.39	0.15	0.55	0.99	−0.99	−0.03	0.87	0.21	0.66	−0.73	0.47	1.56	0.49
0.04	0.49	0.08	0.13	0.19	0.20	−1.30	0.18	−0.19	−0.28	−0.87	−0.95	−0.20	−0.61	−0.66
−0.07	0.17	−0.12	0.17	0.04	−1.36	−1.61	−1.75	−1.15	−1.47	−1.10	−1.44	−1.36	−1.20	−1.28
0.06	0.20	0.07	0.18	0.13	−2.21	−2.53	−2.57	−2.52	−2.46	−1.80	−1.79	−1.64	−1.98	−1.80
0.58	0.71	0.60	0.76	0.66	−1.49	−1.42	−0.38	−0.32	−0.90	−1.34	−1.28	−0.70	−0.80	−1.03
0.78	0.75	0.75	0.27	0.64	−1.12	−3.38	−1.85	−3.52	−2.47	−1.62	−2.23	−1.49	−2.61	−1.99
−0.14	0.05	0.17	0.12	0.05	−1.84	−2.16	−0.60	−0.53	−1.28	−1.59	−1.63	−0.65	−0.97	−1.21
0.00	0.49				−2.43	−1.64				−1.43	−1.45			

South Temperate (60°S–30°S)

	Surface					850–300 mb					300–100 mb			
Year	Win†	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall
1958	0.63	0.70	0.73	0.70	0.69	–0.12	–0.06	0.33	0.89	0.26	–0.34	–0.68	0.08	–0.45
1959	1.10	0.63	0.78	0.68	0.80	0.47	0.00	1.11	1.19	0.69	–0.47	0.51	0.53	–0.35
1960	0.68	0.63	0.67	0.10	0.52	0.90	0.22	0.03	0.42	0.39	–0.71	–0.41	1.68	0.25
1961	0.60	0.42	0.70	0.54	0.57	0.28	0.06	0.00	0.37	0.18	–0.05	0.56	–0.21	–1.02
1962	0.95	0.65	0.55	0.55	0.68	0.62	0.44	0.38	0.18	0.41	–0.54	–1.72	0.06	0.40
1963	0.55	0.28	0.13	0.12	0.27	0.47	0.02	–0.58	–0.46	–0.14	–0.40	0.43	1.00	2.20
1964	–0.45	–0.23	0.03	0.28	–0.09	–1.07	–0.36	–0.95	–0.64	–0.76	0.93	1.12	1.21	0.62
1965	0.38	–0.17	–0.08	0.66	0.20	–0.86	–0.75	0.30	0.43	–0.22	0.47	0.19	–0.84	–0.45
1966	0.65	0.10	–0.15	0.18	0.20	–0.02	–0.17	–0.19	–0.20	–0.15	0.15	0.08	0.18	0.28
1967	–0.15	–0.22	–0.48	0.40	–0.11	–0.12	0.15	0.01	0.29	0.08	0.48	0.59	–0.16	–0.06
1968	0.35	0.47	–0.20	–0.18	0.11	0.10	0.29	–0.40	–0.70	–0.18	0.20	–0.38	–0.52	0.75
1969	–0.93	–0.93	–0.50	–0.36	–0.68	–0.10	–0.09	0.76	0.10	0.17	0.78	0.78	–0.16	–0.69
1970	–0.28	–0.53	–0.28	–0.80	–0.47	–0.16	–0.39	–0.13	–0.46	–0.29	–0.55	–0.25	–0.33	–0.38
1971	–0.55	–0.53	–0.45	–0.65	–0.55	0.43	–0.12	–0.30	–0.36	–0.09	–0.12	0.42	–0.29	–0.62
1972	–0.98	–0.47	–0.50	–0.53	–0.62	–0.48	0.03	0.26	0.49	0.08	–0.12	–0.57	–0.39	–0.37
1973	–0.63	–0.32	–0.50	–0.47	–0.48	0.57	0.58	0.34	–0.40	0.27	–0.59	–0.12	–0.69	–0.14
1974	–0.74	0.20	–0.17	–0.75	–0.37	0.78	0.58	–0.14	–0.19	0.26	–0.37	–1.18	–0.90	–0.74
1975	–0.75	–0.50	–0.32	–0.50	–0.52	–0.06	–0.03	–0.32	0.07	–0.09	–0.11	0.06	–0.08	–0.41
1976	–0.97	–0.62	–0.08	–0.28	–0.49	0.38	0.35	0.26	–0.90	0.02	0.12	–0.63	–0.51	–0.50
1977	–0.55	0.05	–0.13	0.08	–0.14	–0.38	0.87	–0.31	0.00	0.05	–0.26	–0.04	0.63	–0.24
1978	0.15	0.12	0.00	–0.15	0.03	0.15	0.11	0.77	0.16	0.30	–0.19	–0.32	–0.26	–0.18
1979	0.00	0.12	0.48	0.05	0.16	0.49	1.23	1.10	0.36	0.80	0.25	–0.05	0.25	0.45
1980	0.03	0.23	0.29	–0.07	0.12	0.43	0.74	0.61	0.25	0.51	–0.22	0.33	–0.48	0.03
1981	–0.13	0.28	0.31	–0.20	0.07	0.93	0.73	0.71	0.42	0.70	–0.78	–0.82	–0.89	0.00
1982	–0.02	0.28	–0.02	0.02	0.07	0.83	0.64	0.77	0.32	0.64	–0.28	–0.06	0.01	0.80
1983	–0.67	–0.32	–0.42	–0.03	–0.36	–0.29	0.86	0.65	0.83	0.51	–0.11	0.50	0.00	0.38
1984	–0.43	0.14	–0.45	–0.11	–0.21	0.23	0.23	0.02	0.25	0.18	–0.71	–0.56	0.80	0.15
1985	0.06	0.43	0.58	–0.44	0.16	0.14	0.85	0.81	0.12	0.48	–0.70	–0.39	–0.94	–1.30
1986	–0.40	0.32	–0.28	–0.30	–0.17	0.29	0.09	0.43	0.29	0.28	–1.66	–0.70	–0.21	0.01
1987	–0.51	0.45	0.56	–0.11	0.10	0.72	0.65	1.08	0.43	0.72	–0.52	–0.08	–0.22	0.41
1988	–0.74	–0.48	–0.61	0.00	–0.46	0.11	0.48	–0.10	0.18	0.17	–0.54	–0.32	0.23	0.35
1989	–0.11	–0.13	–0.23	–0.08	–0.14	0.49	0.41	0.36	0.49	0.44	–1.20	–0.81	–0.82	–1.01
1990	0.03	–0.15				0.55	0.38				–0.61	0.75		

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*Temperature anomalies (in relation to a 1958–1977 average) expressed in degrees Celsius.

†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

Annual and Seasonal Temperature Anomalies*

	Surface–100 mb					100–50 mb					100–30 mb				
Ann	Win	Spr	Fall	Sum	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
–0.35	–0.04	–0.03	0.34	0.56	0.21										
0.06	0.44	0.23	0.93	0.76	0.59										
0.20	0.45	0.15	0.41	0.33	0.34										
–0.18	0.26	0.23	0.07	–0.01	0.14										
–0.45	0.42	0.02	0.34	0.30	0.27										
0.81	–0.10	–0.17	–0.11	0.23	–0.04										
0.97	–0.28	–0.01	–0.31	–0.21	–0.20	1.90	0.55	–0.29	0.22	0.60	1.12	0.46	1.06	0.47	0.78
–0.16	–0.36	–0.44	0.01	0.17	–0.16	0.89	0.92	1.03	0.86	0.93	1.10	0.59	1.43	1.31	1.11
0.17	0.18	–0.07	–0.09	–0.03	0.00	–0.28	0.08	–1.14	–0.88	–0.56	–0.94	1.03	–1.45	0.77	–0.15
0.21	–0.04	0.18	–0.11	0.22	0.06	0.10	–0.10	0.97	0.27	0.31	0.28	0.13	–0.05	0.47	0.21
0.01	0.16	0.13	–0.37	–0.29	–0.09	–0.63	–0.67	0.21	–0.32	–0.35	0.52	0.33	–0.19	–0.34	0.08
0.18	0.17	–0.04	0.35	–0.15	0.08	1.04	0.47	0.71	0.37	0.65	0.61	0.98	1.57	0.63	0.95
–0.38	–0.44	–0.38	–0.15	–0.50	–0.37	0.02	0.26	0.23	–0.08	0.11	0.27	1.36	0.37	1.24	0.81
–0.15	0.12	–0.10	–0.33	–0.47	–0.20	0.00	–0.40	–0.40	–0.89	–0.42	–0.20	–1.53	–1.14	–0.94	–0.95
–0.36	–0.48	–0.74	–0.09	0.13	–0.30	–0.37	–0.64	0.42	0.59	0.00	0.40	0.29	1.22	1.21	0.78
–0.39	0.11	0.28	0.17	–0.36	0.05	0.92	0.82	–1.39	–0.45	–0.03	1.23	0.04	–1.50	–0.52	–0.19
–0.80	0.27	0.12	–0.33	–0.39	–0.08	–1.77	–1.57	–0.29	–0.57	–1.05	–1.55	–1.56	–0.33	–1.25	–1.17
–0.14	–0.18	–0.14	–0.24	–0.12	–0.17	0.18	0.01	1.64	–1.76	0.02	–0.39	–0.71	–0.45	–2.10	–0.91
–0.38	0.04	–0.03	–0.52	–0.71	–0.31	–1.72	–0.87	–1.13	0.90	–0.71	–2.05	–0.75	–0.38	0.73	–0.61
0.02	–0.38	0.53	–0.07	–0.04	0.01	–0.82	–0.18	0.10	0.25	–0.16	–0.47	–0.21	–0.31	0.50	–0.12
–0.24	0.07	–0.09	0.36	0.04	0.10	0.10	0.30	0.31	–0.50	0.05	–0.29	0.08	0.22	0.49	0.13
0.23	0.30	0.76	0.80	0.32	0.55	0.52	0.47	0.38	0.41	0.45	0.35	0.77	0.90	0.13	0.54
–0.09	0.23	0.56	0.31	0.16	0.32	0.77	–0.11	–0.91	–0.85	–0.28	0.76	–0.28	–1.25	–0.39	–0.29
–0.62	0.45	0.28	0.26	0.23	0.31	–0.64	0.07	–0.94	0.16	–0.34	–0.48	–0.19	–0.99	0.03	–0.41
0.12	0.44	0.42	0.49	0.37	0.43	–0.22	0.53	0.13	1.05	0.37	–0.53	0.36	–0.09	0.39	0.03
0.00	–0.31	0.62	0.33	0.42	0.27	1.72	0.23	0.32	0.56	0.71	1.26	0.32	0.62	0.25	0.61
–0.08	–0.09	0.03	0.12	0.17	0.06	0.42	–0.66	0.14	–0.31	–0.10	–0.01	–0.42	–0.14	–0.47	–0.26
–0.83	0.06	0.55	0.39	–0.29	0.18	–1.09	–1.05	–1.71	–1.87	–1.43	–0.97	–0.61	–1.06	–0.72	–0.84
–0.64	–0.26	–0.05	0.17	0.13	0.00	–1.44	–0.99	0.24	–0.93	–0.78	–0.84	–0.65	–0.09	–0.15	–0.43
–0.10	0.24	0.45	0.71	0.34	0.44	–0.72	–0.72	–0.56	–0.97	–0.74	–0.25	0.01	–1.56	–0.90	–0.68
–0.07	–0.18	0.14	–0.11	0.19	0.01	–1.98	–1.97	–1.53	–2.21	–1.92	–1.45	–1.42	–1.34	–1.56	–1.44
–0.96	0.01	0.06	0.00	0.06	0.03	–1.68	–2.01	–0.84	–0.86	–1.35	–1.18	–1.38	–0.63	–0.50	–0.92
	0.21	0.37				–1.23	–0.59				–0.69	–0.42			

South Polar (90°S–60°S)

	Surface					850–300 mb					300–100 mb				
Year	Win†	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.68	0.36	–0.58	–0.22	0.06	0.11	0.34	1.01	–0.83	0.16	0.56	0.69	–0.41	–0.55	0.07
1959	–0.60	0.84	–0.66	–2.02	–0.61	–0.86	1.12	–0.16	–1.50	–0.35	0.26	1.56	0.25	–2.04	0.01
1960	–1.02	–0.38	–1.88	–0.12	–0.85	–0.09	–0.45	–0.35	–0.23	–0.28	–0.58	2.61	–0.83	–0.92	0.07
1961	–0.65	0.86	–0.61	1.36	0.24	0.10	0.13	0.06	1.10	0.35	0.50	0.96	0.40	–1.49	0.09
1962	–0.58	–0.91	–0.78	–0.37	–0.66	–0.99	–0.65	–0.40	0.06	–0.50	–1.72	–0.89	–0.62	1.93	–0.33
1963	–0.38	–1.36	0.28	0.53	–0.23	–0.23	–0.55	–0.33	–0.56	–0.42	1.06	0.78	0.68	–1.44	0.27
1964	0.10	–1.94	0.71	–0.93	–0.52	0.21	–1.40	0.83	–0.30	–0.17	–0.63	–1.45	–0.90	3.50	0.13
1965	–0.03	–0.37	–0.22	–1.10	–0.43	0.23	–0.34	–0.59	–0.31	–0.25	0.73	–0.46	0.57	–1.59	–0.19
1966	0.40	1.39	0.32	0.30	0.60	0.16	0.74	–0.48	–0.20	0.06	–0.48	0.33	0.64	–0.57	–0.02
1967	1.15	–0.51	1.51	–0.60	0.39	0.58	–0.12	0.26	0.12	0.21	0.27	–0.86	0.26	1.61	0.32
1968	–0.58	0.80	–0.37	–0.96	–0.28	0.00	0.62	–0.48	–0.42	–0.07	0.60	–0.89	–0.52	2.97	0.54
1969	0.35	0.68	–1.05	0.50	0.12	–0.45	–0.03	–0.38	0.12	–0.19	1.66	0.19	0.11	–2.27	–0.08
1970	–0.28	–0.27	–0.53	1.31	0.06	–0.59	0.63	–0.16	0.77	0.16	–1.77	0.09	0.96	0.12	–0.15
1971	0.66	0.00	0.18	–0.46	0.10	0.03	0.15	–0.19	0.16	0.04	–1.07	0.75	0.68	0.44	0.20
1972	0.10	–0.32	1.73	–0.71	0.20	0.41	–0.01	0.75	0.06	0.30	–0.43	–0.55	–0.88	0.65	–0.30
1973	–0.52	1.12	0.08	1.45	0.53	–0.26	0.55	0.29	1.01	0.40	–0.35	–0.60	0.26	–0.44	–0.28
1974	–0.15	1.10	1.20	1.87	1.01	0.09	–0.58	1.26	0.33	0.28	0.56	0.20	0.35	0.91	0.51
1975	1.85	1.80	0.75	–0.05	1.09	0.89	–0.28	–0.37	–0.12	0.03	0.58	–0.26	–0.28	–0.81	–0.19
1976	0.57	–1.59	0.00	–0.05	–0.27	0.54	–0.38	–0.34	–0.51	–0.17	–0.32	–1.20	–0.65	–0.17	–0.59
1977	1.03	1.13	1.93	–1.30	0.70	1.15	0.70	1.30	–0.24	0.73	–0.34	–1.05	–0.24	0.02	–0.40
1978	–1.00	0.50	0.04	–0.10	–0.14	–0.96	1.06	–0.44	0.34	0.00	1.50	1.07	–1.06	1.08	0.65
1979	0.31	0.73	–0.53	1.20	0.43	0.52	0.81	–1.17	0.20	0.09	0.87	–0.12	–1.85	0.95	–0.04
1980	0.70	1.36	1.75	0.06	0.97	0.79	0.54	0.86	0.67	0.72	1.76	0.84	1.54	–1.58	0.64
1981	0.25	0.82	2.88	–0.10	0.96	0.44	0.03	0.77	0.28	0.38	0.75	–0.18	0.98	–0.24	0.33
1982	0.33	–1.26	–0.06	0.71	–0.07	0.72	–0.79	–0.20	–0.17	–0.11	–0.11	–1.07	0.56	–1.07	–0.42
1983	0.77	2.57	0.54	0.00	0.97	0.60	1.18	0.90	0.21	0.72	–1.19	0.60	–0.62	0.22	–0.25
1984	0.18	2.66	–0.08	0.96	0.93	0.14	0.67	–0.23	0.29	0.22	–1.17	–1.72	–0.47	–1.03	–1.10
1985	0.77	0.30	1.59	–0.54	0.53	0.90	–0.21	0.67	–0.30	0.27	–1.25	–0.06	–0.04	–3.36	–1.18
1986	0.92	0.70	0.68	–0.50	0.45	1.06	0.43	0.52	–0.29	0.43	–2.50	–0.72	0.34	–1.72	–1.15
1987	0.21	0.10	1.19	0.19	0.42	0.52	0.39	0.54	0.05	0.38	–2.12	–1.47	–0.49	–4.97	–2.26
1988	0.75	1.98	1.56	1.20	1.37	0.49	0.60	1.04	1.46	0.90	–1.67	–1.32	–0.43	3.42	0.00
1989	–0.52	–0.40	–0.01	–0.24	–0.29	0.84	–0.11	0.78	0.59	0.53	0.54	–0.11	–0.39	–3.35	–0.83
1990	0.16	0.46				0.72	0.24				–0.80	–0.88			

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*Temperature anomalies (in relation to a 1958–1977 average) expressed in degrees Celsius.

†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

Annual and Seasonal Temperature Anomalies*

Surface–100 mb					100–50 mb					100–30 mb				
Win	Spr	Fall	Sum	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
0.41	0.42	0.43	–0.67	0.15	–0.52	1.17	2.42	0.42	0.87	–0.41	–0.14	1.56	0.56	0.39
0.57	1.18	–0.14	–1.71	–0.31	1.38	1.61	–1.02	–6.63	–1.17	0.88	1.04	–0.75	–5.10	–0.98
0.35	0.26	–0.63	–0.36	–0.27	–0.29	0.39	1.04	2.06	0.80	0.47	1.18	2.29	1.84	1.45
0.06	0.44	0.06	0.78	0.34	1.43	0.28	1.66	–6.10	–0.68	1.07	0.57	1.12	–3.09	–0.08
1.08	–0.75	–0.39	0.41	–0.45	2.11	–0.33	0.78	1.91	1.12	1.12	–0.62	2.95	1.20	1.16
0.04	–0.39	0.00	–0.57	–0.23	1.79	1.39	–1.13	0.81	0.72	1.14	0.57	–1.31	0.47	0.22
0.06	–1.51	0.43	0.44	–0.15	–0.85	–1.30	–0.90	4.73	0.42	–0.41	–1.04	–1.22	3.37	0.18
0.30	–0.38	–0.27	–0.73	–0.27	–1.34	1.27	–1.42	3.99	0.63	–1.14	0.28	–1.22	2.79	0.18
0.06	0.76	–0.02	–0.20	0.15	–1.19	–1.73	1.80	–1.28	–0.60	–0.59	–2.23	1.69	0.11	–0.26
0.63	–0.35	0.47	0.26	0.25	–0.34	0.14	–1.61	1.03	–0.20	–0.17	–0.23	–0.81	1.50	0.07
0.04	0.32	–0.45	0.26	0.04	0.14	0.38	–1.57	0.39	–0.17	–0.18	0.01	0.46	0.13	0.11
0.15	0.18	–0.38	–0.35	–0.10	1.00	0.39	–2.00	–3.30	–0.98	0.44	0.59	0.04	–2.14	–0.27
0.80	0.36	0.10	0.74	0.10	–0.08	–0.27	0.53	–3.74	–0.89	0.85	–1.13	0.62	–1.22	–0.22
–0.05	0.22	0.06	0.16	0.10	0.26	1.21	–1.44	0.34	0.09	0.07	0.23	–1.55	0.05	–0.30
0.22	0.28	0.62	0.05	0.29	–0.60	–0.24	–0.04	–0.20	–0.27	–0.52	0.03	–0.35	–0.71	–0.39
0.03	0.45	0.27	0.94	0.42	–0.51	0.47	0.07	–0.94	–0.23	–0.53	0.11	–0.96	–0.70	–0.52
0.09	0.14	1.02	0.76	0.46	–0.22	0.86	–1.55	0.13	–0.20	0.01	1.52	–1.28	0.55	0.20
1.01	0.15	–0.09	–0.03	0.26	0.28	–0.78	–1.19	–2.63	–1.08	–0.15	–0.68	1.16	–0.96	–0.16
0.40	–0.72	–0.32	–0.35	–0.25	–0.46	0.31	–0.40	0.98	0.20	–0.81	1.41	0.77	0.84	0.55
0.80	0.38	1.06	–0.36	0.47	0.37	0.10	–1.63	4.22	0.77	0.19	–0.25	–1.54	0.65	–0.24
0.42	0.97	–0.50	0.44	0.12	0.28	3.27	–0.19	–3.94	–0.15	0.32	1.21	–0.13	–2.64	–0.31
0.57	0.59	–1.21	0.54	0.12	–0.21	–0.15	–0.78	–2.35	–0.87	0.26	0.41	–3.61	–1.18	–1.03
1.11	0.78	1.16	0.16	0.80	–0.34	2.29	1.59	–3.69	–0.04	–0.04	1.50	–0.75	–1.41	–0.18
0.51	0.12	1.33	0.10	0.52	0.71	1.67	–2.82	–0.66	–0.28	0.52	1.15	–1.91	–0.45	–0.17
0.38	–0.93	0.08	–0.23	–0.18	1.63	–0.53	–4.65	–3.49	–1.76	1.10	–0.32	–6.27	–2.35	–1.96
0.21	1.34	0.49	0.22	0.57	0.35	0.52	–2.91	–2.53	–1.14	0.23	–0.20	–1.96	–1.71	–0.91
0.07	0.47	–0.28	0.11	0.06	0.26	0.45	0.45	–2.03	–0.22	0.21				
0.40	–0.09	0.71	–1.02	0.00	–1.50	–0.68	–6.41	–6.16	–3.69					
0.25	0.22	0.72	–0.64	0.14	–1.30	1.02	0.82	–1.95	–0.35					
0.12	–0.18	0.25	–1.04	–0.27	–1.45	–0.12	–3.87	–13.51	–4.74					
0.01	0.40	0.80	1.85	0.77	–0.95	–0.07	–0.65	4.93	0.82					
0.55	–0.16	0.39	–0.42	0.09	–0.92	0.56	–2.64	–7.17	–2.54					
0.29	0.03				–0.63	–0.25								

Tropical (30°S–30°N)

	Surface					850–300 mb					300–100 mb			
Year	Win†	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall
1958	0.59	0.37	–0.29	0.33	0.25	0.41	0.17	0.26	0.40	0.31	0.28	–0.48	0.17	–0.12
1959	0.22	0.04	0.16	0.23	0.15	0.23	0.20	0.16	0.13	0.18	–0.03	–0.03	–0.07	–0.04
1960	0.11	0.04	0.02	0.04	0.05	0.31	0.01	0.40	0.19	0.23	0.39	–0.09	0.26	0.07
1961	0.04	0.03	–0.04	–0.03	0.00	0.01	0.18	0.05	–0.07	0.04	–0.03	0.18	–0.03	–0.03
1962	–0.05	–0.09	–0.09	0.05	–0.05	0.11	–0.22	–0.12	0.11	–0.03	0.28	0.21	0.10	0.27
1963	0.02	–0.02	0.00	0.15	0.04	–0.16	-0.16	0.00	–0.05	–0.09	–0.26	0.15	0.03	0.15
1964	–0.34	–0.16	–0.16	–0.24	–0.23	0.19	0.14	–0.27	–0.50	–0.11	0.42	0.19	–0.17	–0.60
1965	–0.29	–0.22	–0.19	–0.10	–0.20	–0.94	–0.44	–0.52	–0.16	–0.52	–0.98	–0.68	–0.39	0.09
1966	–0.18	–0.01	0.03	–0.07	–0.06	0.16	0.12	0.16	–0.12	0.08	0.54	0.40	0.23	–0.01
1967	–0.10	–0.06	–0.10	–0.25	–0.13	–0.12	–0.26	–0.01	–0.15	–0.14	–0.21	–0.21	0.06	–0.06
1968	–0.08	–0.43	–0.17	–0.04	–0.18	–0.29	–0.43	–0.21	–0.15	–0.27	–0.39	–0.88	–0.28	–0.34
1969	0.23	0.35	0.15	0.18	0.23	0.11	0.46	0.35	0.20	0.28	–0.04	0.76	–0.07	0.11
1970	0.32	0.06	0.03	–0.20	0.05	0.34	0.44	0.37	0.26	0.35	0.23	0.73	0.57	0.54
1971	–0.14	–0.12	–0.26	–0.33	–0.21	–0.22	–0.63	–0.55	–0.61	–0.50	0.14	–0.66	–0.70	–0.77
1972	–0.14	–0.26	0.22	0.16	–0.01	–0.54	–0.16	0.21	0.38	–0.03	–0.46	–0.56	0.07	0.28
1973	0.51	0.53	0.32	0.24	0.40	0.88	0.66	0.27	0.25	0.52	1.03	0.61	0.45	0.21
1974	–0.09	–0.08	0.01	0.03	–0.03	–0.16	–0.18	–0.17	–0.03	–0.14	–0.33	–0.30	–0.13	–0.12
1975	–0.05	0.14	–0.01	–0.09	0.00	0.06	0.01	–0.23	–0.10	–0.07	–0.20	0.05	–0.08	0.09
1976	–0.27	–0.16	–0.13	0.12	–0.11	–0.33	–0.38	–0.37	–0.11	–0.30	–0.36	–0.37	–0.26	0.05
1977	0.08	0.41	0.34	0.40	0.31	0.38	0.27	0.35	0.38	0.35	0.08	0.01	–0.09	–0.05
1978	0.29	0.08	0.24	0.35	0.24	0.27	0.37	0.18	0.05	0.22	0.10	–0.11	–0.31	–0.33
1979	0.16	0.37	0.27	0.36	0.29	0.06	0.24	0.31	0.26	0.22	–0.05	0.11	–0.31	–0.47
1980	0.53	0.81	0.35	0.44	0.53	0.34	0.49	0.56	0.37	0.44	–0.48	–0.19	0.04	–0.12
1981	0.23	0.47	0.17	0.32	0.30	0.30	0.19	0.14	0.25	0.22	–0.55	–0.64	–0.61	–0.54
1982	0.40	0.40	0.51	0.39	0.43	0.33	–0.02	0.33	0.07	0.18	–0.39	–0.60	–0.27	–0.53
1983	0.21	0.40	0.59	0.52	0.43	0.58	0.85	0.42	–0.01	0.46	0.27	0.37	0.15	–0.38
1984	0.28	0.39	0.20	0.44	0.33	0.14	0.35	–0.04	0.02	0.12	–1.04	–0.88	–0.87	–1.08
1985	0.05	0.12	0.28	0.27	0.18	0.20	0.14	–0.12	0.02	0.06	–1.00	–0.82	–1.03	–0.97
1986	–0.09	0.36	0.39	0.38	0.26	0.35	0.11	0.03	0.20	0.17	–0.84	–0.63	–0.55	–0.38
1987	0.68	1.15	0.96	0.88	0.92	0.60	0.47	0.64	0.75	0.62	0.07	–0.23	0.30	0.52
1988	0.60	0.48	0.27	0.44	0.45	0.91	0.71	0.83	0.31	0.69	0.11	0.20	0.45	–0.22
1989	0.03	0.14	0.21	0.19	0.14	–0.04	–0.03	0.13	0.27	0.08	–0.82	–0.87	–0.37	–0.12
1990	0.31	0.49				0.02	0.65				–0.06	0.03		

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*Temperature anomalies (in relation to a 1958–1977 average) expressed in degrees Celsius.

†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

Annual and Seasonal Temperature Anomalies*

	Surface–100 mb					100–50 mb					100–30 mb				
Ann	**Win**	**Spr**	**Fall**	**Sum**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**
–0.04	0.41	–0.22	0.13	0.20	0.13	0.60	0.60	–0.47	0.13	0.22	0.71	1.50	–0.19	0.33	0.59
–0.04	0.18	0.15	0.11	0.17	0.15	–0.93	–1.52	–1.34	0.43	–0.84	0.12	–0.73	–0.11	0.33	–0.10
0.16	0.29	0.00	0.30	0.14	0.18	–0.10	–0.78	–0.93	–0.51	–0.58	–0.31	–0.72	–2.54	–2.01	–1.40
0.02	0.00	0.20	–0.04	–0.05	0.03	–2.81	–1.47	1.11	2.31	–0.22	–2.99	–2.99	0.49	–0.05	–1.39
0.22	0.12	–0.10	–0.09	0.10	0.01	0.61	–0.40	–0.85	–1.16	–0.45	0.23	–0.83	–2.02	–1.48	–1.03
0.02	–0.15	–0.07	0.00	0.02	–0.05	–0.70	–0.61	0.76	0.94	0.10	–2.16	–1.31	1.27	2.51	0.08
–0.04	0.17	0.11	–0.23	–0.46	–0.10	1.24	1.67	1.49	0.81	1.30	0.72	1.27	1.54	0.44	0.99
–0.49	–0.84	–0.49	–0.43	–0.09	–0.46	1.24	0.46	0.57	0.73	0.75	0.80	0.33	0.14	0.67	0.49
0.29	0.16	0.16	0.14	–0.09	0.09	–0.69	–0.67	–0.54	0.79	–0.28	–1.06	–0.54	0.22	1.03	–0.09
–0.11	–0.15	–0.21	–0.01	–0.14	–0.13	0.86	1.03	0.26	–0.43	0.43	0.96	1.14	0.22	–0.25	0.52
–0.47	–0.18	–0.53	–0.22	–0.17	–0.28	–0.48	0.93	–0.10	–0.18	0.04	–0.57	0.63	–0.10	–0.23	–0.07
0.19	0.12	0.35	0.21	0.18	0.22	–0.51	–0.51	–0.32	0.48	–0.22	–0.94	–0.66	–0.35	0.82	–0.28
0.52	0.31	0.44	0.36	0.27	0.35	–0.36	–0.22	0.60	0.27	0.07	–0.80	–0.17	0.67	0.74	0.11
–0.50	–0.14	–0.55	–0.54	–0.60	–0.46	0.41	–0.14	–0.08	0.31	0.13	0.89	0.34	0.02	–0.45	0.20
–0.17	–0.52	–0.27	0.18	0.32	–0.07	0.75	0.05	–0.67	–1.02	–0.22	0.68	0.06	–1.24	–0.96	–0.37
0.58	0.81	0.63	0.32	0.24	0.50	–1.00	–0.52	0.04	–0.03	–0.38	–1.40	–0.72	–0.16	–0.22	–0.63
–0.22	–0.19	–0.23	–0.13	–0.04	–0.15	0.74	–0.14	–0.36	–0.72	–0.12	0.64	–0.49	–0.49	–1.31	–0.41
–0.04	–0.12	0.07	–0.16	–0.05	–0.07	–0.45	–0.02	0.06	0.39	–0.01	–0.44	0.09	–0.44	0.09	–0.18
–0.24	–0.32	–0.35	–0.30	–0.04	–0.25	1.73	0.62	0.50	0.30	0.79	1.36	0.07	0.52	–0.74	0.30
–0.01	0.26	0.23	0.24	0.29	0.26	–1.74	–0.12	–0.18	–0.48	–0.64	–2.66	–0.56	–0.88	–0.30	–1.10
–0.16	0.22	0.23	0.09	0.01	0.14	–0.58	–0.13	0.40	–0.20	–0.13	–1.20	–0.73	–0.19	–0.76	–0.72
–0.18	0.04	0.23	0.29	0.17	0.18	–0.11	0.07	–0.37	–0.93	–0.34	–0.72	–0.04	–0.23	–1.30	–0.57
–0.19	0.25	0.50	0.40	0.30	0.36	–0.29	–1.40	–0.47	0.45	–0.43	–0.36	–2.08	–0.32	0.19	–0.64
–0.59	0.05	0.04	0.02	0.10	0.05	0.23	–0.35	–0.33	0.03	–0.11	0.42	–0.56	–0.32	–0.40	–0.22
–0.45	0.15	–0.07	0.22	–0.01	0.07	–0.51	–0.04	0.52	1.33	0.33	–1.40	–0.57	0.67	1.16	–0.04
0.10	0.47	0.69	0.40	0.06	0.41	1.23	0.02	0.07	0.75	0.52	0.58	–0.44	–0.36	0.34	0.03
–0.97	–0.11	0.08	–0.18	–0.13	–0.09	0.31	–1.13	–0.95	–0.96	–0.68	–0.49	–1.03	–0.81	–0.87	–0.80
–0.96	–0.08	–0.08	–0.28	–0.16	–0.15	–1.76	–1.28	–0.73	–0.18	–0.99	–1.25	–1.04	–0.58	–0.53	–0.85
–0.60	0.01	–0.03	–0.02	0.13	0.02	–1.46	–1.41	–2.01	–2.17	–1.76	–1.23	–1.30	–1.51	–1.66	–1.43
0.17	0.53	0.44	0.56	0.74	0.57	–1.85	–1.72	–1.54	–0.80	–1.48	–1.53	–1.43	–1.21	–0.81	–1.25
0.14	0.69	0.58	0.64	0.21	0.53	–1.39	–2.39	–1.52	–2.46	–1.94	–1.31	–1.72	–1.20	–1.82	–1.51
–0.55	–0.13	–0.20	0.03	0.17	–0.03	–1.07	–1.48	–0.85	–1.08	–1.12	–0.94	–1.19	–0.84	–1.05	–1.01
	0.05	0.49				–0.87	–0.95				–1.26	–1.03			

Northern Hemisphere (0°–90°N)

	Surface					850–300 mb					300–100 mb				
Year	Win†	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.63	–0.06	–0.04	0.29	0.21	0.53	0.42	0.18	0.34	0.37	0.16	–0.15	0.27	0.74	0.26
1959	0.36	0.12	0.18	0.00	0.16	0.42	0.67	0.31	0.38	0.45	0.25	0.61	0.33	0.24	0.36
1960	0.05	–0.30	0.14	–0.32	–0.11	0.13	–0.08	0.38	0.05	0.12	1.05	0.09	0.22	0.27	0.41
1961	0.61	0.13	0.07	0.16	0.24	0.50	0.15	–0.04	0.26	0.22	0.31	0.72	0.52	0.06	0.40
1962	0.42	0.18	–0.05	–0.04	0.12	0.20	0.09	–0.03	0.05	0.08	–0.42	–0.20	–0.16	0.20	–0.15
1963	0.18	–0.03	–0.01	0.50	0.16	0.11	–0.12	–0.02	0.20	0.04	–0.25	0.09	0.27	0.28	0.09
1964	–0.20	–0.51	–0.16	–0.35	–0.31	0.10	0.08	–0.12	–0.37	–0.08	–0.19	0.47	–0.03	–0.06	0.05
1965	–0.41	–0.21	–0.20	–0.13	–0.24	–0.41	–0.39	–0.53	–0.10	–0.36	–0.40	–0.54	–0.28	0.07	–0.29
1966	–0.57	–0.07	–0.07	–0.16	–0.22	–0.15	0.09	0.20	0.21	0.09	0.73	0.14	0.62	0.10	0.40
1967	–0.32	0.31	0.07	0.19	0.06	–0.17	–0.02	0.12	0.21	0.04	–0.29	–0.53	–0.22	–0.42	–0.37
1968	–0.26	0.30	–0.13	–0.19	–0.07	0.04	–0.17	–0.37	–0.30	–0.20	–0.03	–1.49	–0.50	–0.43	–0.61
1969	–0.71	–0.19	0.11	0.22	–0.14	–0.33	0.01	0.24	0.15	0.02	0.21	0.40	–0.06	–0.21	0.09
1970	0.47	0.06	–0.06	–0.11	0.09	0.16	0.01	0.19	0.13	0.12	0.35	0.24	0.33	0.15	0.27
1971	–0.42	–0.12	–0.12	0.04	–0.16	–0.38	–0.56	–0.38	–0.47	–0.45	–0.09	–0.28	–0.46	–0.60	–0.36
1972	–0.40	–0.28	0.07	–0.19	–0.20	–0.67	–0.24	0.00	–0.15	–0.27	–0.85	–0.56	–0.23	0.08	–0.39
1973	0.45	0.22	0.30	0.01	0.25	0.47	0.11	0.15	–0.11	0.16	0.67	0.67	0.15	–0.10	0.35
1974	0.13	–0.07	–0.26	–0.03	–0.06	–0.22	–0.22	–0.29	–0.43	–0.29	–0.75	–0.09	–0.34	–0.04	–0.31
1975	0.23	0.42	0.07	–0.08	0.16	–0.31	0.10	–0.03	–0.12	–0.09	–0.28	0.15	–0.30	–0.07	–0.13
1976	0.03	–0.28	–0.10	–0.26	–0.15	–0.37	–0.62	–0.39	–0.32	–0.43	–0.84	–0.71	–0.64	–0.40	–0.65
1977	–0.26	0.27	0.20	0.26	0.12	–0.01	0.17	0.11	0.16	0.11	0.55	0.38	–0.14	–0.26	0.13
1978	0.27	–0.09	0.16	0.28	0.16	–0.14	0.17	0.06	–0.15	–0.02	0.05	–0.17	–0.25	–0.58	–0.24
1979	–0.10	0.30	0.05	0.22	0.12	–0.29	0.30	0.19	0.24	0.11	–0.29	0.04	–0.38	–0.33	–0.24
1980	0.71	0.41	0.00	0.11	0.31	0.21	0.08	0.34	0.01	0.16	–0.82	0.44	0.28	–0.04	–0.04
1981	0.86	0.74	0.28	0.44	0.58	0.27	0.40	0.12	0.21	0.25	–0.88	–0.83	–0.33	–0.37	–0.60
1982	0.44	–0.02	0.19	0.01	0.16	–0.03	–0.21	0.16	–0.13	–0.05	–0.12	–0.33	–0.13	–0.66	–0.31
1983	1.00	0.34	0.40	0.37	0.53	0.35	0.65	0.41	0.13	0.39	–0.69	–0.16	–0.04	–0.47	–0.34
1984	0.58	0.25	0.05	0.11	0.25	0.04	0.02	–0.02	–0.18	–0.04	–1.16	–0.28	–0.43	–0.62	–0.62
1985	–0.37	–0.13	–0.08	–0.26	–0.21	–0.07	–0.27	–0.35	–0.31	–0.25	0.28	0.19	–0.55	–0.44	–0.13
1986	0.11	0.27	0.01	0.11	0.13	0.16	0.10	0.01	0.10	0.09	–0.54	–0.54	–0.55	–0.47	–0.53
1987	0.35	0.20	0.52	0.14	0.30	0.20	0.21	0.44	0.18	0.26	0.38	–0.38	0.04	0.53	0.14
1988	0.57	0.66	0.30	0.11	0.41	0.39	0.34	0.88	0.32	0.48	–0.36	–0.17	0.03	–0.39	–0.22
1989	0.91	0.53	0.39	0.15	0.50	0.02	0.23	0.28	0.26	0.20	–0.82	–0.32	–0.61	–0.32	–0.52
1990	0.81	1.42				0.17	0.73				–0.44	–0.88			

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*Temperature anomalies (in relation to a 1958–1977 average) expressed in degrees Celsius.

†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

Annual and Seasonal Temperature Anomalies*

Surface–100 mb					100–50 mb					100–30 mb				
Win	Spr	Fall	Sum	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
0.46	0.08	0.15	0.39	0.27	1.32	0.41	0.21	1.38	0.83	0.90	0.44	0.53	1.69	0.89
0.38	0.58	0.29	0.32	0.39	–0.32	1.25	0.20	0.07	0.30	–0.15	1.49	0.61	0.36	0.58
0.33	–0.08	0.30	0.04	0.15	1.30	0.80	0.09	0.43	0.66	1.59	0.00	–0.57	0.04	0.27
0.47	0.30	0.08	0.20	0.26	–1.22	–0.16	0.82	0.92	0.09	–1.02	–0.73	0.69	0.30	–0.19
0.10	0.04	–0.07	0.06	0.03	–0.36	–0.90	–0.85	–0.35	–0.62	–0.41	–1.20	–1.36	–0.46	–0.86
0.04	–0.06	0.04	0.27	0.07	–0.63	–0.59	0.98	0.62	0.10	–0.37	–1.39	1.02	1.13	0.10
0.00	0.08	–0.11	–0.29	–0.08	–0.12	1.20	0.74	0.06	0.47	0.01	1.60	0.61	0.13	0.59
–0.40	–0.41	–0.42	–0.06	–0.32	–0.05	–0.16	0.19	0.22	0.05	–0.44	0.60	0.04	–0.07	0.03
–0.04	0.08	0.24	0.13	0.10	0.38	–0.76	–0.03	0.63	0.06	–0.43	–0.59	0.27	0.87	0.03
–0.21	–0.38	0.04	0.07	–0.12	0.01	–0.31	–0.46	–0.69	–0.36	–0.18	0.40	–0.11	–0.70	–0.15
–0.03	–0.39	–0.36	–0.31	–0.27	–0.45	–0.44	–0.07	–0.25	–0.30	–1.37	–0.31	–0.08	–0.31	–0.52
–0.25	–0.12	0.17	0.10	–0.03	–0.50	–0.35	–0.28	0.64	–0.12	–1.37	–0.54	–0.10	0.03	–0.50
0.30	0.08	0.22	0.13	0.18	0.24	–0.07	0.27	0.31	0.19	–0.02	–0.07	0.38	0.23	0.13
–0.40	–0.51	–0.43	–0.49	–0.46	0.39	–0.52	0.14	0.12	0.03	0.02	–0.35	0.19	–0.41	–0.14
–0.80	–0.39	–0.04	–0.13	–0.34	0.04	0.19	–0.57	–0.54	–0.22	0.47	0.36	–0.93	–0.45	–0.14
0.60	0.31	0.21	–0.10	0.26	0.05	–0.73	–0.22	–0.15	–0.26	–0.03	–1.23	–0.35	–0.48	–0.52
–0.34	–0.22	–0.25	–0.33	–0.29	–0.10	0.45	–0.38	–0.34	–0.09	0.55	0.34	–0.55	–0.28	0.02
–0.25	0.19	–0.08	–0.16	–0.08	–0.16	0.28	–0.06	–0.25	–0.05	–0.23	–0.19	0.04	0.14	–0.06
–0.49	–0.70	–0.57	–0.32	–0.52	0.22	0.76	0.19	0.14	0.33	0.82	0.45	0.02	–0.37	0.23
0.07	0.23	0.07	0.09	0.12	–0.31	0.35	0.35	0.03	0.11	–1.34	–0.07	–0.48	–0.20	–0.52
–0.05	0.11	0.01	–0.17	–0.03	–0.49	–0.53	–0.31	–0.52	–0.46	–1.05	–0.90	–0.52	–0.52	–0.75
–0.24	0.22	0.17	0.16	0.08	0.48	0.31	–0.34	–0.33	0.03	0.15	0.03	–0.29	–0.77	–0.22
0.08	0.24	0.25	0.04	0.15	–0.12	–0.01	–0.06	0.63	0.11	–0.37	–0.63	0.28	0.42	–0.08
0.10	0.17	0.08	0.12	0.12	0.30	–0.41	–0.37	0.03	–0.11	0.48	–0.64	–0.51	–0.14	–0.20
–0.01	–0.17	0.10	–0.22	–0.08	0.35	0.31	0.57	0.52	0.44	0.06	0.16	0.72	0.59	0.38
0.28	0.43	0.29	0.09	0.27	0.00	0.21	–0.29	0.16	0.03	–0.45	–0.18	–0.72	–0.12	–0.37
–0.14	–0.01	–0.09	–0.20	–0.11	–0.12	–0.15	–1.00	–0.49	–0.44	–0.19	–0.25	–0.70	–0.37	–0.38
–0.04	–0.14	–0.34	–0.33	–0.21	–0.42	–0.83	–0.47	0.05	–0.42	–0.33	–0.69	–0.37	–0.19	–0.40
–0.01	–0.02	–0.11	0.00	–0.04	–0.47	–0.28	–1.09	–1.08	–0.73	–0.33	–0.37	–0.85	–0.78	–0.58
0.29	0.08	0.35	0.25	0.24	–0.40	–1.30	–0.77	–0.14	–0.65	–0.32	–0.98	–0.75	–0.10	–0.54
0.26	0.30	0.58	0.12	0.32	–1.48	–0.65	–0.86	–1.20	–1.05	–0.94	–0.45	–0.69	–0.88	–0.74
0.01	0.15	0.11	0.11	0.10	–0.30	–0.60	–0.76	–0.77	–0.61	–0.07	–0.52	–0.72	–0.58	–0.47
0.14	0.49				–1.26	–1.22				–0.89	–1.04			

Southern Hemisphere (0°–90°S)

	Surface					850–300 mb					300–100 mb			
Year	**Win†**	**Spr**	**Sum**	**Fall**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**	**Ann**	**Win**	**Spr**	**Sum**	**Fall**
1958	0.76	0.58	–0.04	0.38	0.42	0.25	0.00	0.37	0.30	0.23	0.05	–0.37	–0.05	–0.68
1959	0.45	0.44	0.34	0.11	0.34	0.08	0.20	0.41	0.20	0.22	–0.35	0.33	0.04	–0.69
1960	0.16	0.20	–0.09	0.18	0.11	0.43	0.00	0.16	0.22	0.20	–0.14	0.21	0.49	0.03
1961	0.13	0.36	0.13	0.50	0.28	0.08	0.20	0.07	0.29	0.16	0.00	0.46	–0.13	–0.70
1962	0.24	0.05	0.02	0.19	0.13	0.08	–0.10	0.01	0.09	0.02	–0.44	–0.66	–0.06	0.60
1963	0.04	–0.17	0.05	0.13	0.01	0.02	–0.15	–0.20	–0.26	–0.15	–0.16	0.33	0.49	0.51
1964	–0.21	–0.42	0.03	–0.11	–0.18	–0.24	–0.28	–0.37	–0.53	–0.36	0.38	0.15	0.09	0.44
1965	–0.01	–0.21	–0.15	–0.04	–0.10	–0.76	–0.54	–0.26	0.01	–0.39	–0.30	–0.37	–0.42	–0.38
1966	0.24	0.20	–0.02	0.02	0.11	0.08	0.05	–0.10	–0.22	–0.05	0.11	0.26	0.17	–0.03
1967	0.16	–0.14	0.03	0.00	0.01	–0.09	–0.05	0.01	0.03	–0.03	0.03	–0.14	–0.06	0.14
1968	0.05	0.02	–0.31	–0.28	–0.13	–0.07	0.03	–0.28	–0.31	–0.16	0.04	–0.67	–0.22	0.75
1969	–0.18	–0.04	–0.34	0.01	–0.14	0.02	0.28	0.41	0.20	0.23	0.63	0.77	0.07	–0.43
1970	–0.07	–0.25	–0.23	–0.19	–0.19	0.06	0.26	0.16	0.14	0.16	–0.25	0.33	0.38	0.25
1971	–0.15	–0.29	–0.23	–0.46	–0.29	0.04	–0.31	–0.39	–0.41	–0.27	0.05	–0.01	–0.24	–0.46
1972	–0.37	–0.32	0.22	–0.28	–0.19	–0.31	–0.01	0.36	0.48	0.13	–0.10	–0.31	–0.23	0.12
1973	–0.04	0.34	0.05	0.15	0.13	0.66	0.71	0.34	0.19	0.48	0.24	0.12	0.08	0.07
1974	–0.40	0.15	0.22	0.06	0.01	0.24	–0.01	0.07	–0.03	0.07	–0.14	–0.45	–0.25	–0.12
1975	–0.07	0.20	0.05	–0.25	–0.02	0.24	–0.09	–0.29	–0.09	–0.06	0.04	0.04	–0.10	–0.26
1976	–0.47	–0.56	–0.15	–0.15	–0.33	0.08	–0.11	–0.15	–0.44	–0.16	–0.25	–0.60	–0.43	–0.10
1977	0.04	0.40	0.42	–0.08	0.20	0.27	0.67	0.45	0.20	0.40	–0.11	–0.15	0.09	0.05
1978	–0.06	0.21	0.06	0.01	0.06	0.08	0.42	0.36	0.21	0.27	0.27	0.12	–0.29	0.10
1979	0.06	0.31	0.20	0.33	0.23	0.39	0.75	0.41	0.32	0.47	0.31	0.04	–0.28	0.21
1980	0.36	0.71	0.58	0.19	0.46	0.54	0.70	0.69	0.42	0.59	–0.01	0.12	0.16	–0.22
1981	0.02	0.39	0.51	0.11	0.26	0.61	0.40	0.47	0.32	0.45	–0.35	–0.53	–0.41	–0.24
1982	0.22	0.22	0.26	0.31	0.25	0.69	0.11	0.43	0.23	0.37	–0.23	–0.37	–0.04	–0.07
1983	0.15	0.67	0.25	0.28	0.34	0.47	1.10	0.63	0.31	0.63	–0.09	0.52	–0.06	–0.20
1984	0.13	0.73	0.05	0.43	0.34	0.23	0.50	0.05	0.22	0.25	–0.99	–0.92	–0.28	–0.60
1985	0.16	0.30	0.66	–0.12	0.25	0.37	0.44	0.39	0.16	0.34	–1.02	–0.59	–0.81	–1.41
1986	–0.16	0.45	0.27	0.07	0.16	0.51	0.18	0.24	0.15	0.27	–1.41	–0.52	–0.23	–0.40
1987	0.25	0.95	0.85	0.37	0.61	0.72	0.67	0.77	0.52	0.67	–0.57	–0.35	0.16	–0.30
1988	0.18	0.37	0.23	0.54	0.33	0.64	0.69	0.58	0.40	0.58	–0.26	–0.12	0.35	0.66
1989	–0.18	0.00	0.02	0.04	–0.03	0.28	0.12	0.32	0.35	0.27	–0.75	–0.66	–0.39	–0.89
1990	0.13	0.35				0.33	0.46				–0.49	0.10		

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*Temperature anomalies (in relation to a 1958–1977 average) expressed in degrees Celsius.

†Northern Hemisphere winter (Dec–Feb).

Note: Data for summer (Jun–Aug) 1989 through spring (Mar–May) 1990 are provisional.

Annual and Seasonal Temperature Anomalies*

	Surface–100 mb					100–50 mb					100–30 mb				
Ann	Win	Spr	Fall	Sum	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
–0.2 6	0.31	–0.11	0.20	0.06	0.12										
–0.17	0.07	0.28	0.32	0.01	0.17										
0.15	0.24	0.09	0.18	0.17	0.17										
–0.09	0.07	0.29	0.01	0.11	0.12										
–0.14	–0.01	–0.19	0.01	0.20	0.00										
0.29	–0.15	–0.15	–0.01	–0.03	–0.09										
0.27	0.00	–0.21	–0.20	–0.24	–0.16	1.11	1.00	0.47	1.36	0.99	0.50	0.68	0.99	0.80	0.74
–0.37	–0.54	–0.46	–0.27	–0.12	–0.35	0.77	0.71	0.42	1.36	0.82	0.42	0.14	0.34	1.38	0.57
0.13	0.10	0.12	–0.02	–0.14	0.02	–0.64	–0.57	–0.45	–0.06	–0.43	–0.84	–0.24	–0.16	1.15	–0.02
–0.01	–0.04	–0.09	0.00	0.04	–0.02	0.56	0.48	0.42	0.27	0.43	0.54	0.57	0.04	0.36	0.38
–0.02	0.07	–0.14	–0.26	–0.07	–0.10	–0.50	0.19	–0.14	0.00	–0.11	–0.24	0.38	0.08	–0.07	0.04
0.26	0.19	0.33	0.21	0.03	0.19	0.26	–0.05	–0.44	–0.27	–0.13	–0.07	0.09	0.25	0.34	0.15
0.17	–0.09	0.19	0.17	0.12	0.10	–0.13	–0.02	0.72	–0.50	0.02	–0.14	0.25	0.75	0.71	0.39
–0.17	0.01	–0.26	–0.33	–0.42	–0.25	0.47	0.05	–0.58	–0.14	–0.05	0.71	–0.30	–0.82	–0.58	–0.25
–0.19	–0.33	–0.28	0.19	0.19	–0.06	0.04	–0.23	0.14	–0.32	–0.09	0.36	0.21	–0.13	–0.19	0.06
0.13	0.49	0.53	0.30	0.18	0.38	–0.33	0.14	–0.50	–0.41	–0.28	–0.20	–0.23	–0.79	–0.39	–0.40
–0.24	0.00	–0.06	0.01	–0.02	–0.02	–0.22	–0.34	–0.36	–0.44	–0.34	–0.36	–0.41	–0.32	–0.86	–0.49
–0.07	0.05	0.02	–0.17	–0.11	–0.05	–0.15	–0.19	0.36	–0.81	–0.20	–0.35	–0.25	–0.43	–0.90	–0.48
–0.35	–0.10	–0.29	–0.39	–0.32	–0.28	0.14	–0.02	–0.30	0.61	0.11	–0.31	–0.05	0.39	0.03	0.02
–0.0	0.14	0.43	0.37	0.12	0.27	–1.21	–0.37	–0.41	0.49	–0.38	–1.52	–0.59	–0.62	0.19	–0.64
0.0	0.10	0.31	0.14	0.15	0.18	–0.12	0.65	0.34	–1.01	–0.04	–0.53	–0.02	0.04	–0.69	–0.30
0.07	0.29	0.52	0.22	0.31	0.34	–0.04	0.18	–0.15	–0.73	–0.19	–0.51	0.36	–0.29	–0.84	–0.32
0.01	0.47	0.67	0.57	0.27	0.50	–0.06	–0.56	–0.43	–0.65	–0.43	0.12	–1.03	–1.00	–0.32	–0.56
–0.38	0.29	0.17	0.31	0.16	0.23	–0.01	0.12	–0.84	0.09	–0.16	0.09	–0.06	–0.46	–0.09	–0.13
–0.18	0.39	0.02	0.32	0.17	0.23	–0.16	0.02	–0.40	0.48	–0.02	–0.71	–0.28	–0.77	0.11	–0.41
0.04	0.30	0.93	0.43	0.22	0.47	1.22	0.03	–0.29	0.18	0.29	0.82	–0.08	–0.11	0.14	0.19
–0.70	–0.06	0.22	–0.03	0.07	0.05	0.33	–0.76	–0.17	–0.91	–0.38	–0.42	–0.62	–0.29	–0.98	–0.58
–0.96	0.07	0.19	0.14	–0.24	0.04	–1.54	–1.24	–2.23	–1.97	–1.75	–1.23	–0.92	–1.85	–1.71	–1.43
–0.64	–0.03	0.07	0.17	0.02	0.06	–1.59	–1.20	–0.94	–1.92	–1.41	–1.27	–0.86	–0.71	–1.37	–1.05
–0.27	0.36	0.48	0.59	0.34	0.44	–1.40	–1.28	–1.58	–2.92	–1.80	–1.15	–0.85	–1.77	–2.97	–1.69
0.16	0.36	0.46	0.46	0.48	0.44	–1.42	–2.18	–1.48	–1.43	–1.63	–1.36	–1.53	–1.24	–0.84	–1.24
–0.67	–0.03	–0.07	0.09	0.02	0.00	–1.44	–1.56	–1.24	–2.05	–1.57	–1.22	–1.12	–1.11	–1.98	–1.36
	0.12	0.36				–1.79	–1.14				–1.15	–0.89			

National

BACKGROUND

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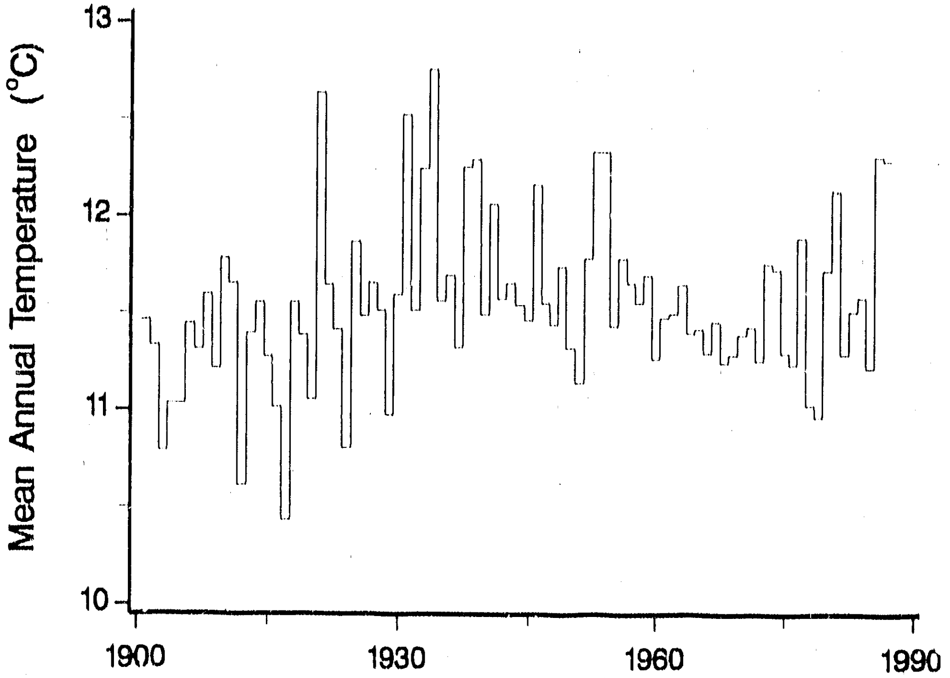
U.S. Department of Energy
Carbon Dioxide Research Program

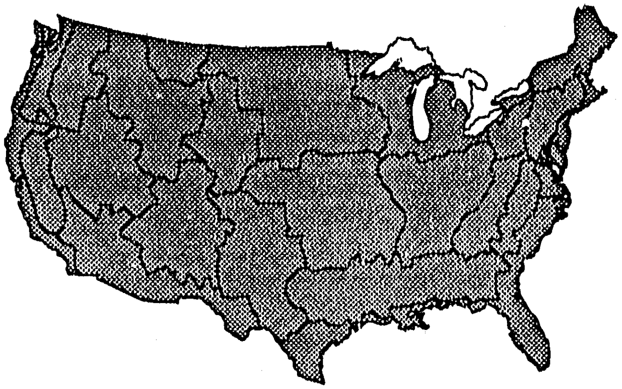
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



National

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed during the recent century but that the changes for the most part have not been monotonic. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. If there are any monotonic trends in the data, it may be the decrease in the diurnal temperature range.

National

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	11.46	0.55	10.59	22.92	12.36	11.61
1902	11.33	−0.21	11.39	21.75	12.46	11.35
1903	10.79	−0.57	10.94	21.23	11.70	10.82
1904	11.03	−0.82	10.74	21.31	12.56	10.95
1905	11.03	−1.37	11.39	21.97	12.25	11.06
1906	11.44	0.88	10.27	21.77	12.15	11.27
1907	11.31	1.51	10.43	21.32	12.07	11.33
1908	11.59	1.20	11.56	21.62	12.21	11.65
1909	11.21	1.35	9.93	22.31	12.68	11.57
1910	11.78	−1.60	12.74	22.10	12.75	11.50
1911	11.65	1.02	11.53	22.35	11.60	11.63
1912	10.61	−1.09	10.02	21.40	11.96	10.57
1913	11.39	0.04	10.62	22.42	12.41	11.37
1914	11.55	0.83	11.17	22.51	12.91	11.85
1915	11.27	−0.39	10.47	20.98	12.88	10.98
1916	11.01	0.30	10.89	21.99	11.59	11.19
1917	10.43	−1.07	9.10	21.85	11.79	10.42
1918	11.55	−1.17	11.66	22.66	12.06	11.30
1919	11.38	1.14	10.99	22.51	12.00	11.66
1920	11.05	−0.28	9.88	21.58	12.26	10.86
1921	12.63	2.04	12.09	22.83	13.15	12.52
1922	11.64	0.22	10.93	22.58	13.12	11.71
1923	11.41	0.88	10.14	22.02	12.08	11.28
1924	10.80	0.83	9.69	21.98	12.32	11.21
1925	11.86	0.36	12.21	22.49	11.57	11.66
1926	11.48	1.16	10.61	22.14	12.17	11.52
1927	11.65	1.39	11.12	21.28	13.30	11.77
1928	11.51	0.27	10.97	21.70	12.28	11.31
1929	10.97	−1.24	11.26	22.14	11.52	10.92
1930	11.59	0.96	11.26	22.64	12.03	11.72
1931	12.52	1.63	10.58	23.12	13.95	12.32
1932	11.51	2.06	10.45	22.65	11.95	11.78
1933	12.24	0.33	10.91	23.14	13.36	11.93
1934	12.75	2.22	12.59	23.61	13.29	12.93
1935	11.36	1.30	10.70	22.61	11.99	11.65
1936	11.69	−1.78	11.87	23.72	12.22	11.51
1937	11.32	−0.26	10.66	22.98	12.30	11.42
1938	12.25	1.43	11.78	22.64	12.85	12.18
1939	12.29	0.96	11.74	22.68	13.15	12.13
1940	11.49	0.34	10.89	22.59	12.42	11.56
1941	12.06	1.61	11.28	22.33	12.96	12.04
1942	11.57	0.76	11.29	22.30	12.58	11.73
1943	11.65	1.08	10.78	22.87	11.98	11.68
1944	11.54	1.12	10.41	22.21	12.75	11.62

Year	Ann*
1945	11.46
1946	12.16
1947	11.55
1948	11.44
1949	11.74
1950	11.32
1951	11.14
1952	11.78
1953	12.33
1954	12.33
1955	11.43
1956	11.78
1957	11.65
1958	11.55
1959	11.69
1960	11.26
1961	11.47
1962	11.49
1963	11.64
1964	11.39
1965	11.41
1966	11.29
1967	11.45
1968	11.24
1969	11.28
1970	11.38
1971	11.42
1972	11.25
1973	11.75
1974	11.72
1975	11.29
1976	11.23
1977	11.88
1978	11.02
1979	10.96
1980	11.71
1981	12.12
1982	11.28
1983	11.50
1984	11.57
1985	11.21
1986	12.30
1987	12.28

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
0.53	11.30	21.69	12.60	11.53
0.48	12.41	22.10	12.32	11.83
1.21	10.46	22.21	12.98	11.72
−0.12	11.01	22.31	12.52	11.43
−0.13	11.41	22.62	12.92	11.71
1.40	10.05	21.42	12.63	11.38
0.88	10.38	21.90	11.63	11.19
1.21	10.52	22.98	12.07	11.70
2.28	10.88	22.71	13.42	12.32
2.32	10.95	22.78	13.24	12.32
0.16	11.41	22.39	12.17	11.53
0.32	10.88	22.46	12.57	11.56
1.64	10.82	22.43	11.58	11.62
1.27	10.62	22.23	12.98	11.77
0.21	11.32	22.81	11.71	11.51
0.49	10.10	22.42	13.05	11.51
0.71	10.65	22.42	11.95	11.43
−0.11	10.91	21.88	12.91	11.40
−0.43	11.74	22.28	14.05	11.91
−0.57	10.83	22.09	12.25	11.15
0.55	10.24	21.61	12.60	11.25
0.05	11.08	22.24	12.37	11.44
0.93	11.05	21.73	12.11	11.45
0.22	11.00	21.99	12.24	11.36
−0.21	10.60	22.24	11.96	11.14
0.32	10.50	22.60	12.00	11.36
0.54	10.21	22.26	12.56	11.39
0.81	11.51	21.95	11.54	11.45
−0.05	11.02	22.44	12.98	11.60
1.02	11.77	22.07	12.01	11.72
0.84	9.82	22.06	12.35	11.27
1.72	11.15	21.82	10.84	11.38
−0.83	12.29	22.79	12.76	11.76
−1.29	10.91	22.42	12.64	11.16
−2.47	10.86	21.92	12.48	10.69
1.06	10.60	22.90	12.46	11.75
1.77	11.81	22.65	12.60	12.20
−0.25	10.96	21.87	12.06	11.16
2.11	10.02	22.79	12.97	11.98
−0.49	10.41	22.47	12.14	11.14
−0.34	12.48	22.14	11.84	11.53
0.76	12.40	22.72	12.21	12.03
1.62	12.24	22.66	12.58	12.27

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North Pacific Coast

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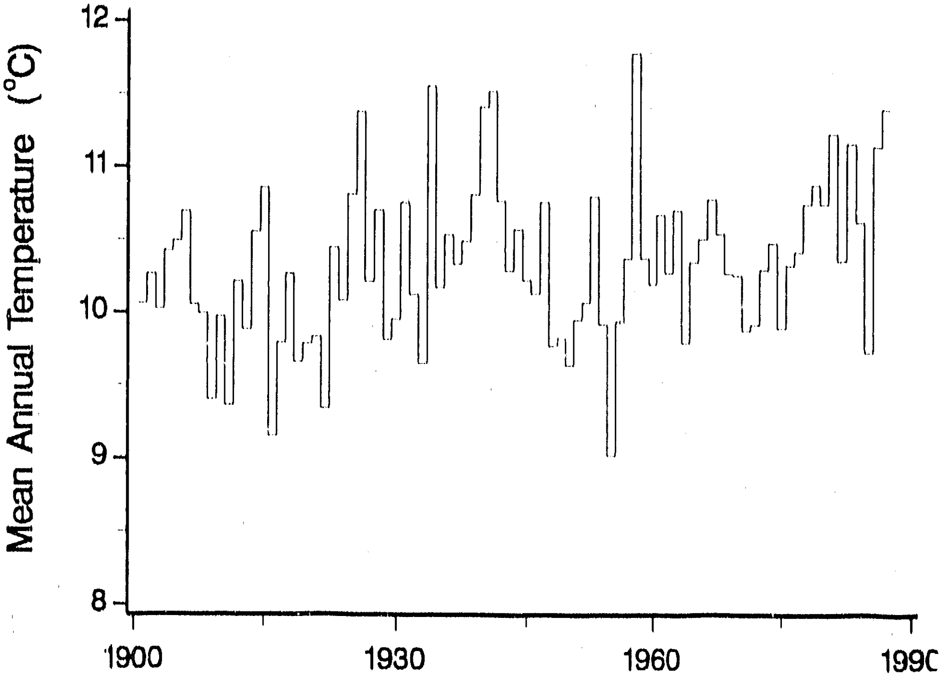
Carbon Dioxide Research Program

Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.

North Pacific Coast

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes for the most part have not been monotonic. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time.

Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated West region, which includes this subregion, Karl et al. (1988a) reported that, since the relatively cool period during the beginning decades of the century, annual mean temperatures have remained relatively constant with the exception of a number of multiyear climate fluctuations.

North Pacific Coast

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	10.06	5.67	8.79	14.51	11.74	10.18
1902	10.26	5.76	9.13	15.36	10.88	10.28
1903	10.02	5.18	8.33	15.40	10.95	9.96
1904	10.42	5.17	9.12	15.12	12.19	10.40
1905	10.49	5.89	10.46	15.49	10.41	10.56
1906	10.69	6.07	9.77	15.87	10.99	10.67
1907	10.05	4.49	9.13	15.05	11.47	10.03
1908	9.99	5.46	8.96	15.25	10.88	10.14
1909	9.40	3.90	8.54	14.76	10.80	9.50
1910	9.97	3.47	10.09	14.52	10.73	9.70
1911	9.36	4.41	8.38	14.92	10.11	9.46
1912	10.21	5.75	9.20	15.40	10.41	10.19
1913	9.88	4.14	8.72	15.80	10.77	9.86
1914	10.55	6.03	10.53	15.17	11.18	10.73
1915	10.85	5.02	10.85	16.27	10.68	10.70
1916	9.15	3.54	9.02	15.18	9.67	9.35
1917	9.79	3.32	7.97	15.03	11.60	9.48
1918	10.26	5.83	8.79	15.50	11.44	10.39
1919	9.66	5.15	9.16	14.63	10.13	9.77
1920	9.78	4.50	7.96	15.33	10.60	9.60
1921	9.83	5.56	8.74	15.02	10.73	10.01
1922	9.34	3.25	7.99	15.37	10.85	9.36
1923	10.44	3.88	9.32	16.14	11.84	10.29
1924	10.08	6.07	9.44	15.00	10.67	10.29
1925	10.81	5.32	9.92	15.61	10.89	10.44
1926	11.37	6.88	11.38	16.22	11.71	11.55
1927	10.21	5.46	8.69	16.06	11.31	10.38
1928	10.70	5.19	10.40	15.81	10.84	10.56
1929	9.81	3.18	8.80	15.74	11.21	9.73
1930	9.95	4.12	9.67	15.43	10.61	9.96
1931	10.75	6.52	10.59	15.77	10.40	10.82
1932	10.12	4.49	9.71	15.22	11.62	10.26
1933	9.65	3.41	8.49	15.01	10.65	9.39
1934	11.55	7.26	11.65	15.57	11.90	11.60
1935	10.17	5.91	8.66	15.56	10.37	10.12
1936	10.53	4.91	9.83	16.30	11.23	10.57
1937	10.33	3.37	9.75	15.86	12.20	10.29
1938	10.49	6.00	9.72	15.37	11.15	10.56
1939	10.81	5.23	9.88	15.52	11.80	10.61
1940	11.41	7.25	11.10	16.10	11.63	11.52
1941	11.52	7.16	11.26	16.42	11.56	11.60
1942	10.77	5.57	9.76	16.50	11.16	10.75
1943	10.29	5.06	9.43	15.07	11.85	10.35
1944	10.57	5.57	9.34	15.40	12.10	10.60

Year	Ann*
1945	10.22
1946	10.13
1947	10.76
1948	9.77
1949	9.83
1950	9.64
1951	9.95
1952	10.07
1953	10.80
1954	9.92
1955	9.02
1956	9.94
1957	10.37
1958	11.78
1959	10.37
1960	10.19
1961	10.67
1962	10.27
1963	10.70
1964	9.79
1965	10.34
1966	10.50
1967	10.77
1968	10.53
1969	10.26
1970	10.25
1971	9.87
1972	9.91
1973	10.29
1974	10.47
1975	9.89
1976	10.32
1977	10.41
1978	10.74
1979	10.87
1980	10.74
1981	11.22
1982	10.35
1983	11.15
1984	10.61
1985	9.72
1986	11.13
1987	11.39

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
5.80	9.17	15.28	10.48	10.18
5.55	9.60	15.57	9.94	10.16
4.92	10.89	15.82	11.07	10.67
5.07	8.73	15.87	10.47	10.04
2.24	10.01	15.02	11.58	9.71
2.47	8.43	15.69	10.75	9.34
5.80	8.85	15.54	11.03	10.30
4.11	9.09	14.97	11.33	9.88
6.49	9.32	15.31	11.93	10.76
5.34	8.64	14.34	11.63	9.98
4.83	7.39	14.47	9.80	9.12
4.12	9.56	15.47	10.39	9.88
3.71	10.18	15.52	11.56	10.24
7.56	10.35	17.57	11.40	11.72
6.11	9.61	15.72	10.76	10.55
5.12	9.35	15.44	10.85	10.19
6.43	9.63	16.75	10.01	10.71
5.16	8.86	14.92	11.63	10.14
5.91	9.49	15.36	12.16	10.73
5.84	8.50	15.14	10.51	10.00
4.60	9.17	15.63	11.63	10.26
5.18	9.44	15.22	11.39	10.31
6.39	8.52	16.64	12.21	10.94
5.88	9.87	15.76	11.14	10.66
2.95	9.93	15.92	11.11	9.98
6.51	9.20	15.65	10.40	10.44
4.87	8.78	15.63	10.52	9.95
3.96	9.56	15.94	10.22	9.92
4.70	9.66	15.06	10.58	10.00
5.59	9.13	15.48	11.79	10.50
5.32	8.50	15.11	10.95	9.97
5.57	8.84	15.02	11.58	10.25
6.12	9.26	15.98	10.48	10.46
6.38	10.23	16.59	10.61	10.95
3.47	10.50	16.19	11.96	10.52
5.86	10.17	15.28	11.76	10.78
7.04	10.47	16.16	11.43	11.29
5.26	9.21	16.03	11.08	10.40
6.87	10.91	16.27	11.31	11.36
5.40	10.22	15.98	10.82	10.60
3.77	9.51	16.51	8.99	9.69
5.69	10.29	16.33	11.35	10.92
6.09	11.10	16.20	12.54	11.48

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South Pacific Coast

BACKGROUND

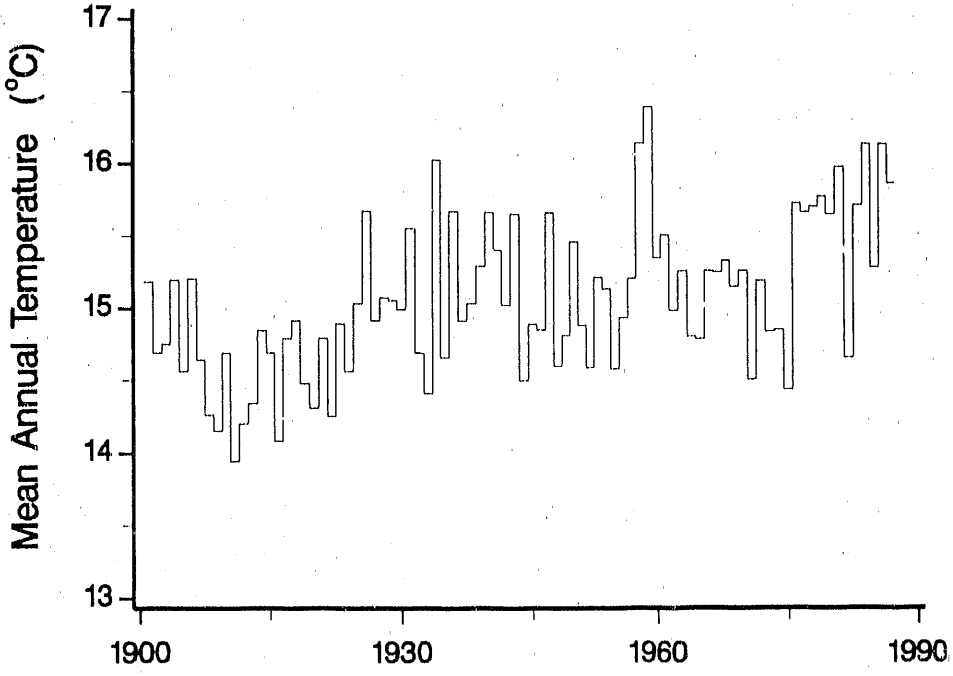
Principal investigators
Thomas R. Karl
Ronald G. Baldwin
Michael G. Burgin
National Oceanic and Atmospheric Administration
National Climatic Data Center
Federal Building
Asheville, North Carolina 28801, U.S.A.

Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

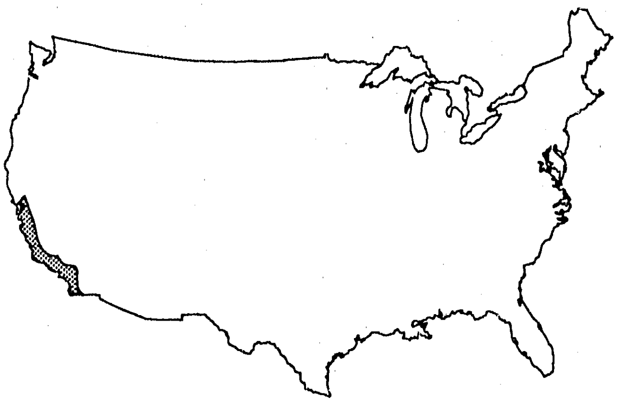
Period of record—1901–1987.

Method—After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability—These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



South Pacific Coast

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes for the most part have not been monotonic. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time.

Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated West region, which includes this subregion, Karl et al. (1988a) reported that, since the relatively cool period during the beginning decades of the century, annual mean temperatures have remained relatively constant with the exception of a number of multiyear climate fluctuations.

South Pacific Coast

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	15.18	11.63	13.42	19.24	16.42	15.18
1902	14.69	11.46	12.87	19.19	15.82	14.84
1903	14.75	10.13	12.54	19.12	16.83	14.66
1904	15.19	11.06	13.74	19.07	17.07	15.24
1905	14.56	11.41	13.04	18.45	15.57	14.62
1906	15.20	11.52	13.14	19.64	16.41	15.18
1907	14.64	11.19	12.74	18.62	15.77	14.58
1908	14.26	10.66	13.54	18.63	14.93	14.44
1909	14.15	10.23	12.25	18.66	15.50	14.16
1910	14.69	9.29	14.51	18.26	15.83	14.47
1911	13.94	10.32	12.76	18.15	15.34	14.14
1912	14.20	10.99	11.64	18.45	15.53	14.15
1913	14.34	9.57	12.49	19.16	16.28	14.37
1914	14.84	10.81	14.08	18.28	16.48	14.91
1915	14.69	9.63	13.30	19.39	15.80	14.53
1916	14.08	10.55	14.09	18.18	14.15	14.24
1917	14.79	8.95	11.70	19.65	17.14	14.36
1918	14.91	11.84	13.10	19.72	16.34	15.25
1919	14.48	10.19	12.93	19.15	15.29	14.39
1920	14.31	10.91	12.51	19.26	14.90	14.39
1921	14.79	10.03	12.57	19.57	16.32	14.62
1922	14.25	9.57	12.15	19.70	15.76	14.29
1923	14.89	10.72	13.50	18.65	16.98	14.96
1924	14.56	11.36	13.24	18.36	15.58	14.63
1925	15.03	10.81	13.61	19.13	15.48	14.76
1926	15.67	11.96	15.51	19.20	16.94	15.90
1927	14.91	10.75	13.46	18.84	16.51	14.89
1928	15.07	11.28	14.80	18.32	15.86	15.06
1929	15.05	9.48	12.74	20.01	16.95	14.79
1930	14.99	11.80	13.75	18.81	16.50	15.22
1931	15.55	11.26	15.74	20.00	15.66	15.66
1932	14.69	9.34	14.05	18.36	17.32	14.77
1933	14.41	8.68	12.76	18.28	17.00	14.18
1934	16.02	11.58	16.33	18.98	16.89	15.94
1935	14.66	11.08	13.03	19.14	15.66	14.73
1936	15.67	10.94	14.77	19.96	17.14	15.70
1937	14.91	8.41	13.73	19.51	17.40	14.76
1938	15.03	11.54	13.16	18.77	16.59	15.02
1939	15.29	10.56	13.74	18.81	17.92	15.26
1940	15.66	11.94	14.90	18.87	16.95	15.66
1941	15.40	12.06	14.60	18.87	16.68	15.55
1942	15.02	10.78	13.60	18.93	16.48	14.95
1943	15.65	11.81	14.79	18.66	17.47	15.68
1944	14.50	10.54	13.35	17.85	16.13	14.47

Year	Ann*
1945	14.89
1946	14.85
1947	15.66
1948	14.60
1949	14.81
1950	15.46
1951	14.88
1952	14.59
1953	15.21
1954	15.13
1955	14.58
1956	14.93
1957	15.20
1958	16.13
1959	16.38
1960	15.34
1961	15.50
1962	14.98
1963	15.25
1964	14.80
1965	14.78
1966	15.25
1967	15.24
1968	15.32
1969	15.14
1970	15.25
1971	14.50
1972	15.18
1973	14.83
1974	14.84
1975	14.43
1976	15.71
1977	15.65
1978	15.69
1979	15.76
1980	15.64
1981	15.96
1982	14.65
1983	15.70
1984	16.12
1985	15.27
1986	16.12
1987	15.85

*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
11.13	12.73	19.12	16.79	14.94
10.38	13.65	19.17	16.17	14.84
11.03	15.06	20.03	16.71	15.71
10.85	12.59	18.85	16.82	14.77
7.48	13.93	19.28	17.89	14.65
9.94	13.93	19.04	18.00	15.23
11.37	13.69	18.65	17.04	15.19
9.71	13.52	18.64	16.36	14.56
11.34	12.87	19.01	17.05	15.07
11.60	13.43	18.89	17.04	15.24
9.65	13.36	18.56	16.57	14.54
10.07	13.61	18.73	16.95	14.84
10.79	13.70	20.24	16.14	15.22
11.88	13.97	19.80	18.21	15.96
12.17	15.51	20.49	17.93	16.53
10.76	14.75	19.80	16.52	15.46
11.64	13.77	20.24	16.46	15.53
10.26	13.55	18.72	16.92	14.86
11.92	13.15	18.73	17.47	15.32
10.77	12.93	18.88	16.62	14.80
11.03	13.43	18.11	17.10	14.92
9.63	14.77	19.14	17.03	15.14
11.28	12.45	19.11	18.46	15.33
11.15	14.39	19.08	16.77	15.35
9.66	13.79	19.02	17.18	14.92
12.19	14.06	19.10	16.57	15.48
10.16	12.92	19.26	16.13	14.62
9.78	15.21	19.59	15.72	15.08
10.02	13.51	19.43	15.77	14.68
10.34	13.45	19.28	16.49	14.89
10.63	12.21	18.39	16.07	14.32
11.85	13.58	19.64	17.64	15.68
12.16	13.21	19.69	17.14	15.55
12.32	15.07	19.54	17.08	16.00
9.79	14.62	19.78	17.80	15.50
12.64	13.78	18.95	17.03	15.60
12.55	14.52	20.53	16.52	16.03
11.28	12.97	18.56	16.37	14.80
11.20	13.75	19.90	17.65	15.63
11.64	15.75	20.34	17.32	16.26
10.41	14.06	20.18	15.79	15.11
12.77	15.05	19.73	16.75	16.07
11.58	15.71	19.20	17.73	16.05

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North Cascades

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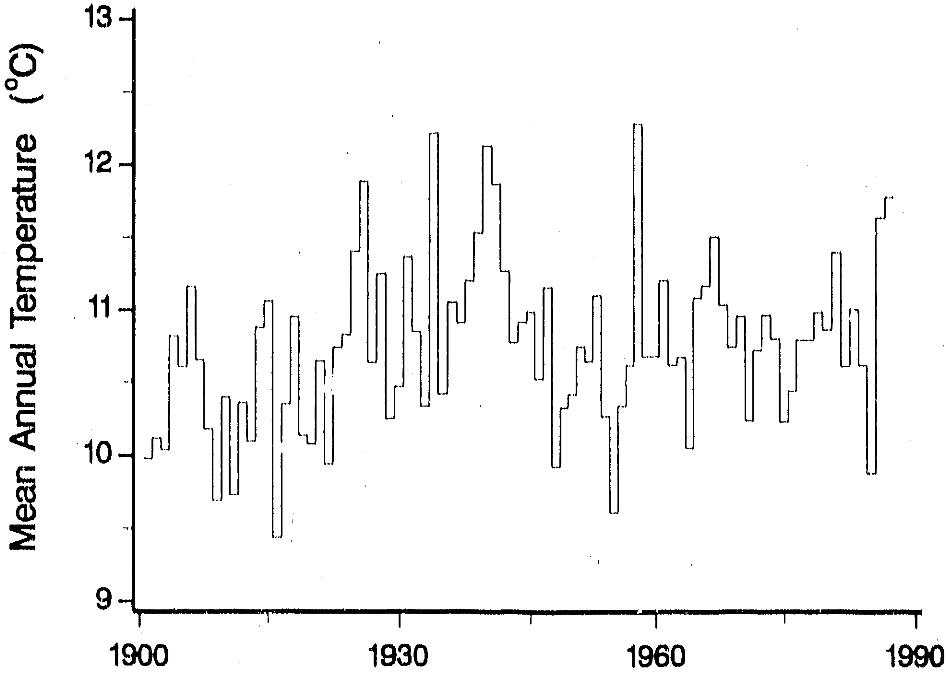
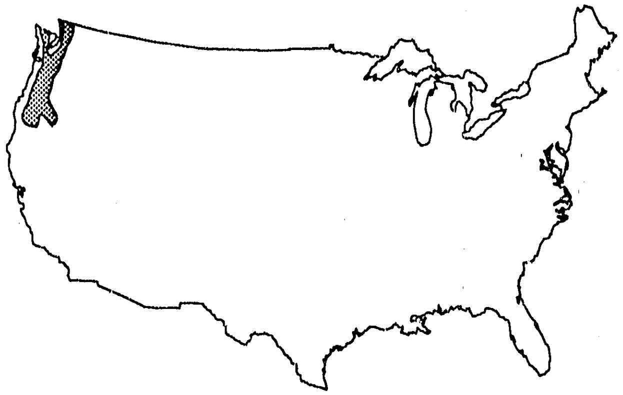


Annual calendar year average temperature.



North Cascades

TRENDS

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North Cascades

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	9.98	4.72	9.23	15.69	10.95	10.15
1902	10.12	4.40	8.94	16.58	10.57	10.12
1903	10.04	3.73	8.77	16.90	10.84	10.06
1904	10.82	3.99	9.48	17.63	11.93	10.76
1905	10.61	4.58	10.54	17.80	9.90	10.70
1906	11.16	4.61	10.03	18.32	11.19	11.04
1907	10.66	4.02	9.63	17.20	11.66	10.63
1908	10.18	4.65	8.76	17.55	10.68	10.41
1909	9.69	2.78	8.94	16.57	11.02	9.83
1910	10.40	1.87	11.14	16.78	10.65	10.11
1911	9.73	3.00	8.93	17.52	9.74	9.79
1912	10.36	4.82	9.31	17.12	10.08	10.33
1913	10.10	2.80	9.13	17.80	10.66	10.10
1914	10.88	4.79	11.42	17.54	10.73	11.12
1915	11.06	3.18	11.28	18.00	10.68	10.78
1916	9.44	2.88	9.28	16.74	9.61	9.63
1917	10.35	2.49	7.95	17.78	11.57	9.95
1918	10.95	5.44	9.23	18.29	11.94	11.22
1919	10.14	3.84	9.98	17.84	9.87	10.38
1920	10.08	2.59	8.41	17.80	10.13	9.73
1921	10.65	5.05	9.67	17.33	11.22	10.82
1922	9.94	2.38	8.84	17.91	10.74	9.97
1923	10.74	3.20	9.71	17.84	11.64	10.60
1924	10.83	5.01	10.62	17.75	10.92	11.07
1925	11.40	4.68	10.87	17.98	10.66	11.05
1926	11.88	5.63	12.19	18.76	11.54	12.02
1927	10.64	4.08	9.06	18.40	11.55	10.78
1928	11.25	3.86	11.43	18.08	11.25	11.15
1929	10.25	1.92	9.67	17.77	10.91	10.07
1930	10.47	3.40	10.66	17.65	10.75	10.62
1931	11.36	5.01	11.70	18.13	10.65	11.37
1932	10.85	3.62	10.25	17.72	12.28	10.97
1933	10.34	2.45	9.03	17.70	10.71	9.97
1934	12.22	7.00	12.88	17.51	12.08	12.37
1935	10.42	4.59	8.95	17.55	10.82	10.48
1936	11.05	3.81	10.89	18.17	11.08	10.99
1937	10.91	2.55	10.33	18.01	12.52	10.85
1938	11.20	4.91	10.45	18.07	11.51	11.24
1939	11.53	4.54	11.09	17.84	12.06	11.38
1940	12.13	6.22	11.98	18.68	12.03	12.23
1941	11.87	6.11	11.70	18.51	11.32	11.91
1942	11.27	4.51	10.16	18.52	11.76	11.24
1943	10.78	4.38	10.23	17.08	12.14	10.96
1944	10.92	4.00	9.70	17.63	12.22	10.89

Year	Ann*
1945	10.99
1946	10.53
1947	11.16
1948	9.93
1949	10.33
1950	10.42
1951	10.75
1952	10.65
1953	11.10
1954	10.27
1955	9.61
1956	10.34
1957	10.62
1958	12.28
1959	10.68
1960	10.68
1961	11.20
1962	10.62
1963	10.67
1964	10.05
1965	11.08
1966	11.16
1967	11.50
1968	11.03
1969	10.74
1970	10.95
1971	10.24
1972	10.72
1973	10.96
1974	10.80
1975	10.23
1976	10.44
1977	10.79
1978	10.79
1979	10.98
1980	10.86
1981	11.39
1982	10.61
1983	11.00
1984	10.62
1985	9.88
1986	11.63
1987	11.77

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann'l
5.03	9.72	17.98	11.07	10.95
4.48	10.43	17.35	9.92	10.55
4.28	11.82	16.74	11.49	11.08
4.21	8.65	17.47	10.44	10.19
1.15	10.77	17.20	11.56	10.17
2.07	9.00	18.08	11.35	10.12
5.40	9.73	17.91	11.52	11.14
3.19	9.92	17.56	11.32	10.50
5.86	9.23	16.80	12.19	11.02
4.75	9.40	15.94	11.38	10.37
3.76	7.63	16.70	10.41	9.62
3.48	10.30	17.46	10.25	10.37
2.88	10.66	17.07	11.29	10.47
6.54	10.73	19.79	11.68	12.19
5.56	9.80	17.74	10.65	10.94
3.83	9.57	17.98	11.32	10.68
5.66	9.81	19.22	9.98	11.17
3.92	9.35	17.05	11.79	10.53
4.89	9.57	16.60	12.04	10.78
4.34	8.69	16.83	10.46	10.08
4.31	10.02	17.98	12.05	11.09
4.15	10.40	17.45	11.80	10.95
5.83	8.86	19.42	12.51	11.65
5.53	10.14	17.58	11.28	11.13
2.62	10.52	17.82	11.21	10.54
5.81	9.31	18.38	10.86	11.09
4.12	9.00	17.69	10.29	10.28
3.87	10.25	18.52	10.72	10.84
3.96	10.19	17.38	10.81	10.59
4.55	9.20	17.70	12.01	10.86
4.87	8.44	16.73	11.00	10.26
5.01	9.07	16.42	11.81	10.58
4.20	9.31	18.37	10.53	10.60
6.12	10.26	18.04	10.01	11.11
2.44	10.65	17.64	11.86	10.64
4.77	10.03	16.74	11.97	10.88
5.83	10.38	17.89	11.50	11.40
4.70	9.39	17.93	10.83	10.71
5.83	10.92	17.08	11.04	11.22
4.45	10.08	17.34	10.39	10.56
2.96	9.91	18.46	8.85	10.05
4.48	10.84	18.66	11.35	11.33
4.91	11.54	18.29	12.58	11.83

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Karl, T.R., C.N. Williams, Jr., and F.T. Quinlan. 1990. *United States Historical Climatology (HCN) serial temperature and precipitation data.* NDP-019/R1. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

California Interior Valleys

BACKGROUND

Principal investigators
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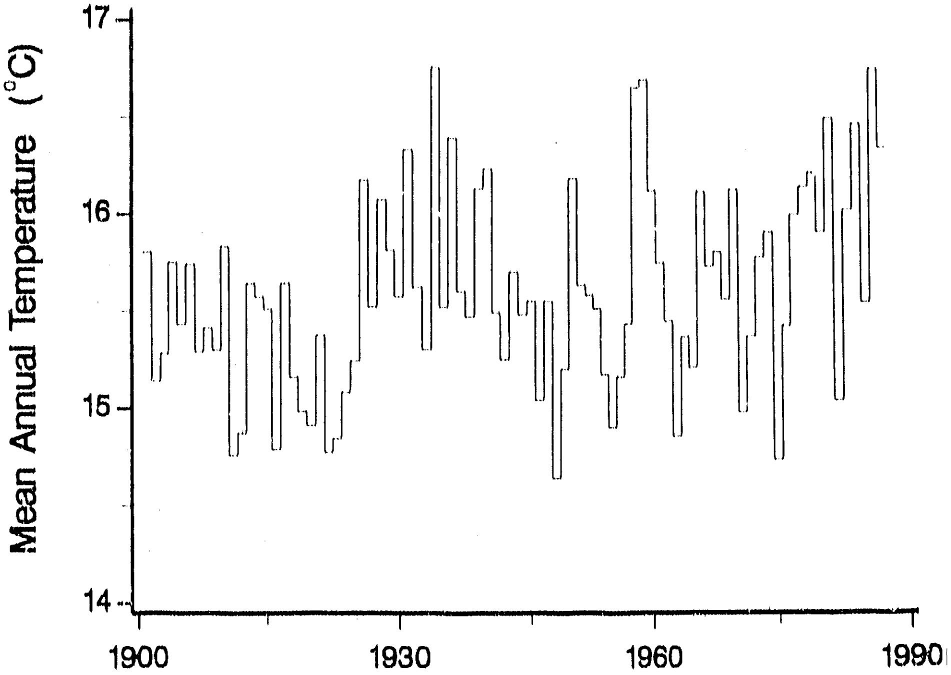
Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

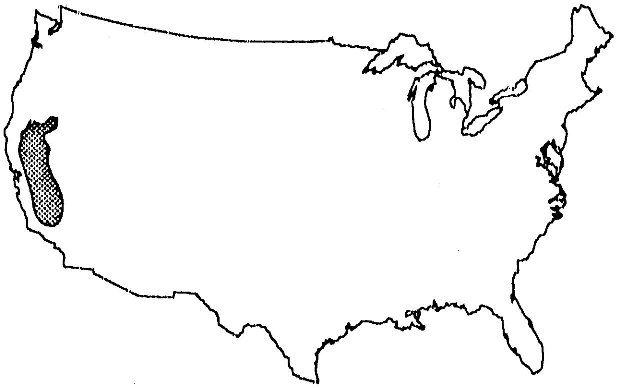
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



California Interior Valleys

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes for the most part have not been monotonic. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time.

Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated West region, which includes this subregion, Karl et al. (1988a) reported that, since the relatively cool period during the beginning decades of the century, annual mean temperatures have remained relatively constant with the exception of a number of multiyear climate fluctuations.

California Interior Valleys

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	15.80	8.45	14.08	23.26	17.02	15.70
1902	15.14	8.50	13.14	23.35	15.90	15.22
1903	15.28	7.12	13.71	22.97	17.15	15.24
1904	15.75	8.27	14.93	24.05	16.09	15.84
1905	15.43	8.82	14.53	23.12	15.54	15.50
1906	15.74	8.98	13.68	23.53	16.28	15.62
1907	15.29	8.67	13.72	22.27	16.34	15.25
1908	15.41	8.20	14.31	23.94	16.19	15.66
1909	15.30	8.06	13.86	22.86	16.02	15.20
1910	15.83	6.81	15.99	23.32	16.48	15.65
1911	14.76	8.06	13.61	22.88	14.99	14.89
1912	14.87	8.61	13.06	22.84	15.04	14.89
1913	15.64	7.35	14.20	23.74	17.17	15.62
1914	15.57	8.64	15.34	22.72	15.86	15.64
1915	15.51	7.53	14.12	23.52	16.34	15.38
1916	14.79	8.17	14.58	22.49	14.47	14.93
1917	15.64	6.91	12.54	24.53	17.50	15.37
1918	15.16	8.46	13.78	23.88	15.67	15.44
1919	14.98	7.00	14.45	23.15	15.03	14.91
1920	14.91	8.25	13.45	22.96	14.73	14.84
1921	15.37	7.92	13.53	23.32	16.21	15.24
1922	14.77	7.16	13.12	23.29	15.65	14.80
1923	14.84	8.03	13.96	21.46	16.58	15.01
1924	15.08	8.11	14.66	22.69	15.22	15.17
1925	15.24	7.78	14.51	23.43	14.48	15.05
1926	16.17	7.77	16.54	24.26	16.33	16.23
1927	15.52	8.55	14.17	23.22	16.10	15.51
1928	16.07	8.28	15.97	23.80	16.35	16.10
1929	15.81	7.27	14.16	23.57	17.22	15.55
1930	15.57	9.42	14.47	23.35	15.99	15.81
1931	16.33	8.32	16.63	24.80	15.54	16.32
1932	15.62	7.50	14.59	23.30	17.86	15.81
1933	15.30	5.94	13.54	24.05	17.04	15.14
1934	16.75	8.37	17.25	23.52	17.22	16.59
1935	15.52	8.53	13.71	24.17	15.79	15.54
1936	16.39	9.00	15.52	24.32	17.23	16.51
1937	15.60	6.10	14.70	23.96	17.03	15.45
1938	15.47	8.39	13.91	23.67	16.05	15.50
1939	16.13	7.78	15.72	23.89	16.92	16.07
1940	16.23	9.46	15.53	24.05	15.77	16.20
1941	15.49	9.64	14.35	22.68	15.59	15.56
1942	15.25	8.02	13.29	23.68	16.38	15.35
1943	15.70	8.31	14.98	22.27	16.97	15.63
1944	15.48	8.15	14.19	22.58	17.00	15.48

Year	Ann*
1945	15.55
1946	15.04
1947	15.55
1948	14.64
1949	15.20
1950	16.18
1951	15.63
1952	15.58
1953	15.51
1954	15.17
1955	14.90
1956	15.16
1957	15.43
1958	16.64
1959	16.68
1960	16.11
1961	15.74
1962	15.44
1963	14.85
1964	15.36
1965	15.20
1966	16.10
1967	15.72
1968	15.79
1969	15.55
1970	16.11
1971	14.97
1972	15.36
1973	15.76
1974	15.89
1975	14.73
1976	15.41
1977	15.98
1978	16.12
1979	16.19
1980	15.89
1981	16.47
1982	15.03
1983	16.00
1984	16.44
1985	15.53
1986	16.72
1987	16.32

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (C), 1901–1987

Win	Spr	Sum	Fall	Ann†
8.01	13.31	23.83	17.30	15.61
7.23	14.49	23.02	15.56	15.07
7.32	16.21	22.51	16.39	15.61
7.99	12.29	22.48	16.05	14.70
5.31	15.03	23.21	17.01	15.14
7.36	15.19	23.77	17.31	15.91
8.60	14.96	23.21	16.66	15.86
7.39	14.58	22.99	17.12	15.52
8.84	13.47	22.56	16.90	15.44
8.24	15.16	22.63	15.54	15.39
6.07	13.61	22.74	16.16	14.65
7.89	14.39	23.11	15.99	15.34
7.52	14.73	23.86	15.58	15.42
8.38	14.59	24.36	18.09	16.35
9.49	16.13	24.69	17.22	16.88
8.12	15.14	25.21	16.36	16.20
7.41	14.28	25.33	16.08	15.78
6.66	14.55	23.48	16.62	15.32
8.47	13.14	22.49	16.47	15.14
6.43	13.87	23.13	16.20	14.91
8.57	14.83	22.66	16.25	15.58
6.54	16.34	23.72	17.07	15.91
7.78	12.91	24.50	17.99	15.79
8.22	15.20	23.80	16.12	15.83
6.50	15.00	23.56	16.28	15.33
9.38	15.01	24.04	16.44	16.22
7.46	13.64	23.91	15.47	15.12
6.53	15.97	24.08	15.11	15.42
6.98	15.33	23.97	15.61	15.47
8.07	14.71	23.97	17.23	15.99
7.16	13.36	22.50	15.83	14.71
7.74	14.42	22.46	16.84	15.36
7.94	14.20	24.38	16.74	15.81
9.78	15.55	23.93	16.71	16.49
7.12	15.41	23.92	17.36	15.95
8.97	14.64	22.85	17.14	15.90
8.69	15.43	24.99	16.54	16.41
7.70	14.29	22.88	15.69	15.14
7.99	14.40	23.37	17.53	15.82
8.65	16.25	24.95	16.64	16.63
7.32	15.10	24.61	15.49	15.63
9.16	16.23	24.47	16.54	16.60
8.00	16.61	23.36	17.41	16.35

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East Slope North Cascades

BACKGROUND

Principal investigators
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Asheville, North Carolina 28801, U.S.A.

Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

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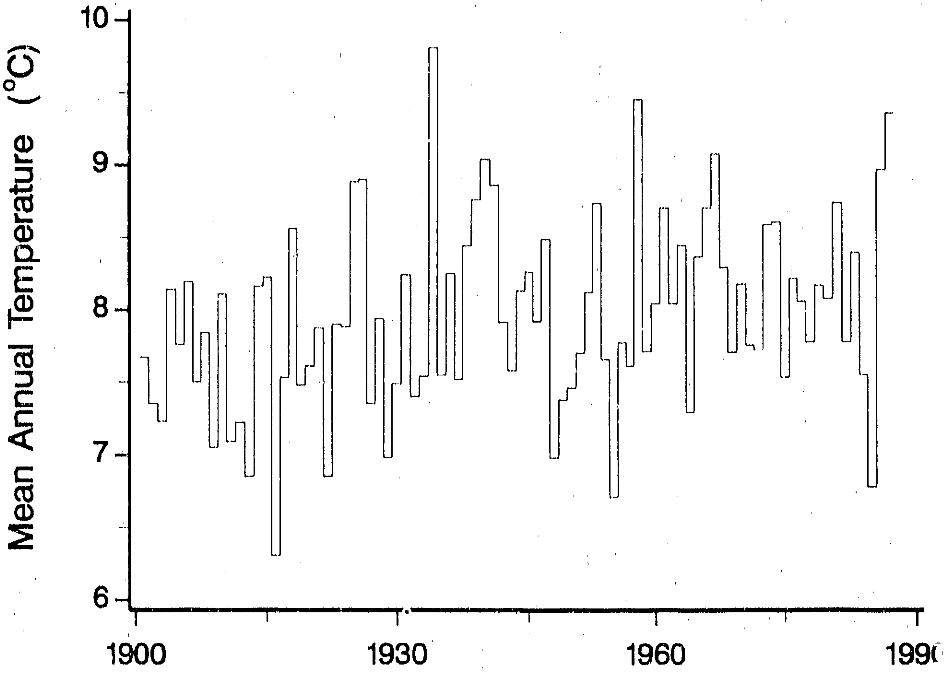
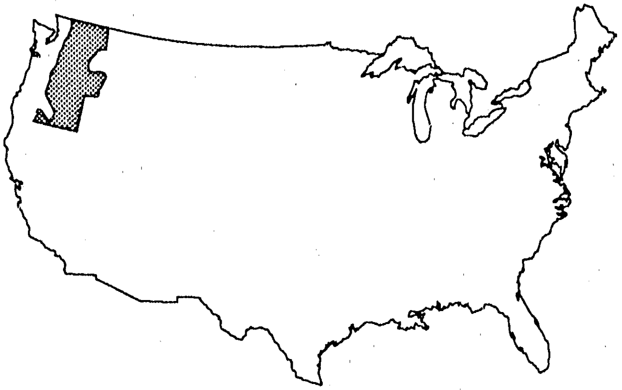


Annual calendar year average temperature.



East Slope North Cascades

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes for the most part have not been monotonic. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time.

Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated West region, which includes this subregion, Karl et al. (1988a) reported that, since the relatively cool period during the beginning decades of the century, annual mean temperatures have remained relatively constant with the exception of a number of multiyear climate fluctuations.

East Slope North Cascades

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	7.67	–0.86	6.90	16.74	8.80	7.89
1902	7.35	–1.04	6.75	16.09	8.03	7.46
1903	7.23	–2.68	6.36	17.62	7.40	7.18
1904	8.14	–1.86	6.98	17.83	9.38	8.08
1905	7.76	–1.28	8.08	17.78	6.98	7.89
1906	8.19	–1.56	7.73	18.13	8.06	8.09
1907	7.50	–3.30	7.08	16.55	9.39	7.43
1908	7.84	–1.25	7.09	17.86	8.59	8.07
1909	7.05	–3.24	6.63	16.56	8.84	7.20
1910	8.11	–4.32	9.91	16.88	8.48	7.74
1911	7.09	–2.74	7.38	18.03	6.65	7.33
1912	7.22	–2.46	7.05	16.90	6.88	7.09
1913	6.85	–4.45	6.65	17.42	7.88	6.87
1914	8.16	–1.12	9.00	17.88	8.26	8.51
1915	8.22	–3.35	9.07	18.09	7.70	7.88
1916	6.31	–4.16	7.13	16.75	6.85	6.64
1917	7.53	–5.06	5.03	18.17	9.69	6.96
1918	8.56	–0.28	7.52	18.29	9.44	8.74
1919	7.48	–1.03	7.93	17.79	6.80	7.87
1920	7.61	–2.85	6.31	17.75	7.40	7.15
1921	7.87	–0.91	7.44	18.07	7.72	8.08
1922	6.85	–5.37	5.98	19.20	8.45	7.06
1923	7.90	–3.82	7.52	17.57	8.96	7.56
1924	7.88	–1.27	8.53	17.71	7.94	8.23
1925	8.88	–1.50	8.86	18.40	7.60	8.34
1926	8.90	0.43	9.53	18.87	7.80	9.16
1927	7.35	–2.19	6.71	18.00	7.92	7.61
1928	7.94	–3.17	8.37	17.74	8.04	7.74
1929	6.98	–6.17	7.21	17.96	7.77	6.69
1930	7.49	–3.14	8.47	18.34	7.49	7.79
1931	8.24	–1.44	8.92	18.35	7.29	8.28
1932	7.40	–4.09	7.26	17.62	9.19	7.50
1933	7.54	–4.86	6.36	18.05	8.43	7.00
1934	9.81	2.15	10.80	18.39	8.93	10.06
1935	7.55	–1.55	6.68	17.42	7.66	7.55
1936	8.25	–3.67	9.22	18.71	8.48	8.19
1937	7.52	–5.66	7.93	18.01	9.68	7.49
1938	8.44	–0.91	7.72	18.59	8.88	8.57
1939	8.76	–1.91	8.90	18.25	8.79	8.51
1940	9.04	0.05	9.38	19.16	8.35	9.24
1941	8.86	–0.09	9.15	18.30	7.81	8.79
1942	7.91	–1.93	7.41	17.91	8.58	7.99
1943	7.58	–2.71	7.06	16.79	9.41	7.64
1944	8.13	–1.92	7.57	17.60	9.57	8.21

Year	Ann*
1945	8.26
1946	7.92
1947	8.49
1948	6.98
1949	7.38
1950	7.46
1951	7.70
1952	8.12
1953	8.74
1954	7.66
1955	6.71
1956	7.77
1957	7.61
1958	9.45
1959	7.71
1960	8.04
1961	8.70
1962	8.04
1963	8.44
1964	7.29
1965	8.36
1966	8.70
1967	9.07
1968	8.29
1969	7.70
1970	8.17
1971	7.75
1972	7.72
1973	8.58
1974	8.60
1975	7.53
1976	8.21
1977	8.05
1978	7.77
1979	8.16
1980	8.07
1981	8.73
1982	7.77
1983	8.39
1984	7.55
1985	6.78
1986	8.96
1987	9.35

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
–0.80	7.14	18.19	8.24	8.19
–1.54	8.54	17.43	6.76	7.80
–1.17	9.57	16.96	8.64	8.50
–1.57	6.23	17.36	7.65	7.42
–7.38	8.57	17.75	9.12	7.01
–4.67	6.65	18.26	8.61	7.21
–0.53	7.15	18.03	8.12	8.19
–3.37	7.93	17.74	9.03	7.83
1.21	7.00	16.42	9.68	8.58
–0.20	7.11	15.86	8.58	7.84
–2.01	4.81	17.34	7.18	6.83
–3.01	8.40	17.54	7.58	7.63
–3.87	8.46	16.97	8.24	7.45
1.76	8.34	19.68	8.24	9.50
60.56	7.32	17.46	7.25	7.87
–2.20	7.11	18.45	8.90	8.07
0.32	7.70	20.31	6.63	8.74
–2.44	7.16	17.07	9.19	7.75
–0.07	7.61	17.22	10.08	8.71
–1.46	6.35	16.94	7.66	7.37
–1.35	7.30	18.06	8.90	8.23
–0.93	8.41	17.14	9.40	8.50
1.36	6.48	19.81	9.81	9.36
–0.53	7.97	17.91	8.18	8.38
–4.62	8.16	18.14	8.20	7.47
–0.52	7.00	19.54	7.25	8.31
–1.00	6.96	18.33	7.11	7.85
–2.93	7.94	18.42	7.63	7.76
–2.14	8.40	18.27	7.99	8.13
–0.41	7.17	18.48	9.50	8.69
–2.03	6.18	17.55	8.43	7.53
–0.14	7.08	16.98	9.36	8.32
–1.47	7.36	19.27	7.17	8.08
–0.61	7.81	18.12	7.10	8.10
–5.27	8.23	18.69	8.78	7.61
–1.13	8.27	16.65	8.57	8.09
1.10	8.06	17.66	8.62	8.86
–1.17	7.05	18.33	7.36	7.89
0.60	8.58	17.33	8.39	8.72
–2.13	7.33	17.93	6.94	7.52
–4.58	8.04	19.04	4.80	6.82
–1.75	8.78	19.23	8.09	8.59
–0.74	9.89	18.48	10.05	9.42

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Great Basin

BACKGROUND

Principal investigators
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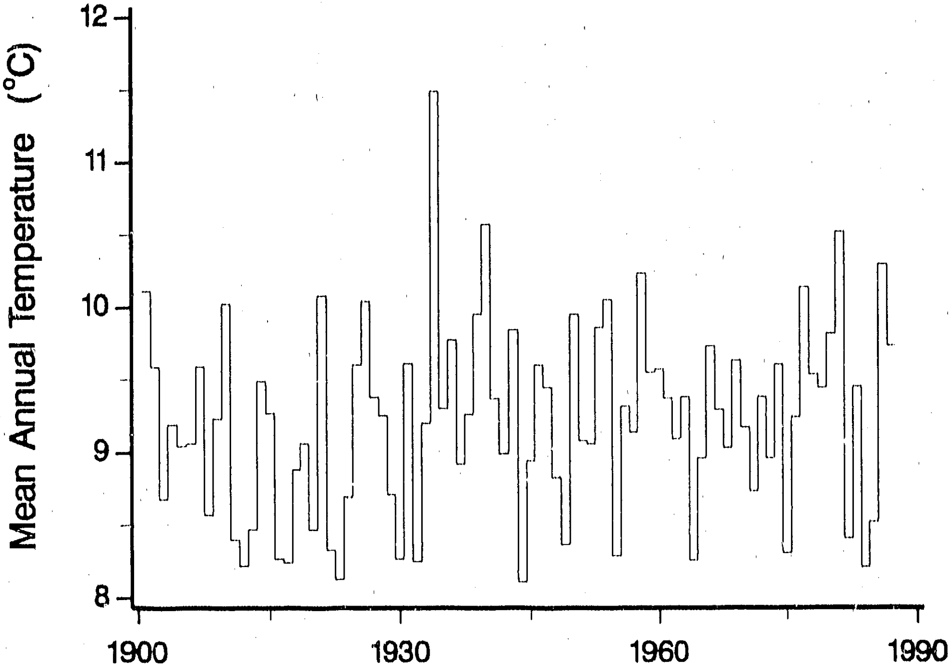
Asheville, North Carolina 28801, U.S.A.

Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

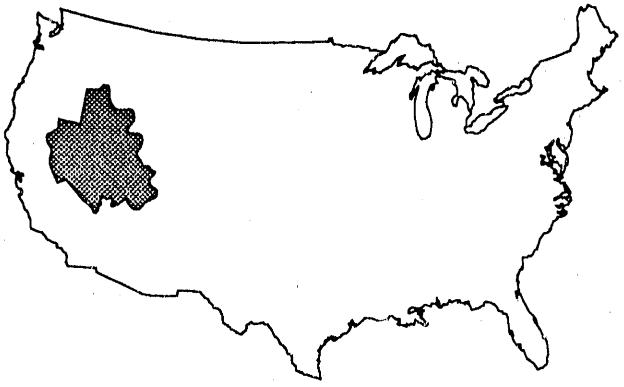
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Great Basin

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes for the most part have not been monotonic. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time.

Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated West region, which includes this subregion, Karl et al. (1988a) reported that, since the relatively cool period during the beginning decades of the century, annual mean temperatures have remained relatively constant with the exception of a number of multiyear climate fluctuations.

Great Basin

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	10.11	–0.05	8.46	21.15	10.99	10.14
1902	9.59	–0.22	8.23	20.65	9.60	9.57
1903	8.68	–3.54	7.64	21.14	10.07	8.82
1904	9.19	–1.58	8.33	20.40	9.61	9.19
1905	9.04	–0.70	8.56	20.82	8.78	9.37
1906	9.06	–2.44	7.72	20.15	8.73	8.54
1907	9.59	1.08	8.85	18.65	9.76	9.58
1908	8.57	0.50	7.49	19.59	8.04	8.91
1909	9.23	–0.29	7.47	20.99	9.55	9.43
1910	10.02	–4.24	11.04	21.11	10.43	9.59
1911	8.40	–1.39	8.14	20.36	7.80	8.72
1912	8.22	–1.58	7.18	19.75	7.19	8.14
1913	8.47	–3.43	8.08	19.99	9.22	8.46
1914	9.49	–1.00	9.93	20.18	9.71	9.70
1915	9.27	–2.82	9.08	20.03	9.25	8.89
1916	8.27	–1.60	8.78	19.37	7.50	8.51
1917	8.24	–5.94	5.37	21.00	10.19	7.65
1918	8.88	0.00	7.92	21.01	8.82	9.44
1919	9.06	–2.48	9.33	22.02	7.46	9.08
1920	8.47	–2.22	7.01	20.12	8.38	8.32
1921	10.08	–0.61	8.43	20.97	10.36	9.78
1922	8.33	–3.62	6.17	21.56	9.71	8.45
1923	8.13	–1.75	7.43	19.32	8.59	8.40
1924	8.69	–2.63	7.98	21.26	9.06	8.92
1925	9.60	–2.33	10.31	20.13	8.32	9.11
1926	10.04	–0.45	10.10	21.51	9.97	10.28
1927	9.38	–0.95	7.88	20.78	10.15	9.47
1928	9.25	–1.99	9.43	20.10	9.46	9.25
1929	8.71	–4.02	7.28	20.84	8.55	8.16
1930	8.27	–0.46	8.54	20.82	7.20	9.03
1931	9.61	–2.96	9.08	22.61	9.01	9.43
1932	8.25	–4.84	8.35	20.39	9.93	8.46
1933	9.20	–6.24	6.81	22.15	11.02	8.43
1934	11.49	2.22	12.57	21.81	10.41	11.75
1935	9.30	–0.07	7.41	21.37	8.85	9.39
1936	9.77	–0.97	9.76	21.33	8.54	9.67
1937	8.92	–5.25	8.52	21.22	10.79	8.82
1938	9.26	–0.25	7.77	20.70	8.96	9.30
1939	9.95	–2.41	10.08	21.11	10.13	9.73
1940	10.57	1.10	10.26	22.33	9.50	10.80
1941	9.37	0.63	8.37	19.90	8.32	9.31
1942	8.99	–1.81	7.01	21.01	9.71	8.98
1943	9.84	0.35	9.39	19.90	10.33	9.99
1944	8.11	–3.14	6.78	19.26	9.78	8.16

Year	Ann*
1945	8.94
1946	9.60
1947	9.45
1948	8.83
1949	8.37
1950	9.95
1951	9.08
1952	9.06
1953	9.86
1954	10.05
1955	8.29
1956	9.32
1957	9.14
1958	10.23
1959	9.55
1960	9.57
1961	9.37
1962	9.09
1963	9.38
1964	8.26
1965	8.96
1966	9.73
1967	9.29
1968	9.03
1969	9.63
1970	9.17
1971	8.73
1972	9.38
1973	8.96
1974	9.60
1975	8.31
1976	9.24
1977	10.13
1978	9.53
1979	9.44
1980	9.81
1981	10.51
1982	8.41
1983	9.45
1984	8.21
1985	8.52
1986	10.29
1987	9.73

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
–0.82	6.97	19.64	9.76	8.89
–1.60	9.42	21.46	8.19	9.37
–0.38	9.83	19.98	9.34	9.69
–0.95	7.28	20.59	9.23	9.04
–7.21	9.23	20.54	10.58	8.29
–1.87	8.09	20.61	11.48	9.58
0.04	8.33	20.45	9.33	9.54
–3.26	7.60	20.64	10.23	8.80
0.93	7.11	20.52	11.39	9.99
–0.15	9.34	20.56	10.43	10.04
–4.86	6.77	20.40	9.90	8.05
–0.52	8.73	20.51	9.39	9.53
–1.41	7.87	20.81	8.53	8.95
0.78	8.11	21.27	10.28	10.11
0.51	8.21	21.84	9.14	9.93
–3.09	9.13	21.70	10.27	9.50
–0.45	8.29	22.15	7.65	9.41
–3.26	7.99	20.14	11.14	9.00
–1.03	7.70	19.91	11.47	9.51
–3.47	6.41	19.99	9.11	8.01
–0.04	7.10	19.33	9.98	9.09
–1.90	9.51	21.16	10.54	9.83
–1.23	7.35	20.93	10.96	9.50
–1.88	7.86	20.03	9.29	8.82
–0.94	8.80	20.83	9.08	9.44
0.87	6.79	21.04	8.61	9.33
–1.04	7.56	21.41	7.83	8.94
–1.53	9.55	21.30	8.70	9.50
–4.00	7.52	20.82	9.44	8.45
–1.13	9.19	21.42	9.84	9.83
–2.50	6.02	19.70	9.26	8.12
–0.57	8.00	20.13	9.90	9.36
–1.41	7.56	22.14	10.81	9.77
1.56	9.08	20.54	9.23	10.10
–3.70	8.75	20.97	10.23	9.06
0.63	7.83	20.43	9.88	9.69
0.98	8.68	21.85	10.43	10.48
–0.72	7.48	20.33	7.92	8.75
–0.15	7.10	20.10	10.26	9.33
–3.26	7.94	20.19	8.82	8.42
–3.98	9.00	21.47	7.86	8.59
0.13	9.57	21.70	8.68	10.02
–1.39	9.77	20.74	10.39	9.87

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Southern Desert

BACKGROUND

Principal investigators

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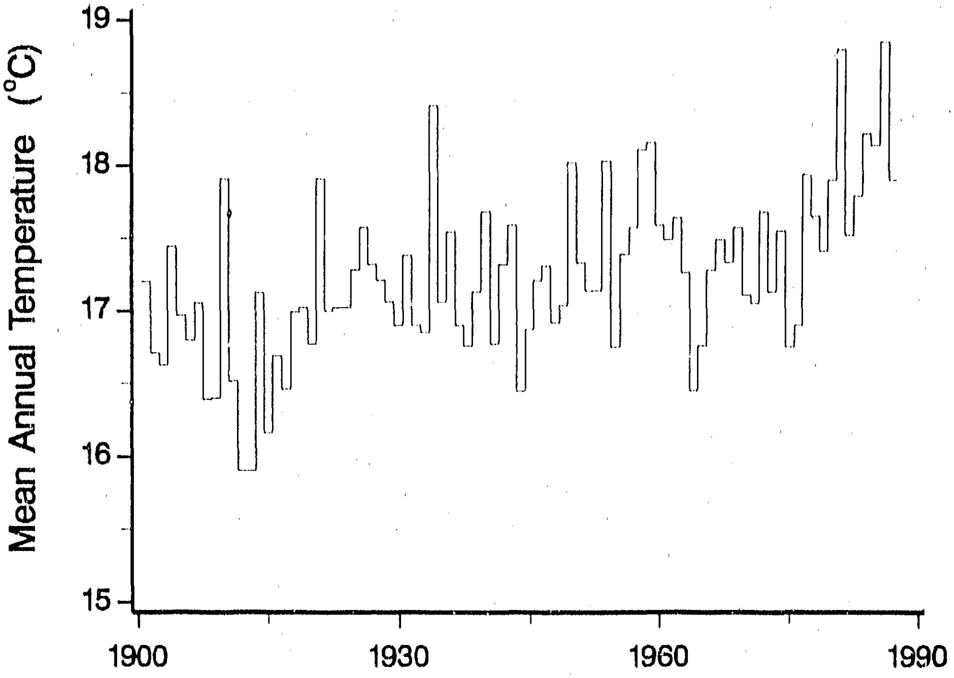
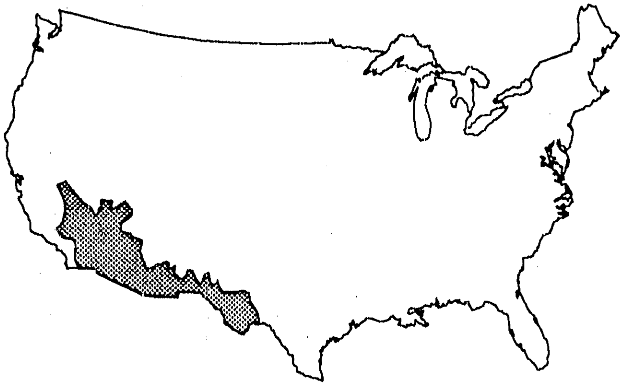


Annual calendar year average temperature.



Southern Desert

TRENDS

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Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated West region, which includes this subregion, Karl et al. (1988a) reported that, since the relatively cool period during the beginning decades of the century, annual mean temperatures have remained relatively constant with the exception of a number of multiyear climate fluctuations.

Southern Desert

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	17.20	7.58	15.90	27.20	18.05	17.18
1902	16.71	7.30	15.81	26.74	17.24	16.77
1903	16.63	6.16	15.42	26.79	17.95	16.58
1904	17.44	7.52	17.82	27.09	17.44	17.47
1905	16.97	7.68	15.54	27.45	17.73	17.10
1906	16.80	7.03	15.70	26.58	16.93	16.56
1907	17.05	8.17	16.49	25.97	17.67	17.08
1908	16.39	7.13	16.10	26.24	16.53	16.50
1909	16.40	7.33	15.00	27.11	17.42	16.72
1910	17.91	5.18	18.30	27.76	18.56	17.45
1911	16.52	7.75	16.33	26.60	16.96	16.91
1912	15.90	5.92	14.86	26.42	16.14	15.84
1913	15.90	4.66	15.29	25.90	17.47	15.83
1914	17.12	6.71	16.93	26.78	18.39	17.20
1915	16.16	5.36	14.85	26.69	17.12	16.01
1916	16.69	7.41	17.05	26.46	16.22	16.78
1917	16.46	5.52	14.06	27.10	18.13	16.20
1918	16.99	7.38	16.31	27.27	17.70	17.17
1919	17.02	6.10	16.98	27.52	16.89	16.87
1920	16.77	8.28	15.79	26.94	16.65	16.92
1921	17.91	7.34	16.95	27.57	18.54	17.60
1922	17.00	7.00	15.53	28.04	17.86	17.11
1923	17.02	8.09	16.58	26.29	17.65	17.15
1924	17.02	6.81	16.39	27.58	17.66	17.11
1925	17.28	7.20	17.96	26.72	16.70	17.14
1926	17.57	7.35	17.50	27.05	18.55	17.61
1927	17.32	8.16	16.69	26.64	18.07	17.39
1928	17.21	6.98	17.18	26.68	17.76	17.15
1929	17.06	6.42	16.22	27.20	17.89	16.93
1930	16.90	7.94	16.26	27.16	16.94	17.08
1931	17.38	7.24	17.51	27.64	17.49	17.47
1932	16.90	5.87	16.57	27.07	17.94	16.86
1933	16.85	4.67	15.16	27.67	19.18	16.67
1934	18.41	8.11	19.56	27.43	18.25	18.34
1935	17.06	8.12	15.83	27.54	17.15	17.16
1936	17.54	7.28	17.92	27.79	17.27	17.57
1937	16.90	4.78	16.38	27.50	18.29	16.73
1938	16.76	8.41	15.93	26.34	16.54	16.80
1939	17.13	6.34	17.10	27.25	17.46	17.04
1940	17.68	8.35	17.69	27.73	17.12	17.72
1941	16.77	8.84	15.65	26.26	16.77	16.88
1942	17.32	7.43	15.64	27.70	17.97	17.18
1943	17.59	8.93	17.48	27.21	17.47	17.77
1944	16.45	6.52	15.52	26.37	17.25	16.41

Year	Ann*
1945	16.87
1946	17.21
1947	17.31
1948	16.92
1949	17.04
1950	18.02
1951	17.33
1952	17.14
1953	17.14
1954	18.03
1955	16.75
1956	17.39
1957	17.57
1958	18.11
1959	18.16
1960	17.59
1961	17.49
1962	17.64
1963	17.26
1964	16.45
1965	16.76
1966	17.28
1967	17.49
1968	17.33
1969	17.57
1970	17.11
1971	17.05
1972	17.68
1973	17.13
1974	17.55
1975	16.75
1976	16.90
1977	17.94
1978	17.65
1979	17.41
1980	17.90
1981	18.80
1982	17.52
1983	17.79
1984	18.22
1985	18.14
1986	18.85
1987	17.90

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
7.55	15.14	27.36	17.74	16.94
6.39	17.18	27.92	16.50	17.00
8.31	17.43	27.07	17.49	17.57
6.69	15.85	27.52	17.37	16.86
5.00	16.79	27.64	18.62	17.01
7.73	17.63	27.34	18.54	17.81
8.25	16.58	27.50	17.80	17.53
7.32	16.03	27.41	18.05	17.20
7.83	15.74	27.40	17.72	17.17
8.14	17.46	27.40	18.69	17.92
6.14	15.83	26.52	18.03	16.63
8.16	16.73	27.57	17.39	17.46
9.13	16.13	28.14	16.69	17.52
8.70	16.46	28.42	18.55	18.03
8.67	17.83	28.47	18.02	18.25
6.81	17.63	28.58	18.00	17.75
7.85	16.99	28.09	16.74	17.42
7.68	16.28	27.29	18.85	17.53
8.49	16.28	26.39	18.45	17.40
6.15	15.37	26.97	17.06	16.39
8.15	15.32	26.12	17.62	16.80
5.98	17.20	27.58	18.15	17.23
8.15	16.14	27.50	18.80	17.64
8.10	16.43	26.98	17.87	17.34
7.16	16.65	27.74	17.81	17.33
8.54	15.67	27.95	16.74	17.22
7.95	15.77	27.75	17.04	17.13
7.64	18.10	27.92	16.82	17.62
6.85	15.79	27.70	17.62	16.99
7.75	17.53	27.69	18.03	17.75
7.19	14.63	27.08	17.45	16.59
8.46	16.13	26.71	16.73	17.01
8.00	15.34	28.36	19.04	17.69
8.91	16.89	28.02	17.96	17.94
6.57	16.89	27.30	18.19	17.23
9.25	15.37	28.10	18.07	17.70
10.32	17.68	29.05	18.46	18.88
9.28	16.83	27.52	17.23	17.71
8.39	15.60	27.37	19.25	17.65
9.50	18.56	27.87	17.65	18.39
7.78	18.08	28.66	17.54	18.02
10.48	19.17	28.87	17.36	18.97
7.87	17.46	27.60	19.05	18.00

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Northern Rockies

BACKGROUND

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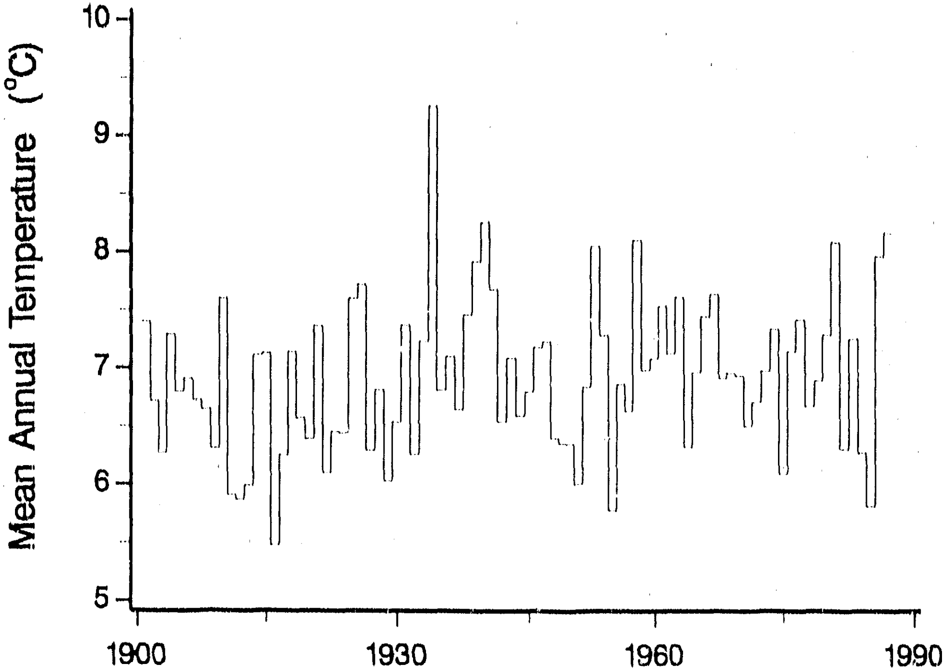
Sponsoring agencies

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

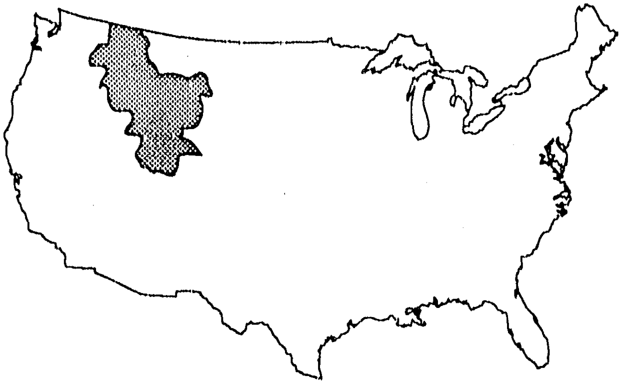
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Northern Rockies

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes for the most part have not been monotonic. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time.

Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated West region, which includes this subregion, Karl et al. (1988a) reported that, since the relatively cool period during the beginning decades of the century, annual mean temperatures have remained relatively constant with the exception of a number of multiyear climate fluctuations.

Northern Rockies

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	7.40	–2.53	6.54	17.85	8.25	7.53
1902	6.72	–2.33	5.58	16.76	7.34	6.84
1903	6.27	–4.60	4.91	17.59	6.97	6.21
1904	7.29	–3.02	5.91	17.12	8.95	7.24
1905	6.80	–3.32	6.69	17.68	6.81	6.96
1906	6.91	–3.21	5.42	17.26	7.23	6.67
1907	6.73	–2.86	5.89	15.93	8.15	6.78
1908	6.65	–2.60	5.92	16.92	7.00	6.81
1909	6.31	–3.64	4.57	17.87	7.74	6.64
1910	7.60	–6.64	8.94	17.92	8.24	7.11
1911	5.91	–4.09	5.73	17.40	5.64	6.17
1912	5.87	–3.97	4.40	16.74	5.76	5.73
1913	5.99	–5.60	5.50	17.43	6.93	6.06
1914	7.11	–3.21	7.17	17.61	7.91	7.37
1915	7.13	–4.63	7.38	17.20	7.20	6.79
1916	5.48	–5.46	5.91	17.11	5.65	5.80
1917	6.25	–6.77	2.59	17.96	8.77	5.64
1918	7.14	–2.50	5.90	18.41	7.81	7.40
1919	6.57	–3.15	6.53	18.82	5.45	6.91
1920	6.39	–4.18	4.20	17.73	6.45	6.05
1921	7.36	–2.59	6.02	18.39	7.57	7.35
1922	6.10	–6.28	4.11	19.21	8.16	6.30
1923	6.45	–4.95	5.00	17.75	7.57	6.34
1924	6.44	–3.54	5.72	17.66	7.13	6.74
1925	7.60	–3.63	7.45	17.99	6.36	7.04
1926	7.72	–1.56	7.66	18.63	7.30	8.01
1927	6.29	–3.74	4.76	17.49	7.75	6.56
1928	6.81	–4.86	6.87	17.00	7.41	6.61
1929	6.03	–7.66	5.33	18.42	6.53	5.66
1930	6.53	–3.90	6.99	18.24	6.30	6.91
1931	7.37	–3.56	6.69	19.35	6.88	7.34
1932	6.26	–5.66	5.58	18.00	7.91	6.46
1933	7.23	–6.61	5.01	19.23	8.80	6.61
1934	9.26	0.48	10.19	18.75	8.48	9.48
1935	6.81	–2.65	4.97	18.11	6.92	6.84
1936	7.10	–5.31	6.98	19.41	7.27	7.08
1937	6.65	–7.06	6.19	18.20	9.12	6.61
1938	7.46	–2.13	6.13	18.10	7.77	7.47
1939	7.92	–3.72	7.65	18.00	8.70	7.66
1940	8.26	–1.40	8.07	19.59	7.70	8.49
1941	7.68	–1.62	7.24	18.30	6.91	7.71
1942	6.54	–4.79	5.51	17.85	7.71	6.57
1943	7.09	–3.35	5.89	17.22	8.63	7.10
1944	6.59	–3.58	5.59	16.80	8.15	6.74

Year	Ann*
1945	6.80
1946	7.18
1947	7.23
1948	6.40
1949	6.36
1950	6.35
1951	6.01
1952	6.84
1953	8.05
1954	7.28
1955	5.78
1956	6.86
1957	6.63
1958	8.10
1959	6.98
1960	7.08
1961	7.53
1962	7.12
1963	7.61
1964	6.32
1965	6.96
1966	7.44
1967	7.63
1968	6.91
1969	6.95
1970	6.93
1971	6.50
1972	6.70
1973	6.97
1974	7.33
1975	6.09
1976	7.14
1977	7.41
1978	6.67
1979	6.89
1980	7.28
1981	8.08
1982	6.30
1983	7.25
1984	6.27
1985	5.81
1986	7.96
1987	8.16

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
−2.88	5.32	17.55	7.28	6.81
−3.62	7.21	18.21	5.88	6.92
−2.71	7.24	17.50	7.40	7.36
−3.39	5.18	17.91	7.30	6.75
−8.77	7.37	17.92	8.02	6.14
−5.59	4.71	17.03	8.00	6.04
−2.45	5.25	16.89	6.44	6.53
−5.88	5.83	17.76	8.17	6.47
−0.51	5.38	17.73	9.50	8.03
−1.75	5.91	17.13	8.24	7.38
−4.72	3.70	17.76	6.38	5.78
−4.14	6.42	17.82	7.17	6.82
−4.70	6.10	17.70	6.78	6.47
−0.95	6.61	18.58	8.04	8.07
−2.17	5.91	18.23	6.53	7.13
−4.21	6.38	18.47	8.13	7.19
−1.82	6.36	20.23	5.68	7.61
−4.72	5.99	17.05	8.94	6.82
−2.37	6.36	17.69	9.82	7.87
−4.07	4.68	17.31	7.34	6.31
−2.81	4.98	17.33	7.90	6.85
−3.63	6.84	18.05	8.61	7.47
−1.67	5.34	18.56	8.96	7.80
−3.19	6.31	17.35	7.26	6.93
−4.99	6.56	17.89	7.26	6.68
−1.66	4.95	19.03	6.12	7.11
−3.27	5.51	18.32	5.94	6.63
−4.52	7.00	18.02	6.58	6.77
−5.02	5.90	18.13	7.25	6.56
−3.04	6.35	18.30	8.10	7.43
−3.90	4.01	17.15	6.73	6.00
−2.16	5.68	17.16	8.05	7.18
−2.76	6.27	18.70	7.53	7.43
−2.66	6.51	17.52	6.87	7.06
−7.34	6.46	18.29	8.00	6.35
−2.42	6.56	17.02	7.99	7.28
−0.74	7.20	17.99	8.27	8.18
−3.77	5.44	17.84	6.33	6.46
−1.46	6.01	17.95	7.99	7.62
−5.67	5.77	17.98	6.37	6.11
−6.64	7.10	18.56	4.51	5.88
−3.27	7.85	18.96	6.85	7.60
−2.47	8.57	17.89	8.86	8.22

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Southern Rockies

BACKGROUND

Principal investigators
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Sponsoring agencies
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Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

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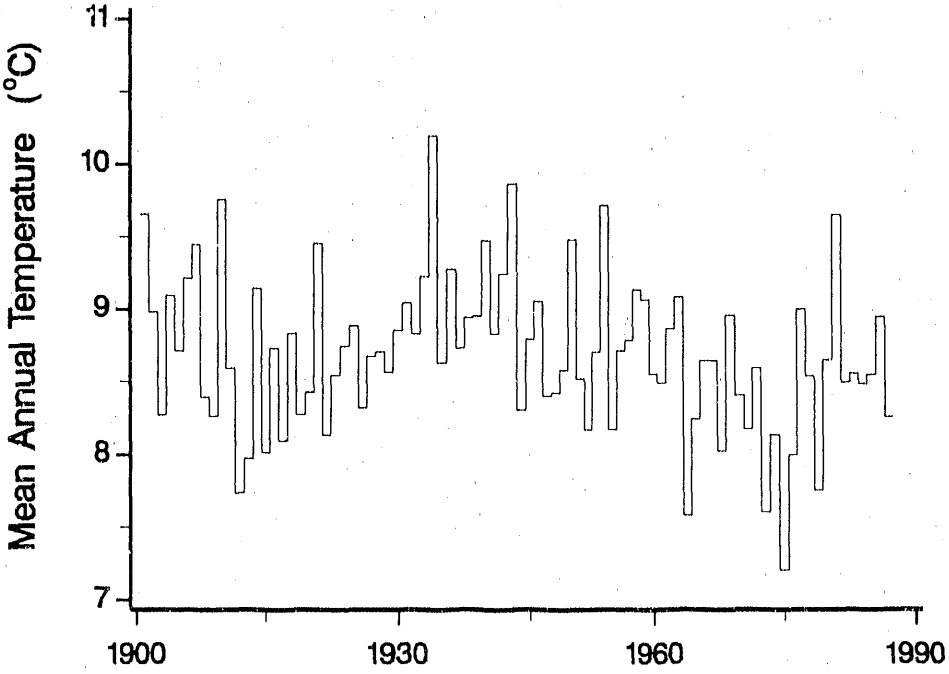
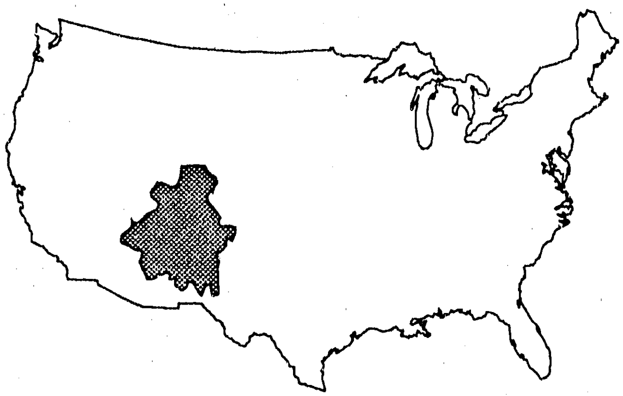


Annual calendar year average temperature.



Southern Rockies

TRENDS

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Southern Rockies

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	9.65	−0.11	8.63	19.32	10.59	9.60
1902	8.98	−0.91	8.47	19.37	9.56	9.12
1903	8.27	−3.22	8.06	18.81	9.41	8.26
1904	9.09	−1.52	9.67	18.68	9.40	9.06
1905	8.71	−1.51	8.35	19.11	9.71	8.91
1906	9.21	−2.24	8.97	18.65	9.56	8.73
1907	9.44	1.23	9.21	18.13	9.91	9.62
1908	8.39	−1.06	8.46	18.61	8.24	8.56
1909	8.26	−1.82	6.32	19.67	9.92	8.52
1910	9.75	−3.58	10.20	19.83	10.74	9.30
1911	8.59	−0.45	9.25	18.06	9.02	8.97
1912	7.73	−3.29	7.28	18.28	8.21	7.62
1913	7.97	−3.98	7.63	18.76	9.64	8.01
1914	9.14	−2.39	9.46	18.82	10.26	9.04
1915	8.01	−3.19	7.42	18.24	9.07	7.89
1916	8.73	−1.12	9.01	18.48	9.04	8.86
1917	8.09	−2.96	5.22	18.43	10.25	7.74
1918	8.83	−1.49	8.70	19.98	9.45	9.16
1919	8.27	−3.54	8.42	18.98	8.64	8.13
1920	8.42	−0.39	7.12	18.77	8.82	8.58
1921	9.45	−1.42	8.58	18.52	10.55	9.06
1922	8.13	−1.64	7.02	19.26	8.71	8.34
1923	8.54	−1.04	7.79	18.97	8.44	8.54
1924	8.74	−1.23	7.19	19.81	9.95	8.93
1925	8.88	−2.46	9.46	19.31	8.74	8.76
1926	8.32	−2.49	7.73	18.53	10.15	8.48
1927	8.67	−1.26	7.38	18.59	10.12	8.71
1928	8.70	−2.59	8.76	19.00	9.71	8.72
1929	8.56	−4.07	7.74	19.63	9.13	8.11
1930	8.85	0.11	8.24	19.60	8.67	9.15
1931	9.04	−1.50	8.63	19.76	9.82	9.18
1932	8.83	−2.81	8.24	19.41	9.88	8.68
1933	9.22	−2.70	7.91	19.69	11.21	9.03
1934	10.19	−0.06	10.89	19.94	9.95	10.18
1935	8.63	−0.76	7.12	19.34	9.24	8.73
1936	9.27	−0.92	9.05	20.09	9.09	9.33
1937	8.73	−3.79	7.71	19.56	10.91	8.60
1938	8.94	−0.40	7.69	19.32	9.13	8.93
1939	8.95	−3.02	8.92	19.47	9.95	8.83
1940	9.47	−0.68	9.10	19.90	9.93	9.56
1941	8.83	−0.42	7.93	18.66	9.28	8.87
1942	9.24	−1.68	8.24	19.68	10.41	9.16
1943	9.86	0.22	10.19	20.22	9.99	10.16
1944	8.30	−2.77	6.66	19.15	9.65	8.17

Year	Ann*
1945	8.79
1946	9.05
1947	8.40
1948	8.42
1949	8.58
1950	9.48
1951	8.52
1952	8.17
1953	8.70
1954	9.71
1955	8.17
1956	8.71
1957	8.78
1958	9.13
1959	9.06
1960	8.55
1961	8.49
1962	8.86
1963	9.08
1964	7.58
1965	8.24
1966	8.64
1967	8.64
1968	8.02
1969	8.95
1970	8.40
1971	8.17
1972	8.59
1973	7.60
1974	8.13
1975	7.20
1976	7.99
1977	8.99
1978	8.53
1979	7.75
1980	8.64
1981	9.64
1982	8.49
1983	8.55
1984	8.48
1985	8.54
1986	8.94
1987	8.25

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
−0.94	7.26	19.15	9.90	8.84
−1.97	8.84	19.46	8.89	8.80
−1.03	7.96	18.69	9.48	8.78
−2.54	6.73	18.94	9.31	8.11
−2.15	8.07	18.62	10.59	8.78
−0.91	8.59	17.96	10.92	9.14
−0.16	7.20	19.12	9.13	8.82
−2.18	6.88	19.20	9.20	8.27
−1.65	7.07	19.29	9.89	8.65
−0.17	8.81	18.74	11.04	9.60
−3.23	7.04	18.26	9.98	8.01
−0.89	8.30	19.09	9.26	8.94
0.13	7.09	19.10	8.11	8.61
−0.84	7.20	19.79	9.69	8.96
0.03	8.09	19.62	9.23	9.24
−3.07	8.43	19.55	10.02	8.73
−1.75	8.17	19.44	8.15	8.50
−1.84	7.21	18.43	10.60	8.60
−0.67	8.17	18.79	11.03	9.33
−4.07	6.34	18.61	9.19	7.52
−1.72	6.08	18.16	10.10	8.15
−3.00	8.75	19.16	9.81	8.68
−1.27	8.03	18.45	10.03	8.81
−1.80	6.45	18.14	9.16	7.99
−1.42	7.59	19.34	9.10	8.65
−0.15	6.57	19.07	8.63	8.53
−1.01	7.44	18.87	8.22	8.38
−1.78	9.05	18.71	8.39	8.59
−3.23	5.81	18.20	9.15	7.48
−3.09	7.95	18.95	9.47	8.32
−4.05	5.04	18.36	9.17	7.13
−2.23	6.81	18.33	8.63	7.88
−1.86	7.17	19.36	10.21	8.72
−0.53	7.58	18.98	9.79	8.95
−3.83	6.09	18.28	9.45	7.49
−0.52	5.15	19.42	9.50	8.39
1.05	8.01	19.80	10.40	9.81
−0.72	7.54	18.83	9.29	8.74
−2.30	5.74	19.10	10.74	8.32
−1.80	7.76	19.04	9.16	8.54
−2.48	8.15	19.51	9.19	8.59
−0.63	8.57	19.28	8.48	8.93
−2.21	6.74	18.79	9.86	8.29

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Northern Steppes

BACKGROUND

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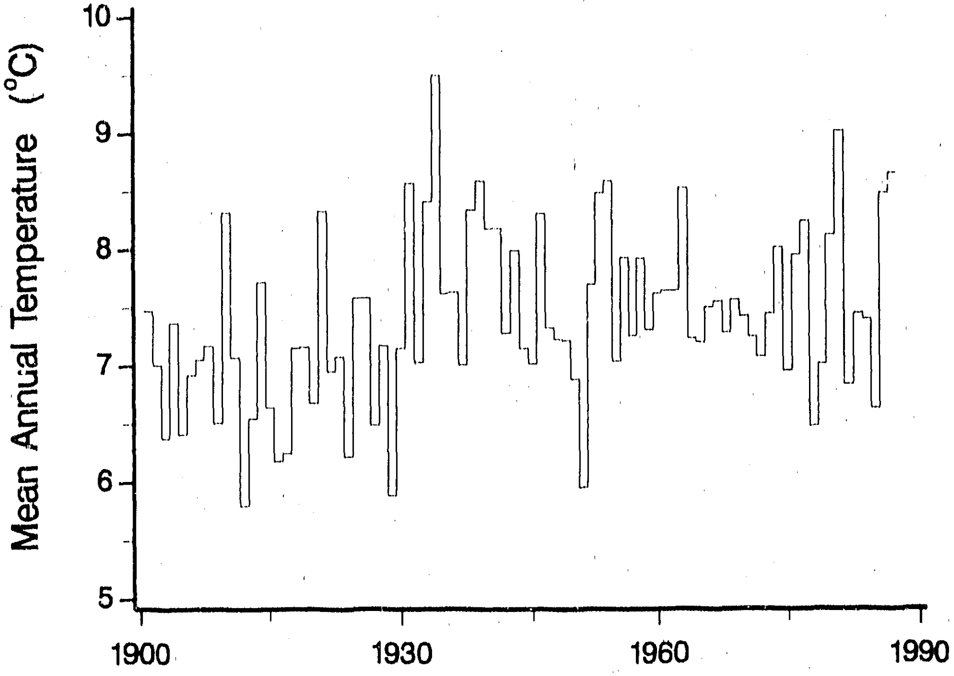
Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

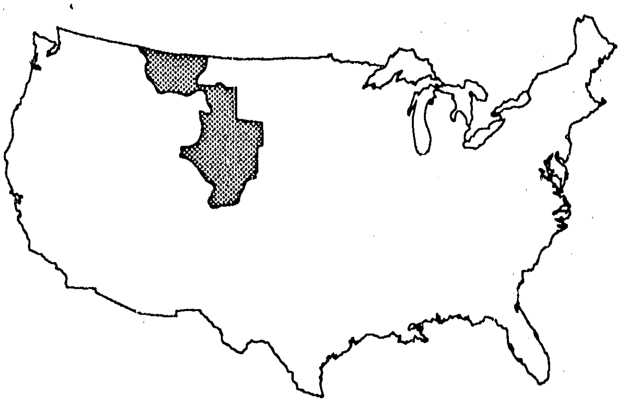
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Northern Steppes

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated Central region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a cool beginning until the 1920s, followed by several decades of warm weather until about 1960, and a somewhat cooler period that was not as cool as earlier in the century.

Northern Steppes

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	7.47	–4.35	6.61	19.95	8.65	7.71
1902	7.01	–4.08	6.41	18.59	7.62	7.14
1903	6.38	–6.34	5.05	18.30	7.32	6.08
1904	7.37	–3.72	6.01	18.12	9.10	7.38
1905	6.41	–5.90	5.87	18.51	7.53	6.50
1906	6.92	–2.87	4.70	17.80	7.31	6.74
1907	7.05	–3.10	5.64	18.25	7.90	7.17
1908	7.17	–2.84	6.38	17.98	7.63	7.29
1909	6.51	–4.46	4.31	19.89	8.35	7.02
1910	8.32	–7.25	9.30	19.63	9.02	7.68
1911	7.07	–3.55	7.32	19.14	6.47	7.35
1912	5.80	–5.84	3.62	17.94	6.63	5.59
1913	6.55	–6.18	5.53	19.75	7.87	6.74
1914	7.72	–4.44	6.67	19.89	9.67	7.95
1915	6.64	–5.79	5.53	16.72	8.35	6.20
1916	6.18	–5.86	6.49	19.22	6.73	6.64
1917	6.25	–7.06	3.12	18.76	8.91	5.93
1918	7.15	–5.86	6.63	19.92	7.35	7.01
1919	7.16	–3.50	6.42	20.91	5.77	7.40
1920	6.68	–4.06	4.01	18.62	7.40	6.49
1921	8.33	–2.54	6.59	20.23	8.90	8.30
1922	6.95	–6.39	5.67	20.24	8.78	7.07
1923	7.08	–4.12	5.14	19.20	7.61	6.95
1924	6.22	–3.83	3.60	18.86	8.20	6.71
1925	7.58	–4.75	7.92	19.09	6.20	7.11
1926	7.58	–2.59	6.84	19.22	7.43	7.72
1927	6.49	–4.02	5.34	17.71	8.22	6.81
1928	7.17	–4.85	6.82	17.65	7.51	6.78
1929	5.89	–7.76	5.40	19.88	5.73	5.81
1930	7.15	–5.32	6.34	19.93	7.46	7.10
1931	8.57	–1.32	5.84	21.08	8.72	8.58
1932	7.03	–3.84	5.68	20.18	7.96	7.49
1933	8.41	–6.18	6.00	21.23	9.98	7.76
1934	9.50	–0.55	9.17	21.10	9.00	9.68
1935	7.62	–1.91	4.81	20.11	7.53	7.63
1936	7.63	–7.34	7.29	22.32	8.19	7.61
1937	7.01	–7.19	6.33	20.60	8.72	7.12
1938	8.34	–3.48	7.12	20.40	8.95	8.25
1939	8.59	–4.44	7.88	20.05	9.62	8.28
1940	8.18	–3.68	7.16	20.92	9.03	8.36
1941	8.18	–1.86	7.10	19.60	8.07	8.23
1942	7.28	–4.60	6.52	19.10	8.07	7.27
1943	7.99	–2.44	5.82	20.02	8.61	8.00
1944	7.15	–3.35	5.21	18.82	8.70	7.35

Year	Ann*
1945	7.02
1946	8.31
1947	7.33
1948	7.23
1949	7.22
1950	6.89
1951	5.96
1952	7.70
1953	8.49
1954	8.59
1955	7.04
1956	7.93
1957	7.26
1958	7.92
1959	7.31
1960	7.62
1961	7.64
1962	7.64
1963	8.52
1964	7.23
1965	7.20
1966	7.50
1967	7.55
1968	7.28
1969	7.56
1970	7.42
1971	7.24
1972	7.07
1973	7.44
1974	8.01
1975	6.95
1976	7.94
1977	8.23
1978	6.48
1979	7.01
1980	8.11
1981	9.00
1982	6.83
1983	7.44
1984	7.39
1985	6.63
1986	8.47
1987	8.64

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
–3.76	5.52	18.44	8.24	7.11
–2.89	8.15	19.69	6.84	7.95
–3.19	5.37	19.39	8.18	7.44
–4.17	6.28	19.52	8.35	7.49
–8.03	7.28	19.92	9.21	7.10
–4.37	4.36	18.18	8.36	6.63
–3.10	4.55	17.78	6.51	6.43
–4.63	5.86	20.38	7.95	7.39
–1.78	5.47	20.16	10.04	8.47
–1.22	5.53	20.31	9.27	8.47
–4.38	6.15	19.90	7.34	7.25
–4.27	6.32	20.13	8.63	7.70
–3.76	5.32	19.68	7.15	7.10
–1.06	5.93	19.03	8.99	8.22
–4.49	5.87	20.69	6.28	7.09
–4.04	6.57	20.22	8.95	7.92
–2.19	6.34	20.68	6.27	7.77
–5.65	6.71	18.80	9.42	7.32
–3.91	7.40	20.62	11.07	8.79
–4.04	5.51	19.69	7.94	7.27
–3.91	4.63	18.84	7.99	6.88
–4.80	7.02	19.91	8.50	7.66
–2.42	6.45	18.68	8.55	7.82
–4.20	6.14	18.93	8.10	7.24
–5.31	6.93	19.55	7.67	7.21
–2.30	5.14	20.63	6.85	7.58
–4.23	6.07	20.07	7.21	7.28
–4.31	7.67	19.21	6.84	7.35
–5.31	5.36	19.94	7.77	7.07
–3.50	7.48	19.82	8.17	7.99
–4.33	4.68	19.36	7.60	6.83
–1.91	6.71	19.77	7.37	7.98
–3.24	7.86	20.35	8.59	8.39
–6.70	6.87	19.44	7.87	6.87
–8.71	6.42	19.42	8.31	6.36
–3.58	6.53	20.48	8.76	8.05
–0.66	8.19	19.91	9.41	9.21
–4.68	5.96	19.28	6.93	6.87
–0.97	4.95	20.38	8.47	8.21
–5.85	5.98	20.29	6.91	6.83
–6.17	8.47	19.71	4.72	6.68
–3.16	8.27	20.29	7.22	8.15
–1.51	8.18	19.66	8.62	8.74

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Southern Steppes

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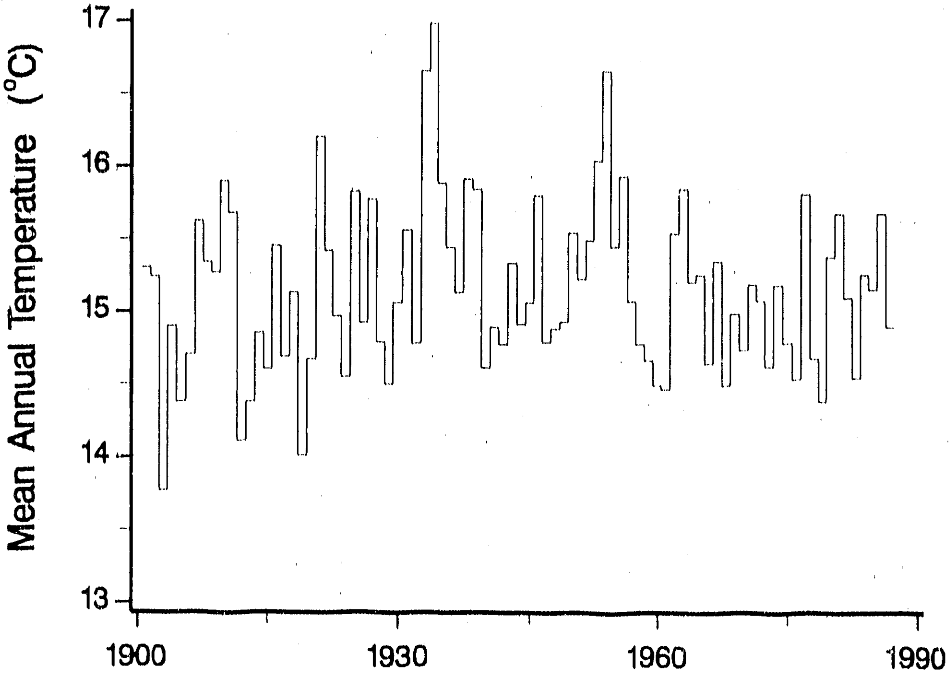
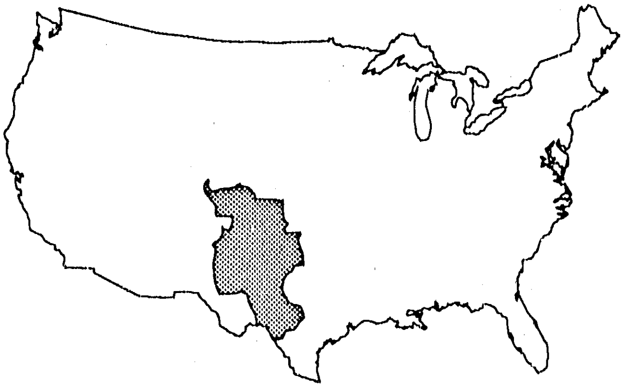


Annual calendar year average temperature.



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Southern Steppes

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	15.30	4.33	14.27	26.51	16.47	15.39
1902	15.24	3.81	16.15	25.57	15.47	15.25
1903	13.77	2.79	13.70	23.79	14.55	13.71
1904	14.90	4.97	15.53	24.00	15.24	14.94
1905	14.38	1.64	15.30	25.13	16.03	14.53
1906	14.70	4.21	14.13	24.23	14.42	14.25
1907	15.62	7.74	15.27	25.16	15.49	15.92
1908	15.34	5.09	15.94	24.82	14.98	15.21
1909	15.27	6.20	14.43	26.09	16.24	15.74
1910	15.90	2.73	16.16	26.31	16.73	15.48
1911	15.68	6.00	15.98	26.38	15.51	15.97
1912	14.11	1.98	13.69	24.97	15.27	13.98
1913	14.38	2.80	14.60	25.41	15.08	14.47
1914	14.85	4.41	14.31	25.17	16.00	14.97
1915	14.60	3.40	12.96	24.10	16.26	14.18
1916	15.45	5.75	15.88	25.74	15.02	15.60
1917	14.69	4.65	13.28	25.46	15.40	14.70
1918	15.13	3.42	15.63	26.77	14.61	15.11
1919	14.01	2.95	14.08	24.11	15.11	14.06
1920	14.67	4.75	14.23	24.31	15.21	14.63
1921	16.20	5.83	15.54	25.52	17.05	15.99
1922	15.42	4.83	14.61	25.88	16.18	15.38
1923	14.97	6.37	13.98	25.73	14.56	15.16
1924	14.55	4.18	12.75	25.96	16.42	14.83
1925	15.82	3.89	17.49	26.46	14.80	15.66
1926	14.92	4.92	13.67	24.90	16.07	14.89
1927	15.77	5.43	16.17	24.88	17.18	15.91
1928	14.79	3.79	14.51	24.89	15.27	14.61
1929	14.50	2.83	15.17	25.68	14.01	14.42
1930	15.06	4.31	15.33	25.82	15.49	15.24
1931	15.56	4.78	13.02	25.85	17.92	15.39
1932	14.78	5.71	14.41	25.77	14.51	15.10
1933	16.65	3.88	15.86	26.49	18.01	16.06
1934	16.98	6.84	16.34	27.98	17.48	17.16
1935	15.88	6.67	15.60	26.23	15.55	16.01
1936	15.44	3.53	16.28	26.88	14.70	15.35
1937	15.13	3.85	14.97	26.63	15.65	15.27
1938	15.91	5.41	16.02	25.84	15.86	15.78
1939	15.84	4.79	15.79	26.07	16.39	15.76
1940	14.61	3.40	14.98	24.76	15.47	14.65
1941	14.89	5.41	13.94	24.35	15.91	14.90
1942	14.77	4.24	14.50	25.00	15.49	14.81
1943	15.33	5.83	14.86	26.57	14.78	15.51
1944	14.91	4.42	13.87	25.53	15.65	14.86

Year	Ann*
1945	15.06
1946	15.80
1947	14.79
1948	14.88
1949	14.93
1950	15.54
1951	15.22
1952	15.49
1953	16.04
1954	16.66
1955	15.45
1956	15.93
1957	15.07
1958	14.77
1959	14.66
1960	14.49
1961	14.46
1962	15.53
1963	15.84
1964	15.20
1965	15.25
1966	14.64
1967	15.34
1968	14.49
1969	14.98
1970	14.73
1971	15.18
1972	15.07
1973	14.62
1974	15.18
1975	14.78
1976	14.53
1977	15.80
1978	14.67
1979	14.38
1980	15.37
1981	15.67
1982	15.09
1983	14.54
1984	15.25
1985	15.15
1986	15.67
1987	14.89

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*Calendar year mean (Jan–Dec).

†Season year mean = (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
4.48	15.03	24.77	16.07	15.09
4.69	16.16	25.70	15.37	15.48
4.47	13.57	25.54	16.40	15.00
3.10	15.07	25.61	15.21	14.75
4.02	14.70	24.96	16.22	14.98
6.33	14.81	24.76	16.30	15.55
5.03	14.60	25.91	15.35	15.22
6.82	14.03	26.95	14.59	15.60
6.07	15.45	26.81	16.07	16.10
6.18	15.34	27.15	16.96	16.41
5.09	15.93	25.24	15.98	15.56
4.81	15.77	26.48	16.28	15.83
6.62	13.60	25.82	14.05	15.02
5.17	13.03	25.88	15.81	14.97
4.06	14.52	25.21	14.37	14.54
3.30	14.13	25.45	16.08	14.74
3.87	14.93	24.39	14.44	14.41
4.21	15.09	25.60	16.53	15.35
3.86	16.88	26.56	17.49	16.19
2.61	15.09	26.24	15.77	14.93
5.02	13.98	25.18	16.32	15.12
3.32	15.13	25.45	15.61	14.88
4.80	16.75	24.87	15.05	15.37
3.97	13.94	24.73	15.13	14.44
5.35	13.41	25.72	14.78	14.81
5.05	13.65	25.40	14.33	14.61
6.07	14.81	24.97	15.31	15.29
5.64	16.48	24.93	14.49	15.39
3.00	13.75	24.66	16.20	14.40
4.76	16.87	25.12	14.42	15.29
4.33	14.17	24.84	14.98	14.58
6.34	14.68	24.63	13.09	14.68
3.92	15.33	26.28	16.99	15.63
2.46	15.47	25.95	15.88	14.94
1.94	14.62	24.74	15.31	14.15
5.00	13.86	27.10	15.21	15.29
5.89	15.52	25.60	16.11	15.78
4.10	15.23	25.45	15.77	15.14
4.43	13.41	25.40	16.65	14.97
2.58	14.65	25.95	15.08	14.56
4.51	16.35	25.65	15.65	15.54
5.61	16.21	25.43	15.07	15.58
4.96	14.12	25.11	15.52	14.93

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Northern Plains

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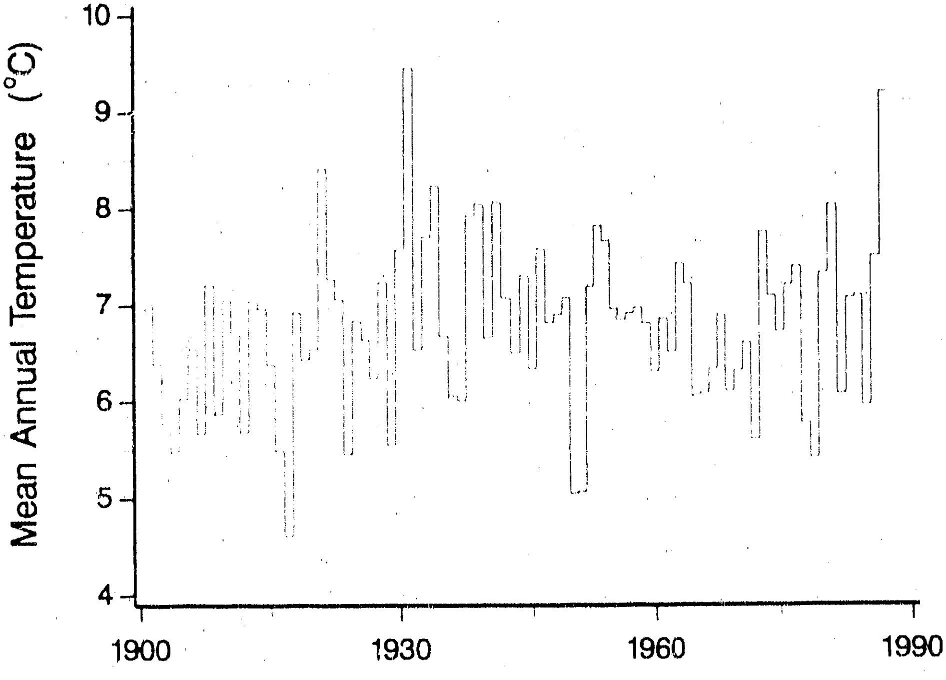
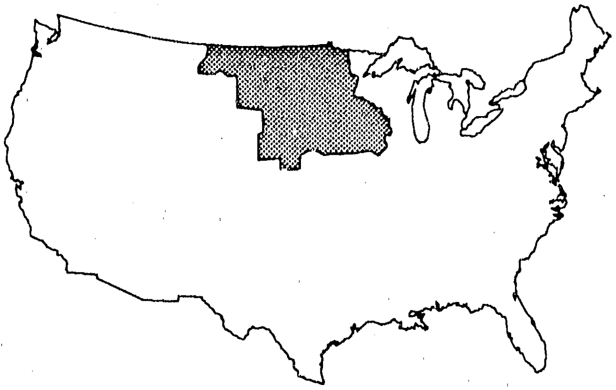
Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Northern Plains

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated Central region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a cool beginning until the 1920s, followed by several decades of warm weather until about 1960, and a somewhat cooler period that was not as cool as earlier in the century.

Northern Plains

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	7.01	−8.20	7.28	22.15	8.01	7.31
1902	6.39	−8.70	7.60	19.11	7.89	6.47
1903	5.77	−10.10	7.00	18.86	7.25	5.76
1904	5.48	−12.20	5.39	18.74	9.14	5.27
1905	6.03	−11.30	6.69	19.78	8.36	5.88
1906	6.54	−6.80	5.69	19.65	8.18	6.68
1907	5.67	−9.38	4.04	19.60	7.55	5.45
1908	7.21	−5.98	6.69	19.40	9.34	7.36
1909	5.87	−8.28	4.53	20.91	8.20	6.34
1910	7.05	−11.40	9.35	20.61	8.18	6.68
1911	6.71	−8.72	8.20	20.92	5.83	6.56
1912	5.68	−11.30	5.61	19.43	8.55	5.57
1913	7.04	−8.43	5.74	21.43	8.77	6.88
1914	6.96	−7.04	6.77	21.12	9.99	7.71
1915	6.38	−9.33	6.37	17.62	9.01	5.92
1916	5.49	−10.20	5.80	20.75	7.43	5.94
1917	4.61	−12.60	4.66	19.53	7.28	4.71
1918	6.92	−12.20	8.08	20.72	8.05	6.16
1919	6.43	−5.75	6.34	21.33	6.42	7.08
1920	6.54	−10.30	5.21	19.94	9.51	6.09
1921	8.41	−5.07	8.40	22.23	7.94	8.37
1922	7.27	−9.13	7.67	21.04	10.43	7.50
1923	7.05	−8.85	5.09	20.93	8.99	6.54
1924	5.46	−7.19	4.88	19.01	8.70	6.35
1925	6.83	−9.83	8.34	20.49	6.69	6.42
1926	6.64	−6.66	6.85	20.26	6.48	6.73
1927	6.24	−7.76	6.72	18.88	8.51	6.59
1928	7.23	−8.77	6.71	19.68	8.15	6.44
1929	5.55	−11.10	6.99	20.66	6.85	5.85
1930	7.57	−8.05	7.31	21.75	8.43	7.36
1931	9.45	−3.14	6.75	22.49	11.07	9.29
1932	6.53	−6.40	5.89	21.69	6.95	7.03
1933	7.70	−7.75	6.62	22.64	8.81	7.58
1934	8.23	−6.64	8.59	22.22	9.16	8.33
1935	6.68	−7.64	5.82	21.26	7.00	6.61
1936	6.06	−14.60	6.94	23.37	7.96	5.90
1937	6.01	−11.00	6.10	22.10	7.69	6.21
1938	7.92	−8.57	7.88	21.80	9.67	7.70
1939	8.05	−7.96	7.73	21.39	9.73	7.72
1940	6.66	−7.93	5.34	21.17	9.15	6.93
1941	8.07	−7.39	8.21	21.48	9.31	7.90
1942	7.07	−5.74	7.97	20.29	7.75	7.57
1943	6.51	−9.58	5.28	21.50	7.42	6.16
1944	7.31	−5.19	5.65	20.52	9.09	7.52

Year	Ann*
1945	6.34
1946	7.58
1947	6.82
1948	6.91
1949	7.08
1950	5.05
1951	5.07
1952	7.19
1953	7.82
1954	7.66
1955	6.96
1956	6.84
1957	6.91
1958	6.97
1959	6.80
1960	6.31
1961	6.85
1962	6.51
1963	7.42
1964	7.21
1965	6.05
1966	6.08
1967	6.33
1968	6.88
1969	6.10
1970	6.31
1971	6.60
1972	5.60
1973	7.73
1974	7.08
1975	6.71
1976	7.19
1977	7.38
1978	5.77
1979	5.41
1980	7.31
1981	8.01
1982	6.07
1983	7.05
1984	7.08
1985	5.95
1986	7.48
1987	9.17

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*Calendar year mean (Jan–Dec).

†Season year mean = (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
–7.72	6.98	19.33	7.84	6.61
–8.67	9.14	20.37	7.89	7.18
–7.29	4.82	21.18	9.15	6.97
–9.42	6.79	20.85	9.41	6.91
–10.10	7.30	21.91	9.08	7.04
–10.00	3.70	19.29	8.20	5.29
–9.45	4.65	19.03	6.16	5.10
–8.47	6.15	21.28	8.31	6.82
–6.66	6.03	21.41	10.50	7.82
–5.81	5.60	21.35	9.16	7.58
–8.05	8.36	22.30	7.39	7.50
–10.80	5.38	21.28	9.28	6.29
–7.90	6.32	21.15	7.55	6.78
–6.36	7.25	19.53	9.45	7.47
–10.50	7.44	22.01	5.93	6.21
–7.07	4.46	20.48	9.21	6.77
–7.28	6.00	21.07	8.24	7.01
–10.30	6.10	19.98	9.12	6.23
–9.76	8.16	21.54	11.49	7.85
–7.43	6.86	20.80	8.23	7.11
–10.80	4.86	20.24	7.42	5.43
–9.05	6.33	20.93	7.65	6.47
–8.75	6.42	19.53	7.79	6.24
–8.23	7.76	20.50	8.46	7.12
–10.10	5.82	20.02	7.89	5.91
–9.62	5.89	21.55	7.95	6.44
–10.10	6.35	20.76	9.10	6.53
–10.40	6.61	20.23	7.13	5.88
–8.32	7.90	21.59	8.99	7.54
–8.78	6.91	20.79	8.19	6.78
–7.74	4.98	21.41	8.64	6.82
–6.15	7.78	21.87	6.41	7.48
–10.20	10.80	20.79	7.94	7.34
–12.80	6.63	20.75	8.74	5.84
–14.00	4.93	20.18	8.15	4.82
–7.19	7.35	21.47	8.66	7.58
–5.90	8.92	20.71	8.92	8.17
–11.30	6.45	19.98	7.67	5.72
–4.72	5.75	22.53	8.76	8.08
–9.52	5.51	21.35	8.07	6.35
–9.35	9.75	19.35	5.74	6.39
–9.59	8.59	20.75	7.39	6.79
–3.57	10.08	21.67	8.42	9.15

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Southern Plains

BACKGROUND

Principal investigators

Thomas R. Karl
Ronald G. Baldwin
Michael G. Burgin
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Sponsoring agencies

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

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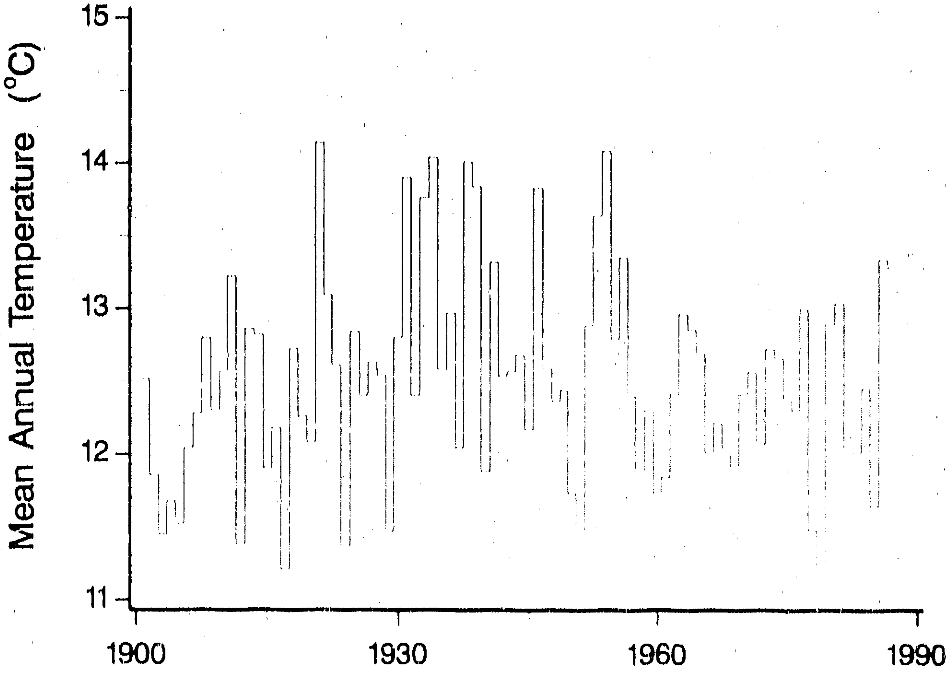
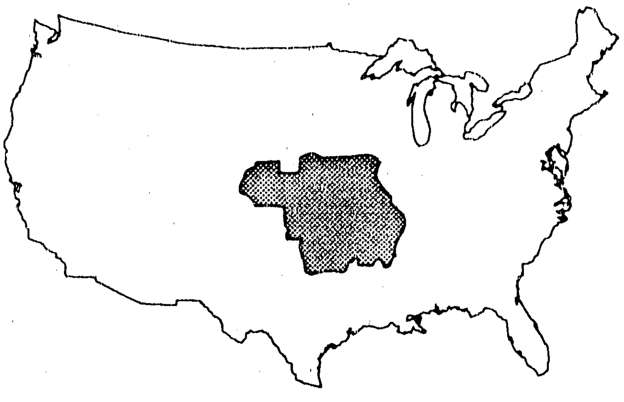


Annual calendar year average temperature.



Southern Plains

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated Central region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a cool beginning until the 1920s, followed by several decades of warm weather until about 1960, and a somewhat cooler period that was not as cool as earlier in the century.

Southern Plains

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	12.52	–0.02	11.17	26.40	13.73	12.82
1902	11.86	–2.31	13.12	23.44	13.25	11.88
1903	11.45	–1.60	12.09	22.57	12.26	11.33
1904	11.68	–1.18	11.19	22.56	14.02	11.64
1905	11.52	–4.14	12.98	23.80	13.38	11.50
1906	12.04	0.64	10.98	23.04	12.81	11.87
1907	12.28	1.20	11.27	23.95	12.93	12.34
1908	12.80	1.29	13.04	23.25	13.45	12.76
1909	12.30	1.24	11.12	24.73	14.55	12.91
1910	12.57	–2.62	13.81	23.67	13.81	12.16
1911	13.22	1.10	13.23	25.25	12.93	13.13
1912	11.38	–2.71	10.76	23.78	13.45	11.32
1913	12.86	–0.56	11.87	26.08	13.88	12.82
1914	12.82	0.89	12.06	25.78	14.64	13.34
1915	11.90	–1.25	10.78	21.64	14.60	11.44
1916	12.18	–0.58	12.24	24.68	13.39	12.43
1917	11.21	–1.04	10.65	23.53	12.46	11.40
1918	12.73	–3.63	13.29	25.96	12.93	12.13
1919	12.26	1.37	11.75	24.66	13.16	12.73
1920	12.08	–0.86	11.28	23.07	13.52	11.75
1921	14.14	2.67	13.85	25.10	14.60	14.06
1922	13.09	0.51	12.61	24.67	14.80	13.15
1923	12.61	1.41	11.01	24.57	12.79	12.44
1924	11.37	0.28	10.09	23.80	13.66	11.95
1925	12.84	–0.74	13.58	25.05	12.41	12.57
1926	12.40	1.36	11.17	24.26	12.77	12.39
1927	12.63	1.18	12.83	22.55	14.64	12.80
1928	12.54	0.32	12.15	23.15	13.24	12.22
1929	11.47	–2.40	12.59	24.10	11.76	11.51
1930	12.80	0.19	12.50	24.98	13.63	12.83
1931	13.90	2.54	10.40	24.95	16.51	13.60
1932	12.40	2.89	11.69	25.05	12.02	12.91
1933	13.76	0.74	12.39	25.47	14.67	13.32
1934	14.04	2.15	13.05	28.07	14.20	14.37
1935	12.58	1.04	11.96	24.85	12.44	12.57
1936	12.97	–3.73	13.43	27.70	13.50	12.73
1937	12.04	–0.83	11.60	25.64	12.75	12.29
1938	14.01	1.14	13.65	25.42	15.14	13.84
1939	13.84	1.35	13.07	25.11	15.22	13.69
1940	11.88	–1.98	11.65	24.32	13.90	11.97
1941	13.32	1.04	12.78	24.75	14.43	13.25
1942	12.53	0.69	12.82	24.24	13.50	12.81
1943	12.56	0.78	11.41	25.79	12.42	12.60
1944	12.68	1.16	11.22	24.54	14.12	12.76

Year	Ann
1945	12.17
1946	13.83
1947	12.59
1948	12.36
1949	12.44
1950	11.73
1951	11.45
1952	12.88
1953	13.64
1954	14.08
1955	12.79
1956	13.35
1957	12.40
1958	11.89
1959	12.30
1960	11.73
1961	11.84
1962	12.41
1963	12.96
1964	12.85
1965	12.69
1966	12.01
1967	12.21
1968	12.04
1969	11.92
1970	12.41
1971	12.56
1972	12.07
1973	12.72
1974	12.66
1975	12.38
1976	12.29
1977	12.99
1978	11.48
1979	11.22
1980	12.89
1981	13.03
1982	12.02
1983	12.01
1984	12.45
1985	11.64
1986	13.33
1987	13.28

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*Calendar year mean (Jan–Dec).

†Season year mean = (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
–0.23	12.71	23.05	13.61	12.28
0.71	14.15	24.48	13.79	13.28
0.84	10.36	24.86	14.91	12.74
–0.65	12.48	24.12	13.60	12.39
–0.62	12.35	24.42	13.51	12.42
1.24	10.99	22.31	13.21	11.94
0.10	10.78	23.31	11.60	11.45
1.57	11.07	25.85	12.70	12.79
1.77	11.95	25.67	14.82	13.55
2.39	12.04	26.73	15.01	14.04
0.36	13.67	24.78	13.28	13.02
–0.65	12.68	25.43	14.81	13.07
0.92	11.56	24.79	11.88	12.29
0.34	10.82	23.62	14.32	12.27
–1.13	12.76	24.43	11.82	11.97
–0.14	9.98	23.84	14.49	12.04
0.49	11.25	23.39	12.75	11.97
–1.35	12.53	24.03	13.57	12.20
–1.69	13.88	25.28	16.00	13.37
–0.74	12.85	24.34	13.63	12.52
–0.20	11.58	23.84	13.97	12.30
0.23	12.16	24.10	13.05	12.38
0.26	13.17	22.63	12.38	12.11
–0.28	12.23	24.21	12.82	12.24
–0.96	11.30	24.04	12.90	11.82
–0.75	12.19	24.67	12.73	12.21
–0.28	11.63	24.18	14.61	12.53
0.68	12.95	23.94	12.36	12.48
–0.93	12.24	24.49	14.43	12.56
0.02	13.86	23.89	12.49	12.57
–0.01	11.13	24.44	13.35	12.30
2.42	12.48	23.92	11.05	12.47
–1.66	14.77	24.99	13.76	12.96
–4.42	11.69	24.82	14.10	11.51
–4.80	11.76	23.66	13.22	10.96
–0.10	11.44	26.71	13.84	12.96
1.37	13.48	24.40	13.55	13.19
–2.00	12.28	23.59	13.17	11.78
1.58	10.34	25.60	14.24	12.94
–2.30	10.33	24.73	13.21	11.53
–1.48	14.11	23.40	12.50	12.14
0.08	14.02	24.54	13.10	12.94
1.73	13.84	24.71	12.88	13.25

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South Coastal Plain

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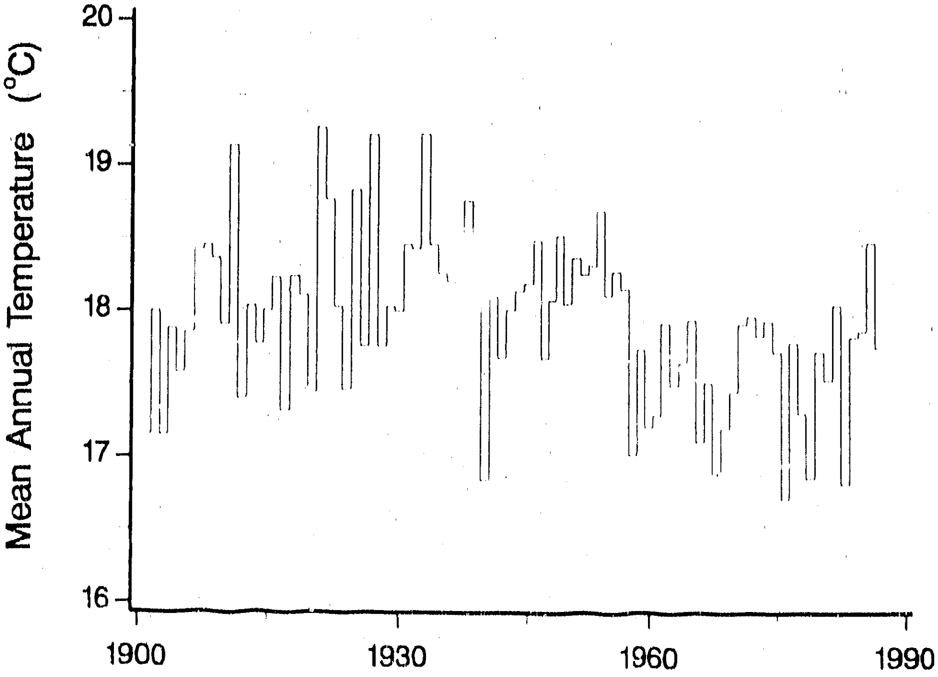
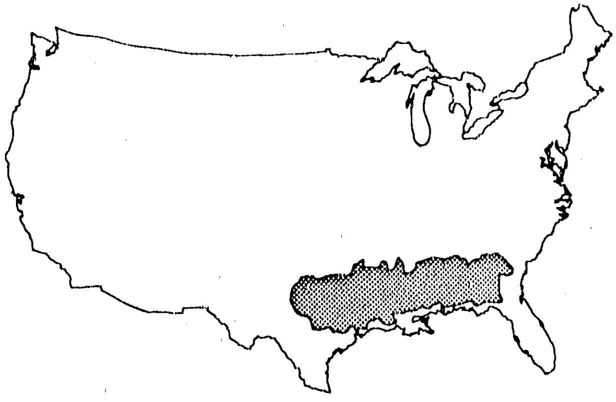


Annual calendar year average temperature.



South Coastal Plain

TRENDS

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South Coastal Plain

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	17.15	8.40	16.64	26.97	17.42	17.36
1902	18.00	6.38	18.69	27.64	18.73	17.86
1903	17.15	8.26	17.86	25.65	17.40	17.29
1904	17.88	7.69	18.00	26.03	18.99	17.68
1905	17.58	6.06	19.27	26.66	19.15	17.78
1906	17.85	7.76	17.22	26.41	18.53	17.48
1907	18.42	11.41	18.28	26.63	18.00	18.58
1908	18.45	8.37	20.12	26.39	18.23	18.28
1909	18.36	10.77	17.80	26.99	19.65	18.80
1910	17.91	7.31	18.48	26.12	19.14	17.76
1911	19.14	10.68	18.88	26.76	19.46	18.94
1912	17.40	7.41	17.72	26.07	18.73	17.48
1913	18.03	9.55	17.57	26.78	18.12	18.00
1914	17.77	8.95	17.32	27.42	18.22	17.98
1915	18.00	7.98	17.06	26.46	19.67	17.79
1916	18.23	9.93	18.05	26.41	18.42	18.20
1917	17.32	9.97	17.36	26.45	16.83	17.65
1918	18.24	7.13	19.01	27.02	18.08	17.81
1919	18.11	9.00	17.51	26.10	20.47	18.27
1920	17.44	8.68	17.25	25.74	18.23	17.47
1921	19.26	10.0[illegible]	18.86	27.00	20.15	19.01
1922	18.77	1[illegible]	18.40	26.45	19.35	18.68
1923	18.03	10.99	17.27	26.08	17.86	18.05
1924	17.46	8.83	16.22	27.35	18.45	17.71
1925	18.83	9.86	18.99	27.59	19.47	18.98
1926	17.76	8.58	16.12	26.38	18.92	17.50
1927	19.21	11.48	19.22	26.42	20.47	19.40
1928	17.76	8.58	17.17	26.56	18.64	17.74
1929	18.03	8.38	19.19	26.57	18.08	18.05
1930	18.00	9.28	17.93	26.98	18.28	18.11
1931	18.46	8.40	15.78	26.71	21.05	17.99
1932	18.43	12.83	17.26	27.40	17.32	18.70
1933	19.22	10.23	18.76	26.68	19.91	18.89
1934	18.46	10.35	17.76	27.71	19.62	18.86
1935	18.26	9.31	19.07	26.78	18.85	18.50
1936	18.21	6.57	18.51	27.46	18.84	17.84
1937	17.98	10.68	17.37	27.00	17.39	18.11
1938	18.76	10.05	19.17	26.67	19.04	18.73
1939	18.49	9.94	17.97	26.70	18.87	18.37
1940	16.84	6.38	16.95	25.66	18.17	16.79
1941	18.10	8.92	17.23	26.57	19.92	18.16
1942	17.68	8.05	17.56	26.47	18.79	17.72
1943	18.01	9.80	17.78	27.73	17.21	18.13
1944	18.14	9.60	17.74	26.92	18.63	18.22
1945	18.19					
1946	18.49					
1947	17.68					
1948	18.08					
1949	18.52					
1950	18.05					
1951	18.36					
1952	18.25					
1953	18.31					
1954	18.69					
1955	18.11					
1956	18.27					
1957	18.15					
1958	17.01					
1959	17.73					
1960	17.20					
1961	17.28					
1962	17.91					
1963	17.49					
1964	17.64					
1965	17.93					
1966	17.10					
1967	17.50					
1968	16.88					
1969	17.19					
1970	17.44					
1971	17.90					
1972	17.95					
1973	17.82					
1974	17.92					
1975	17.71					
1976	16.71					
1977	17.77					
1978	17.29					
1979	16.85					
1980	17.71					
1981	17.52					
1982	18.03					
1983	16.81					
1984	17.81					
1985	17.85					
1986	18.46					
1987	17.74					

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*Calendar year mean (Jan–Dec).

†Season year mean = (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
8.76	18.98	26.27	19.09	18.28
8.48	18.89	25.85	19.05	18.07
8.93	16.74	26.36	19.02	17.84
7.84	18.91	26.97	18.07	17.95
11.21	17.70	26.47	18.79	18.54
12.43	17.25	25.84	17.91	18.36
8.58	17.53	27.54	18.36	18.00
11.77	17.16	27.93	17.08	18.49
9.59	18.42	27.02	18.34	18.34
9.82	17.59	28.09	19.04	18.63
8.78	19.37	25.89	18.38	18.10
9.12	17.90	26.68	18.08	17.94
11.89	17.54	26.55	17.47	18.36
6.93	16.83	26.55	18.75	17.27
7.95	17.58	26.31	18.30	17.53
8.07	15.92	26.67	19.05	17.43
7.71	17.26	25.17	18.22	17.09
9.55	17.26	26.82	18.46	18.03
6.31	19.18	26.65	18.98	17.78
5.89	18.16	26.47	18.20	17.18
9.01	17.82	26.03	18.95	17.95
7.60	17.33	25.83	17.97	17.18
8.15	19.24	25.32	16.67	17.35
7.46	17.23	26.29	17.56	17.13
7.81	16.47	26.61	17.65	17.14
6.81	17.78	26.10	18.07	17.19
9.45	16.30	26.16	18.99	17.73
10.78	18.02	25.95	18.26	18.25
7.94	17.54	26.03	19.98	17.87
10.12	19.03	25.50	17.01	17.92
9.81	17.44	25.86	17.93	17.76
9.15	17.48	25.39	15.41	16.83
5.74	18.77	27.27	18.80	17.64
5.08	17.41	27.05	19.47	17.25
6.38	17.73	25.90	17.72	16.88
7.99	16.91	27.77	18.28	17.72
7.77	17.71	27.03	18.00	17.59
7.94	18.22	26.41	18.31	17.70
8.81	16.04	26.38	18.15	17.34
6.79	17.25	26.01	18.49	17.13
8.46	18.84	26.45	19.99	18.43
8.49	18.12	27.13	19.44	18.30
8.19	17.63	26.77	17.65	17.56

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Karl, T.R., C.N. Williams, Jr., and F.T. Quinlan. 1990. *United States Historical Climatology (HCN) serial temperature and precipitation data.* NDP-019/R1. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Gulf Coast

BACKGROUND

Principal investigators
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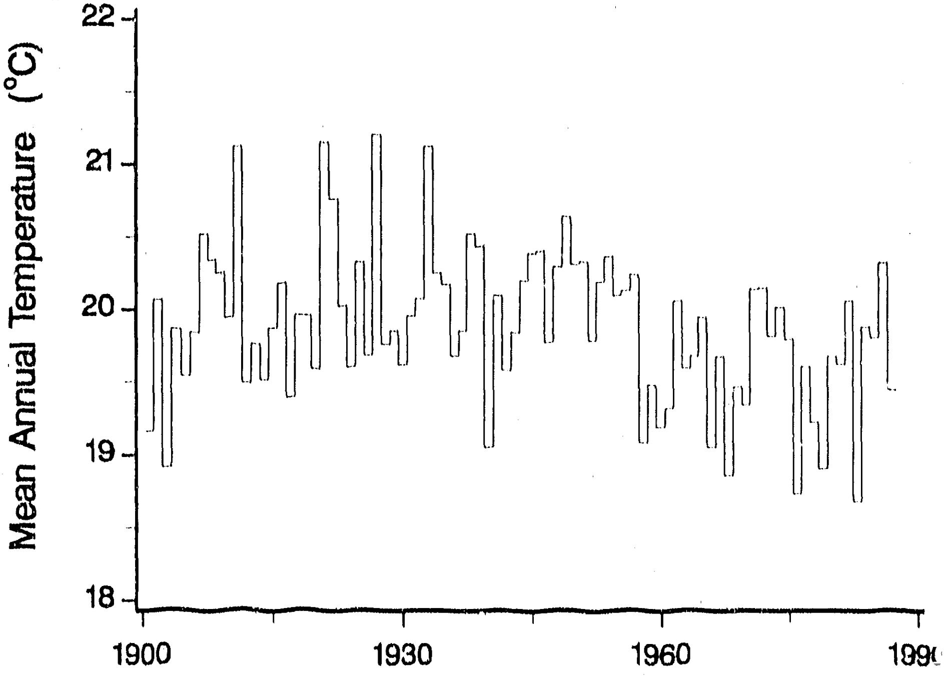
Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

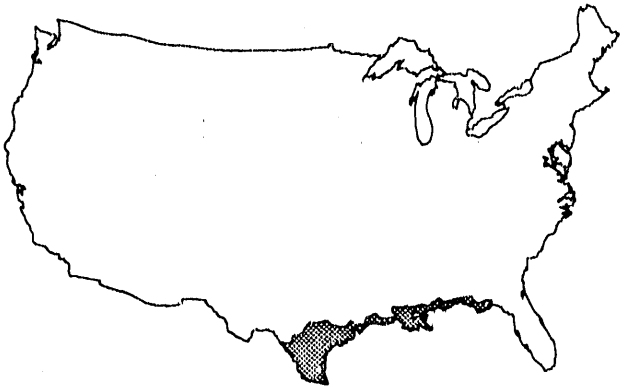
Period of record — 1901–1987.

Method — After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability — These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Gulf Coastal

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated East region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a warm epoch from the early 1920s to the mid 1950s, preceded and followed by periods during which temperatures were generally at or below the mean for the century.

Gulf Coast

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	19.16	11.18	18.68	27.52	19.68	19.27
1902	20.06	9.98	20.62	28.09	21.08	19.94
1903	18.91	11.07	19.39	26.23	19.48	19.04
1904	19.86	11.43	20.14	26.54	20.84	19.74
1905	19.54	9.26	21.00	27.29	21.34	19.72
1906	19.84	10.26	19.23	27.59	20.60	19.42
1907	20.52	14.84	20.72	27.24	20.08	20.72
1908	20.34	11.75	21.96	27.12	19.77	20.15
1909	20.25	13.70	19.87	27.53	21.55	20.66
1910	19.94	10.62	20.26	27.05	20.99	19.73
1911	21.11	14.44	20.99	27.47	21.12	21.00
1912	19.49	10.66	19.88	26.94	20.91	19.60
1913	19.76	12.41	19.24	26.92	20.32	19.72
1914	19.52	11.98	18.91	27.83	20.29	19.75
1915	19.87	10.61	18.39	27.75	21.65	19.60
1916	20.18	13.33	20.13	27.26	19.99	20.17
1917	19.39	13.10	19.36	27.33	18.75	19.63
1918	19.95	10.53	20.49	27.64	20.05	19.67
1919	19.95	11.42	19.28	26.91	22.41	20.00
1920	19.59	12.07	19.68	26.91	20.13	19.70
1921	21.15	12.92	20.70	27.74	21.93	20.82
1922	20.76	13.73	20.51	27.34	21.16	20.68
1923	20.02	14.28	19.50	27.01	19.70	20.12
1924	19.60	11.60	18.47	28.11	21.06	19.81
1925	20.32	12.70	20.72	27.73	20.92	20.52
1926	19.68	11.00	18.11	27.30	20.86	19.32
1927	21.20	14.73	21.22	27.62	22.24	21.45
1928	19.76	11.18	19.42	27.81	20.63	19.76
1929	19.85	11.41	21.22	27.12	19.76	19.88
1930	19.62	11.77	19.51	27.36	20.23	19.71
1931	19.95	11.06	17.41	26.95	22.60	19.50
1932	20.07	15.48	18.80	27.96	18.96	20.30
1933	21.12	13.02	20.91	27.15	21.96	20.76
1934	20.25	13.67	19.51	27.75	21.57	20.62
1935	20.17	12.56	21.02	27.34	20.59	20.38
1936	19.68	10.16	19.87	27.50	20.20	19.43
1937	19.85	13.42	19.09	27.59	19.66	19.94
1938	20.52	12.78	21.08	27.69	20.37	20.48
1939	20.43	12.88	20.24	27.61	20.58	20.32
1940	19.05	9.68	19.27	26.93	20.06	18.98
1941	20.09	12.24	19.07	27.50	21.75	20.14
1942	19.58	11.08	19.30	27.33	20.70	19.60
1943	19.84	12.68	20.25	28.06	18.92	19.98
1944	20.20	12.71	19.82	27.85	20.51	20.22

Year	Ann*
1945	20.39
1946	20.40
1947	19.77
1948	20.29
1949	20.64
1950	20.31
1951	20.33
1952	19.79
1953	20.19
1954	20.36
1955	20.09
1956	20.12
1957	20.23
1958	19.08
1959	19.48
1960	19.19
1961	19.32
1962	20.05
1963	19.59
1964	19.67
1965	19.94
1966	19.05
1967	19.67
1968	18.86
1969	19.46
1970	19.34
1971	20.13
1972	20.14
1973	19.81
1974	20.01
1975	19.79
1976	18.73
1977	19.60
1978	19.22
1979	18.90
1980	19.67
1981	19.62
1982	20.05
1983	18.68
1984	19.87
1985	19.80
1986	20.31
1987	19.44

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*Calendar year mean (Jan–Dec).

†Season year mean = (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
12.27	21.08	27.43	21.06	20.46
11.31	20.67	27.01	21.35	20.08
11.60	19.16	27.48	21.38	19.91
11.04	21.13	28.08	20.13	20.09
14.42	19.93	27.33	20.99	20.67
15.82	19.17	27.09	20.26	20.59
11.88	19.68	28.24	20.46	20.07
14.81	18.91	27.96	18.43	20.03
12.29	21.00	27.79	19.97	20.27
12.50	19.68	28.10	20.64	20.23
11.90	21.24	26.75	20.40	20.07
12.35	19.92	27.21	20.16	19.91
14.99	19.80	27.59	19.38	20.44
9.64	19.05	27.54	20.75	19.24
10.74	19.26	27.18	20.22	19.35
10.43	18.46	27.57	20.89	19.34
10.51	19.64	26.24	20.11	19.13
12.68	19.29	27.95	20.87	20.19
9.48	21.57	27.54	20.92	19.88
8.74	20.21	27.47	20.52	19.23
12.01	19.77	26.88	21.10	19.94
10.40	19.48	26.58	20.18	19.16
10.97	21.32	26.66	19.09	19.51
10.43	19.26	26.95	19.60	19.06
11.27	18.41	27.65	20.07	19.35
10.19	19.60	26.98	19.77	19.14
12.95	19.04	26.98	20.96	19.98
14.09	20.48	26.98	20.43	20.50
10.49	19.69	27.08	22.08	19.84
12.98	21.01	26.54	19.36	19.97
12.89	19.75	26.77	20.04	19.86
11.89	19.76	26.37	17.34	18.84
8.97	20.10	27.68	20.97	19.43
8.50	19.51	27.56	21.35	19.23
9.58	19.67	26.93	19.61	18.95
11.23	19.19	28.27	19.95	19.66
10.45	19.77	27.78	20.55	19.64
11.08	20.07	27.69	20.47	19.83
11.36	18.04	27.08	20.03	19.13
9.47	19.68	26.87	20.79	19.20
11.31	20.79	27.33	22.04	20.37
11.39	19.96	27.78	21.61	20.18
10.99	18.99	27.36	19.61	19.24

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Great Lakes

BACKGROUND

Principal investigators
Thomas R. Karl
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National Oceanic and Atmospheric Administration
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Asheville, North Carolina 28801, U.S.A.

Sponsoring agencies
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U.S. Department of Energy
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Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

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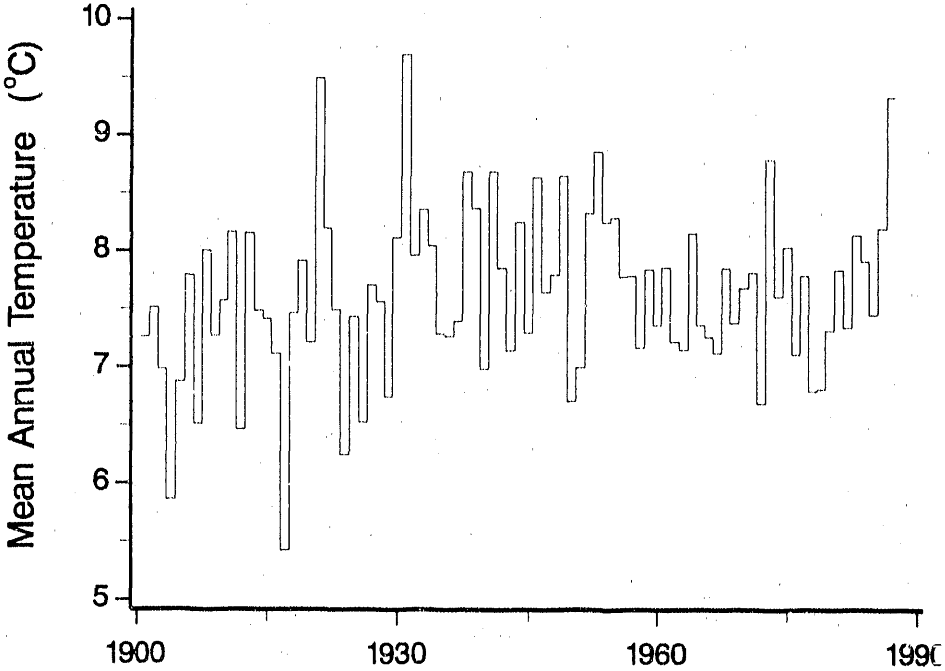
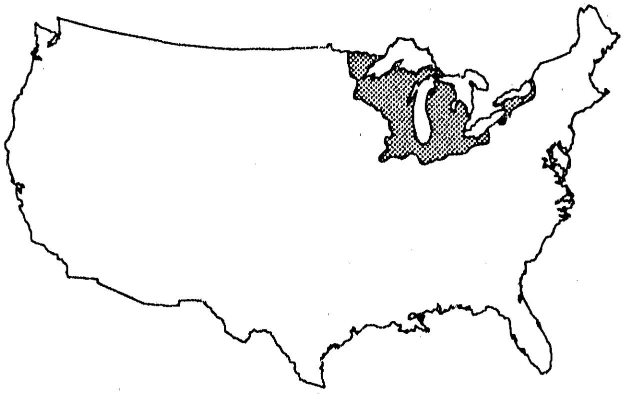


Annual calendar year average temperature.



Great Lakes

TRENDS

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Great Lakes

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	7.26	-6.78	6.48	21.35	8.82	7.47
1902	7.51	-6.83	7.87	18.78	10.00	7.46
1903	6.98	-6.37	8.48	18.35	8.42	7.22
1904	5.86	-10.4	5.54	18.56	9.04	5.69
1905	6.87	-9.01	6.78	19.56	9.01	6.58
1906	7.79	-4.07	5.85	20.07	9.67	7.88
1907	6.51	-5.98	4.75	18.81	8.07	6.41
1908	8.00	-5.04	7.36	19.68	10.40	8.10
1909	7.27	-4.50	5.37	19.95	9.31	7.53
1910	7.57	-7.39	8.57	20.11	8.81	7.52
1911	8.16	-5.39	7.71	20.53	7.99	7.71
1912	6.46	-8.39	5.68	18.87	9.94	6.52
1913	8.15	-5.01	6.52	20.52	9.99	8.01
1914	7.48	-4.92	6.69	20.30	10.10	8.04
1915	7.41	-5.87	6.79	17.70	10.15	7.19
1916	7.11	-5.97	5.65	20.55	8.90	7.28
1917	5.42	-8.52	5.04	18.81	7.13	5.62
1918	7.46	-9.77	7.94	20.05	8.81	6.76
1919	7.91	-2.85	6.63	21.17	9.46	8.60
1920	7.21	-9.10	5.79	19.35	10.67	6.67
1921	9.49	-2.95	9.60	21.95	9.72	9.58
1922	8.19	-5.66	8.13	19.97	10.74	8.29
1923	7.49	-6.35	5.07	20.24	9.16	7.03
1924	6.24	-4.97	5.09	18.61	9.12	6.96
1925	7.43	-6.36	7.36	20.26	7.79	7.26
1926	6.52	-5.60	4.64	19.16	7.96	6.54
1927	7.70	-5.40	7.12	18.05	10.74	7.63
1928	7.56	-5.26	5.91	19.27	9.23	7.29
1929	6.74	-7.21	7.69	19.14	8.28	6.97
1930	8.11	-5.21	7.15	20.62	9.60	8.04
1931	9.69	-3.04	6.61	21.20	12.55	9.33
1932	7.96	-1.13	5.47	20.69	8.36	8.35
1933	8.35	-3.87	6.83	21.48	9.01	8.36
1934	8.04	-5.78	6.75	21.31	10.32	8.15
1935	7.28	-5.93	6.10	20.27	8.77	7.30
1936	7.26	-9.31	7.12	21.12	8.78	6.93
1937	7.39	-4.37	5.90	20.91	8.28	7.68
1938	8.68	-4.96	8.37	20.50	10.17	8.52
1939	8.36	-4.67	6.68	20.58	9.94	8.13
1940	6.98	-5.52	4.72	20.10	9.09	7.10
1941	8.68	-4.71	7.56	20.54	10.74	8.53
1942	7.85	-4.40	8.49	20.01	9.30	8.35
1943	7.14	-6.47	5.24	21.08	8.00	6.96
1944	8.24	-3.80	6.41	21.00	10.06	8.42

Year	Ann*
1945	7.29
1946	8.63
1947	7.64
1948	7.79
1949	8.64
1950	6.70
1951	6.99
1952	8.32
1953	8.85
1954	8.24
1955	8.28
1956	7.77
1957	7.78
1958	7.16
1959	7.83
1960	7.35
1961	7.85
1962	7.21
1963	7.14
1964	8.14
1965	7.35
1966	7.25
1967	7.11
1968	7.84
1969	7.37
1970	7.67
1971	7.80
1972	6.68
1973	8.77
1974	7.60
1975	8.02
1976	7.10
1977	7.77
1978	6.78
1979	6.80
1980	7.30
1981	7.82
1982	7.33
1983	8.12
1984	7.90
1985	7.44
1986	8.18
1987	9.31

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*Calendar year mean (Jan–Dec).

†Season year mean = (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
–7.01	8.30	18.95	9.11	7.33
–5.81	8.85	19.31	10.69	8.26
–4.91	5.08	20.41	10.44	7.75
–6.67	7.07	20.12	10.34	7.71
–3.82	7.28	21.58	9.36	8.60
–4.13	4.76	18.75	9.04	7.10
–6.42	6.77	18.93	7.87	6.79
–4.37	6.79	20.88	8.91	8.05
–3.03	6.86	20.81	10.91	8.89
–3.05	6.30	20.21	9.92	8.34
–5.17	8.40	21.54	9.19	8.49
–5.69	5.67	19.87	9.87	7.43
–4.95	7.01	20.16	8.80	7.76
–5.21	7.14	18.84	10.09	7.71
–8.20	7.54	21.12	8.41	7.22
–3.80	5.25	19.40	10.33	7.79
–5.52	6.19	19.86	10.46	7.75
–7.09	7.48	19.44	9.26	7.28
–9.05	7.20	19.87	11.55	7.39
–5.89	7.85	19.92	9.44	7.83
–6.40	6.03	18.94	9.28	6.96
–5.10	6.12	20.37	8.88	7.57
–5.71	6.15	19.28	8.24	6.99
–5.83	7.82	20.01	10.02	8.00
–5.60	6.76	19.55	8.82	7.38
–7.21	6.99	20.61	10.06	7.61
–6.40	5.71	19.93	11.25	7.62
–5.80	6.13	19.18	8.26	6.94
–4.80	8.00	20.99	10.68	8.72
–5.65	7.01	19.78	8.67	7.45
–4.09	6.09	20.49	9.95	8.11
–4.62	7.75	20.19	6.80	7.53
–9.29	10.39	19.67	9.26	7.51
–8.77	6.04	19.80	9.80	6.72
–9.15	6.51	19.41	9.32	6.52
–5.28	6.82	20.30	8.56	7.59
–5.54	7.64	20.08	8.80	7.74
–7.71	7.02	18.89	9.62	6.95
–2.10	6.22	21.56	10.05	8.93
–6.41	5.33	20.60	9.63	7.27
–5.93	9.40	18.95	9.56	8.00
–6.87	8.82	19.68	9.08	7.68
–3.17	9.48	21.29	9.25	9.21

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Karl, T.R., C.N. Williams, Jr., and F.T. Quinlan. 1990. *United States Historical Climatology (HCN) serial temperature and precipitation data*. NDP-019/R1. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Eastern Prairies

BACKGROUND

Principal investigators
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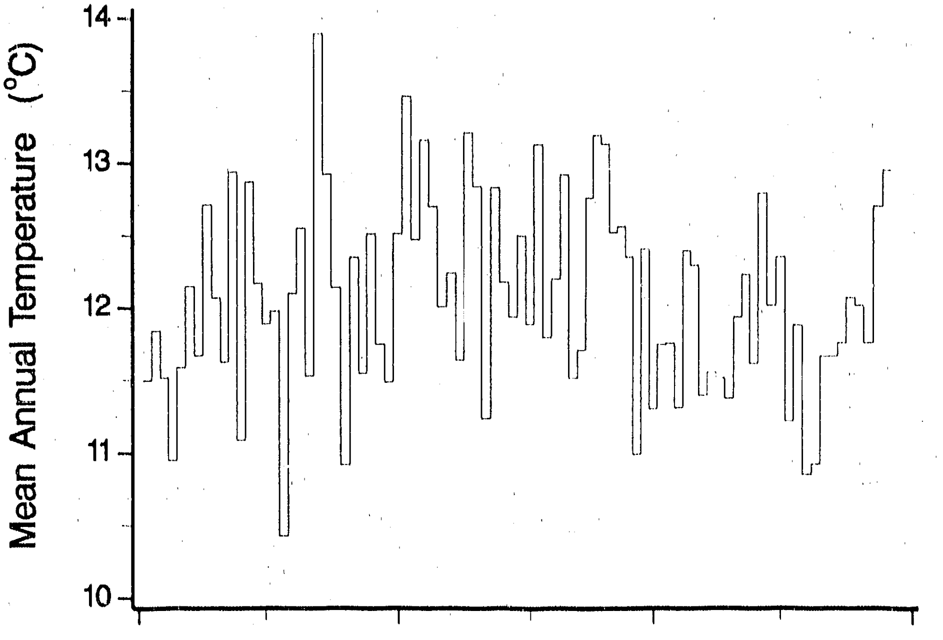
Federal Building
Asheville, North Carolina 28801, U.S.A.

Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

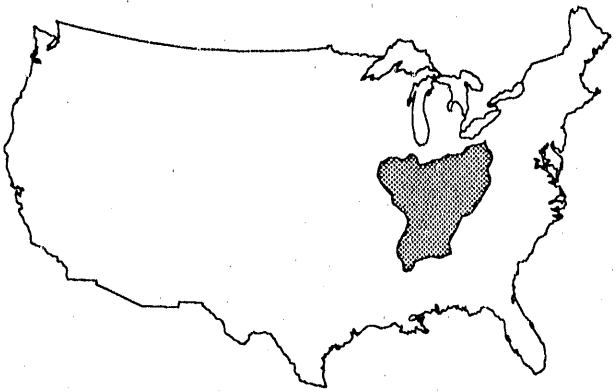
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Eastern Prairies

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated East region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a warm epoch from the early 1920s to the mid 1950s, preceded and followed by periods during which temperatures were generally at or below the mean for the century.

Eastern Prairies

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	11.50	–0.38	10.55	24.78	12.13	11.77
1902	11.84	–2.55	12.39	22.91	14.01	11.69
1903	11.52	–0.38	13.09	22.18	12.14	11.76
1904	10.95	–2.93	10.60	22.26	12.88	10.70
1905	11.59	–3.12	12.87	23.33	12.98	11.51
1906	12.15	0.83	10.72	23.35	13.36	12.06
1907	11.67	1.55	10.68	22.50	11.97	11.67
1908	12.71	0.62	13.10	23.27	13.75	12.68
1909	12.07	2.23	10.97	23.39	13.60	12.55
1910	11.63	–1.97	12.65	22.47	12.88	11.50
1911	12.94	1.12	12.23	23.76	12.96	12.52
1912	11.09	–2.13	11.10	22.40	13.46	11.21
1913	12.87	1.21	11.57	24.64	13.71	12.78
1914	12.17	0.79	11.34	24.72	13.54	12.60
1915	11.89	–0.27	10.99	21.63	14.30	11.66
1916	11.98	0.69	11.16	23.48	12.90	12.06
1917	10.43	–0.47	10.30	22.22	11.10	10.78
1918	12.10	–3.87	13.12	23.69	12.30	11.31
1919	12.55	2.54	11.51	24.03	14.37	13.12
1920	11.53	–1.64	10.69	22.30	13.63	11.25
1921	13.89	2.35	14.04	24.64	14.20	13.80
1922	12.92	1.19	13.01	23.32	14.32	12.96
1923	12.14	1.03	10.59	23.22	12.48	11.83
1924	10.92	0.88	9.69	22.59	12.83	11.49
1925	12.35	0.75	12.31	23.79	12.49	12.33
1926	11.55	0.35	9.61	23.09	12.83	11.47
1927	12.51	1.44	12.25	21.36	14.95	12.50
1928	11.75	0.41	10.48	22.64	12.90	11.61
1929	11.49	–0.88	12.89	22.40	11.95	11.59
1930	12.51	1.40	12.02	23.88	12.99	12.57
1931	13.46	1.68	10.18	24.11	16.11	13.02
1932	12.47	5.06	10.57	23.85	12.04	12.88
1933	13.16	1.91	11.94	24.16	13.59	12.90
1934	12.70	1.08	11.60	25.38	13.97	13.01
1935	12.01	0.86	11.83	23.39	12.91	12.25
1936	12.24	–3.58	12.19	25.47	13.06	11.78
1937	11.64	1.80	10.77	23.56	11.48	11.90
1938	13.21	1.49	13.35	23.45	14.01	13.07
1939	12.84	1.72	11.85	23.43	13.92	12.73
1940	11.24	–1.84	10.12	23.40	12.83	11.13
1941	12.83	0.97	11.89	23.83	14.64	12.83
1942	12.18	0.57	12.76	23.45	13.44	12.55
1943	11.94	0.62	10.73	24.66	11.65	11.91
1944	12.50	1.27	11.95	24.19	13.14	12.64

Year	Ann*
1945	11.89
1946	13.13
1947	11.80
1948	12.20
1949	12.92
1950	11.52
1951	11.71
1952	12.76
1953	13.19
1954	13.13
1955	12.52
1956	12.56
1957	12.35
1958	10.99
1959	12.40
1960	11.30
1961	11.74
1962	11.75
1963	11.31
1964	12.39
1965	12.29
1966	11.39
1967	11.55
1968	11.51
1969	11.37
1970	11.93
1971	12.22
1972	11.61
1973	12.78
1974	12.01
1975	12.34
1976	11.21
1977	11.87
1978	10.85
1979	10.92
1980	11.66
1981	11.66
1982	11.75
1983	12.06
1984	12.01
1985	11.75
1986	12.69
1987	12.94

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

n*	Win	Spr	Sum	Fall	Ann†
.89	−1.10	13.10	22.41	13.33	11.93
.13	0.25	13.63	22.35	14.24	12.62
.80	0.88	9.87	23.20	13.95	11.98
.20	−0.70	12.53	23.28	13.27	12.10
.92	2.86	11.68	24.15	12.85	12.89
.52	3.27	10.56	21.76	12.50	12.02
.71	−0.42	11.08	23.01	11.86	11.38
.76	2.37	11.44	24.78	12.06	12.66
.19	2.70	12.03	24.40	13.90	13.26
.13	2.49	11.59	24.59	13.93	13.15
.52	0.59	13.33	23.60	13.04	12.64
.56	0.39	11.57	23.21	13.40	12.14
.35	2.06	12.14	23.37	12.22	12.45
.99	−0.48	10.80	22.33	13.38	11.51
.40	−1.14	12.43	23.72	12.64	11.91
.30	1.06	9.24	22.85	13.87	11.75
.74	−0.58	10.58	22.39	13.76	11.54
.75	−0.20	12.00	22.97	12.86	11.91
.31	−3.30	12.60	22.60	14.50	11.60
.39	−1.67	12.78	23.27	13.07	11.86
.29	0.40	11.80	22.59	13.48	12.06
.39	0.24	11.02	23.17	12.13	11.64
.55	0.31	12.17	21.84	11.45	11.44
.51	−0.99	11.58	23.33	12.87	11.70
.37	−0.34	11.00	23.07	12.11	11.46
.93	−2.16	12.05	22.83	13.76	11.62
.22	0.10	10.26	22.87	14.87	12.02
.61	1.40	11.78	22.22	12.39	11.95
2.78	0.61	12.32	23.52	14.80	12.81
2.01	1.12	12.73	22.20	11.86	11.94
2.34	1.43	11.07	23.33	13.26	12.30
1.21	1.51	12.49	22.19	9.92	11.55
1.87	−4.11	14.46	23.34	13.22	11.75
.85	−4.67	10.58	23.22	13.65	10.67
.92	−3.41	11.54	22.58	12.69	10.84
1.66	−0.41	10.65	24.14	12.61	11.76
1.66	−0.15	11.83	23.18	12.47	11.82
1.75	−2.19	12.03	22.11	13.14	11.24
2.06	2.53	10.58	24.50	13.78	12.87
2.01	−1.45	9.79	23.30	13.29	11.23
1.75	−0.67	13.60	22.28	14.49	12.42
2.69	−0.69	13.10	23.37	13.55	12.33
2.94	0.92	13.34	24.13	12.80	12.82

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Northern Appalachians

BACKGROUND

Principal investigators
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Sponsoring agencies
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U.S. Department of Energy
Carbon Dioxide Research Program

Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

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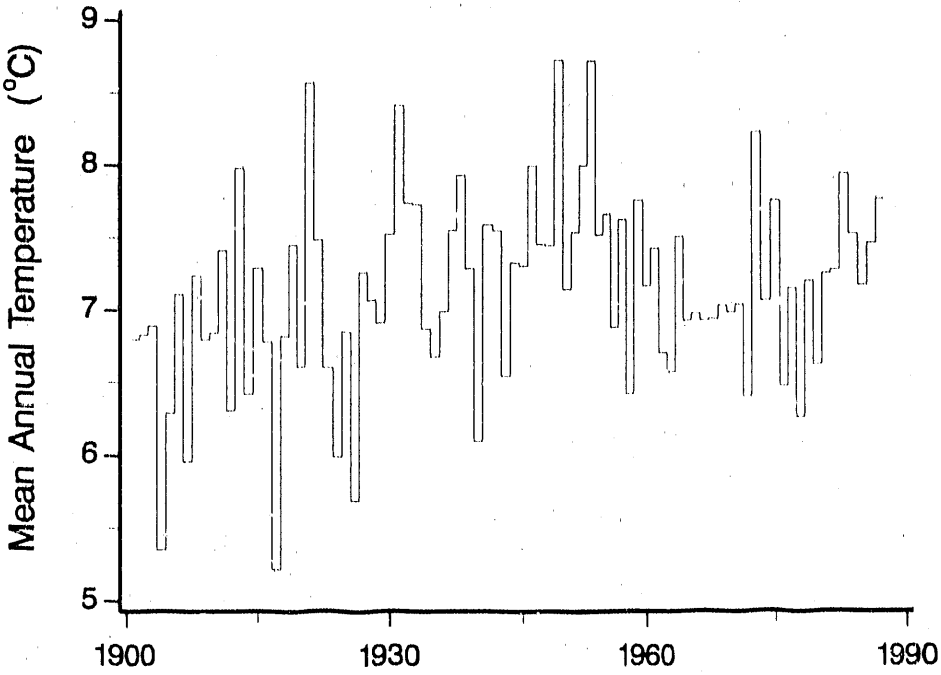
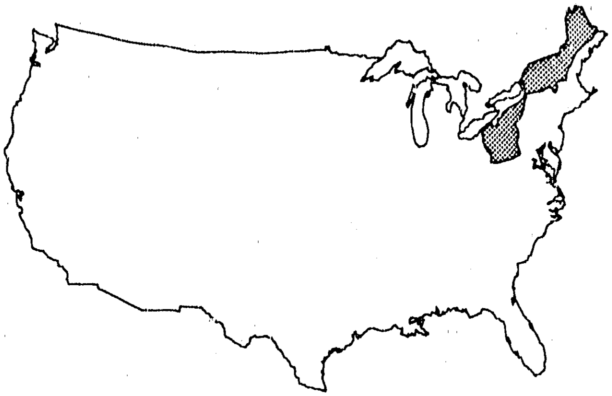


Annual calendar year average temperature.



Northern Appalachians

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated East region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a warm epoch from the early 1920s to the mid 1950s, preceded and followed by periods during which temperatures were generally at or below the mean for the century.

Northern Appalachians

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	6.80	-6.66	5.95	20.15	7.77	6.80
1902	6.83	-6.24	6.93	17.60	9.56	6.96
1903	6.89	-5.48	8.23	17.15	8.10	7.00
1904	5.35	-9.23	5.48	18.24	7.10	5.40
1905	6.29	-8.78	5.64	18.59	8.06	5.88
1906	7.11	-3.68	4.71	19.55	8.80	7.34
1907	5.96	-7.18	4.41	17.81	7.68	5.68
1908	7.24	-5.61	6.32	19.22	9.67	7.40
1909	6.80	-4.22	4.96	18.32	8.59	6.91
1910	6.84	-6.15	7.64	18.38	8.27	7.04
1911	7.41	-6.29	6.07	19.47	7.83	6.77
1912	6.31	-6.74	5.11	17.61	9.56	6.38
1913	7.98	-3.10	6.80	18.72	9.70	8.03
1914	6.42	-6.09	5.48	18.61	8.84	6.71
1915	7.29	-4.57	5.54	17.92	9.83	7.18
1916	6.78	-4.96	4.54	19.20	8.56	6.83
1917	5.22	-6.67	4.20	18.85	6.24	5.65
1918	6.82	-9.53	7.20	18.54	8.36	6.14
1919	7.45	-3.12	6.08	19.50	9.13	7.90
1920	6.61	-8.63	5.45	18.45	9.66	6.23
1921	8.57	-3.49	9.23	19.92	9.34	8.75
1922	7.48	-5.63	7.02	18.87	9.44	7.43
1923	6.60	-6.75	4.42	18.38	8.73	6.19
1924	5.99	-4.46	4.49	17.96	8.09	6.52
1925	6.85	-5.26	6.15	18.79	7.30	6.74
1926	5.69	-5.73	3.23	17.86	8.14	5.87
1927	7.26	-5.41	6.15	17.08	10.10	6.98
1928	7.07	-4.63	4.79	18.94	8.59	6.92
1929	6.91	-4.82	6.90	17.99	8.59	7.17
1930	7.52	-4.41	5.89	19.03	9.34	7.46
1931	8.41	-4.85	6.57	19.58	11.48	8.20
1932	7.74	-1.35	4.72	18.73	8.93	7.76
1933	7.73	-1.77	6.47	19.77	7.74	8.05
1934	6.87	-7.64	6.04	19.53	9.68	6.90
1935	6.68	-6.49	5.41	19.50	8.69	6.78
1936	6.99	-7.99	7.05	19.13	8.29	6.62
1937	7.55	-2.32	5.08	20.11	8.22	7.77
1938	7.93	-4.93	7.16	19.90	8.90	7.76
1939	7.29	-4.32	5.26	19.74	8.52	7.30
1940	6.10	-6.69	4.39	18.72	7.78	6.05
1941	7.59	-5.19	6.17	19.22	10.00	7.55
1942	7.55	-5.15	8.33	19.13	9.31	7.90
1943	6.55	-6.25	4.66	19.82	7.98	6.55
1944	7.33	-5.35	5.87	19.95	8.94	7.35

Year	Ann*
1945	7.31
1946	8.00
1947	7.46
1948	7.45
1949	8.73
1950	7.15
1951	7.54
1952	8.00
1953	8.72
1954	7.52
1955	7.66
1956	6.88
1957	7.62
1958	6.42
1959	7.75
1960	7.16
1961	7.42
1962	6.70
1963	6.57
1964	7.50
1965	6.92
1966	6.97
1967	6.92
1968	6.93
1969	7.02
1970	6.98
1971	7.03
1972	6.40
1973	8.21
1974	7.05
1975	7.74
1976	6.47
1977	7.14
1978	6.26
1979	7.19
1980	6.62
1981	7.24
1982	7.26
1983	7.92
1984	7.51
1985	7.16
1986	7.45
1987	7.75

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
-7.29	8.34	18.84	9.37	7.31
-5.98	7.93	18.03	10.73	7.68
-4.47	5.28	19.82	10.08	7.68
-7.01	6.54	19.12	10.05	7.18
-1.93	6.78	21.01	9.04	8.73
-2.73	4.61	18.56	9.07	7.38
-4.08	6.80	18.67	8.35	7.43
-3.51	6.14	19.95	8.93	7.88
-2.21	7.22	19.38	10.01	8.60
-3.06	6.25	18.54	9.56	7.82
-5.43	7.66	20.53	8.77	7.88
-5.43	4.09	18.27	8.77	6.43
-4.32	6.75	18.83	9.11	7.59
-5.08	6.32	17.99	9.13	7.09
-7.71	6.73	20.16	9.54	7.18
-3.57	5.60	18.48	9.64	7.54
-6.70	5.43	18.93	10.90	14
-5.57	6.84	18.46	7.92	.91
-7.57	6.11	18.54	9.99	6.77
-6.17	7.24	18.44	8.79	7.07
-5.32	5.79	17.92	8.71	6.78
-4.73	5.50	19.18	8.65	7.15
-4.70	4.62	19.41	7.97	6.83
-6.70	7.04	18.81	9.61	7.19
-5.51	5.89	19.00	8.87	7.06
-7.75	6.19	19.06	10.22	6.93
-6.50	4.48	18.63	10.34	6.74
-4.81	5.00	18.19	7.51	6.47
-4.53	7.66	20.19	9.48	8.20
-4.50	6.04	18.75	7.74	7.00
-3.38	5.70	19.67	9.73	7.93
-5.37	6.96	18.71	6.63	6.73
-8.16	8.35	18.50	9.02	6.93
-7.96	5.24	19.06	8.19	6.13
-7.33	7.22	18.73	9.54	7.04
-4.85	6.23	18.98	7.80	7.06
-6.18	7.13	19.00	7.87	6.95
-6.45	6.38	17.95	9.85	6.93
-2.38	6.46	19.90	9.66	8.44
-4.90	4.67	19.41	9.01	7.05
-4.74	7.41	17.99	9.81	7.62
-5.94	7.95	18.24	8.35	7.15
-5.04	7.96	19.49	8.35	7.69

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Southern Appalachians

BACKGROUND

Principal investigators
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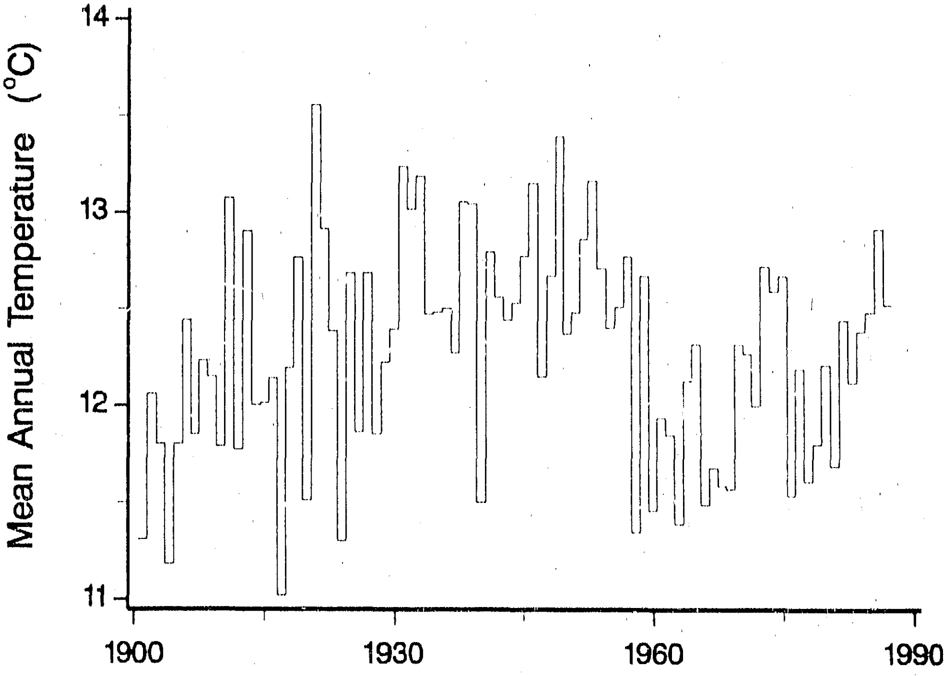
Asheville, North Carolina 28801, U.S.A.

Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

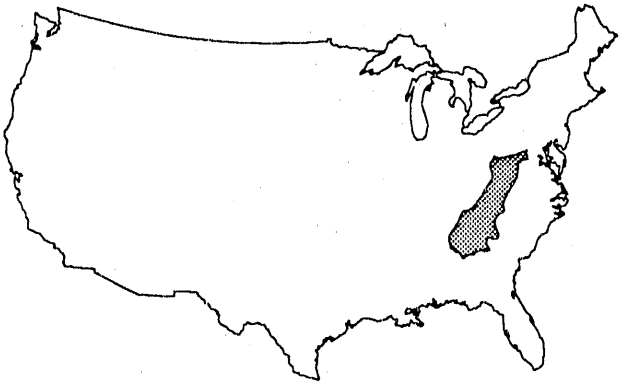
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Southern Appalachians

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated East region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a warm epoch from the early 1920s to the mid 1950s, preceded and followed by periods during which temperatures were generally at or below the mean for the century.

Southern Appalachians

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	11.31	1.21	10.64	22.76	11.29	11.48
1902	12.06	−0.21	12.05	22.17	13.75	11.94
1903	11.80	2.03	13.08	21.41	11.69	12.05
1904	11.18	−0.79	11.01	21.43	12.30	10.99
1905	11.80	−0.82	12.95	22.00	12.81	11.73
1906	12.44	2.56	11.14	22.38	13.32	12.35
1907	11.85	3.24	11.37	21.15	11.93	11.92
1908	12.23	0.70	13.55	21.81	12.55	12.15
1909	12.15	4.13	11.38	21.68	12.74	12.48
1910	11.79	0.48	12.60	21.33	12.95	11.84
1911	13.07	2.60	11.58	22.80	13.47	12.61
1912	11.77	0.38	12.03	21.45	13.60	11.86
1913	12.90	3.84	12.44	22.49	12.68	12.86
1914	12.00	2.28	11.30	22.98	12.64	12.30
1915	12.01	1.67	10.89	21.35	13.80	11.92
1916	12.14	2.71	11.64	21.79	12.28	12.10
1917	11.02	2.15	11.08	21.70	10.82	11.44
1918	12.19	−1.17	12.99	21.72	12.40	11.48
1919	12.76	3.24	12.08	22.23	14.77	13.08
1920	11.51	0.84	10.59	21.19	13.00	11.41
1921	13.55	3.05	13.81	22.45	14.38	13.42
1922	12.91	3.31	12.88	22.00	13.36	12.89
1923	12.38	2.90	11.35	22.10	12.46	12.20
1924	11.30	2.51	10.13	21.97	12.00	11.65
1925	12.68	3.05	12.06	22.75	13.10	12.74
1926	11.86	1.84	10.17	22.16	12.94	11.77
1927	12.68	3.63	12.17	20.68	14.27	12.69
1928	11.85	2.19	10.69	21.90	12.57	11.84
1929	12.22	1.79	12.95	21.34	12.62	12.18
1930	12.39	3.74	11.90	22.25	12.74	12.66
1931	13.23	1.90	10.43	22.80	15.50	12.66
1932	13.01	6.85	10.93	22.71	12.60	13.27
1933	13.18	3.99	12.35	22.39	13.47	13.05
1934	12.47	2.30	11.51	23.51	13.69	12.75
1935	12.48	2.34	12.47	22.57	13.64	12.76
1936	12.50	−0.85	12.44	23.26	13.54	12.10
1937	12.27	4.32	11.13	22.80	11.35	12.40
1938	13.05	3.27	13.24	22.20	13.36	13.02
1939	13.04	3.60	12.24	22.69	13.27	12.95
1940	11.50	0.18	10.65	22.05	12.49	11.35
1941	12.79	2.31	11.59	22.61	14.79	12.82
1942	12.56	2.04	12.92	22.75	13.64	12.84
1943	12.44	2.72	11.41	23.48	11.88	12.37
1944	12.53	3.03	12.26	22.54	12.95	12.70

Year	Ann*
1945	12.77
1946	13.15
1947	12.15
1948	12.67
1949	13.39
1950	12.37
1951	12.48
1952	12.86
1953	13.16
1954	12.71
1955	12.40
1956	12.51
1957	12.77
1958	11.35
1959	12.67
1960	11.46
1961	11.94
1962	11.85
1963	11.39
1964	12.13
1965	12.32
1966	11.49
1967	11.68
1968	11.59
1969	11.57
1970	12.32
1971	12.27
1972	12.00
1973	12.72
1974	12.59
1975	12.67
1976	11.54
1977	12.19
1978	11.61
1979	11.80
1980	12.21
1981	11.69
1982	12.44
1983	12.12
1984	12.38
1985	12.48
1986	12.91
1987	12.52

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
1.58	13.85	22.11	13.81	12.84
1.93	13.30	21.51	14.12	12.72
2.72	11.01	21.96	13.74	12.36
1.29	13.32	22.31	13.17	12.52
5.72	11.91	22.85	13.14	13.40
5.58	11.20	21.43	12.55	12.69
2.01	11.68	22.48	12.68	12.21
4.24	11.82	23.52	12.11	12.92
3.78	12.90	22.80	13.11	13.14
3.45	11.82	22.74	13.30	12.82
1.64	13.41	22.15	12.77	12.49
1.74	11.45	21.98	12.55	11.93
4.86	12.58	22.13	12.70	13.07
0.36	11.03	22.10	13.14	11.66
1.49	12.37	22.53	13.11	12.37
2.46	9.62	21.99	13.27	11.84
0.70	10.71	21.36	13.93	11.68
2.53	11.74	21.54	12.40	12.06
–0.75	12.62	21.32	13.05	11.56
–0.19	12.22	21.91	12.59	11.63
2.53	12.20	21.50	13.06	12.32
1.35	11.31	21.88	12.01	11.64
1.85	12.28	20.87	10.99	11.50
0.63	11.83	22.33	12.79	11.89
0.73	11.16	22.37	12.13	11.60
–0.06	12.15	22.11	13.96	12.04
1.88	10.27	21.73	14.12	12.00
3.71	11.39	20.94	12.45	12.12
2.88	12.09	22.43	14.34	12.94
4.32	12.86	21.11	12.09	12.59
3.45	11.54	22.18	13.56	12.68
2.90	12.44	21.10	10.48	11.73
−1.27	13.79	22.53	13.34	12.10
−1.47	11.24	22.38	13.71	11.47
0.35	12.35	21.23	13.06	11.78
1.78	11.48	22.90	12.89	12.30
1.18	11.65	22.41	12.11	11.86
0.85	12.35	21.73	13.12	12.01
3.10	11.07	22.55	12.86	12.54
1.57	10.62	21.96	13.19	11.88
2.47	13.07	21.43	14.92	12.97
1.62	12.57	22.78	13.79	12.72
1.87	12.17	23.28	12.33	12.43

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Northern Piedmont

BACKGROUND

Principal investigators
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Sponsoring agencies
U.S. Department of Commerce
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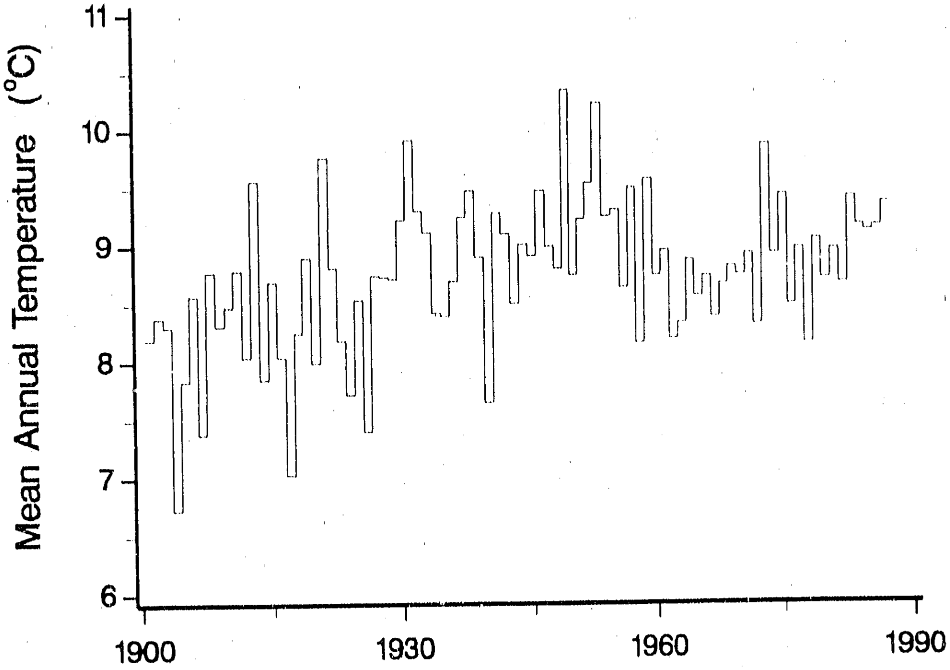
U.S. Department of Energy
Carbon Dioxide Research Program

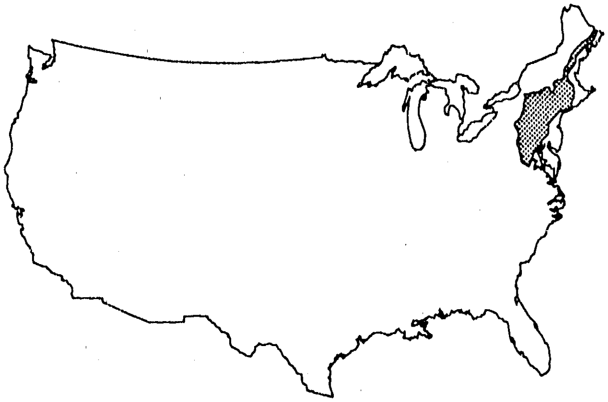
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Northern Piedmont

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated East region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a warm epoch from the early 1920s to the mid 1950s, preceded and followed by periods during which temperatures were generally at or below the mean for the century.

Northern Piedmont

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	8.19	-4.50	7.13	21.21	9.03	8.22
1902	8.38	-4.23	8.67	18.81	10.72	8.50
1903	8.30	-3.52	9.68	17.98	9.36	8.37
1904	6.73	-7.10	7.01	19.21	8.24	6.84
1905	7.83	-6.88	7.39	19.64	9.35	7.37
1906	8.57	-1.79	6.45	20.50	10.14	8.82
1907	7.38	-5.48	5.86	19.02	9.00	7.10
1908	8.77	-3.29	8.06	20.40	10.49	8.91
1909	8.31	-2.23	6.81	19.38	9.75	8.43
1910	8.47	-4.07	9.24	19.53	9.86	8.64
1911	8.79	-4.20	7.63	20.35	9.19	8.24
1912	8.04	-4.58	7.16	19.16	10.64	8.10
1913	9.56	-1.09	8.61	20.00	10.84	9.59
1914	7.85	-3.99	7.08	19.46	10.13	8.17
1915	8.69	-2.60	7.24	18.95	10.79	8.60
1916	8.04	-3.35	5.95	19.76	9.78	8.03
1917	7.03	-4.07	5.76	20.28	7.84	7.45
1918	8.25	-7.50	8.77	19.57	9.76	7.65
1919	8.90	-1.43	8.10	20.11	10.37	9.29
1920	7.99	-6.39	6.54	19.58	10.76	7.62
1921	9.76	-1.82	10.49	20.48	10.61	9.94
1922	8.81	-3.79	8.49	20.01	10.59	8.83
1923	8.18	-5.18	6.49	19.68	10.04	7.75
1924	7.72	-2.32	6.29	19.27	9.33	8.15
1925	8.53	-3.25	7.99	20.24	8.75	8.43
1926	7.40	-3.52	5.55	19.21	9.40	7.66
1927	8.74	-3.59	7.37	18.43	11.37	8.39
1928	8.73	-2.22	6.52	20.22	10.03	8.63
1929	8.71	-2.49	8.55	19.64	10.02	8.93
1930	9.22	-2.39	7.78	20.63	10.76	9.19
1931	9.91	-2.74	8.10	20.77	12.61	9.68
1932	9.30	0.34	6.82	20.12	10.27	9.39
1933	9.11	-0.45	7.96	20.66	9.39	9.39
1934	8.42	-5.55	7.71	20.53	10.74	8.36
1935	8.39	-4.30	7.34	20.69	10.33	8.52
1936	8.69	-5.77	8.92	20.49	9.69	8.33
1937	9.24	-0.30	7.09	21.30	9.60	9.42
1938	9.47	-2.69	8.65	21.08	10.41	9.36
1939	8.90	-2.19	7.14	21.03	9.70	8.92
1940	7.65	-4.13	5.96	19.58	8.99	7.60
1941	9.28	-3.18	8.14	20.32	11.64	9.23
1942	9.10	-2.96	9.81	20.28	10.63	9.44
1943	8.50	-3.91	6.80	21.39	9.61	8.47
1944	9.01	-3.19	7.71	21.18	10.31	9.00

Year	Ann*
1945	8.91
1946	9.47
1947	8.99
1948	8.80
1949	10.34
1950	8.74
1951	9.22
1952	9.53
1953	10.22
1954	9.24
1955	9.30
1956	8.63
1957	9.49
1958	8.15
1959	9.56
1960	8.73
1961	8.94
1962	8.18
1963	8.32
1964	8.86
1965	8.55
1966	8.72
1967	8.37
1968	8.65
1969	8.80
1970	8.73
1971	8.91
1972	8.30
1973	9.84
1974	8.91
1975	9.41
1976	8.47
1977	8.95
1978	8.14
1979	9.03
1980	8.69
1981	8.94
1982	8.65
1983	9.39
1984	9.15
1985	9.10
1986	9.14
1987	9.34

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
–4.73	9.98	19.95	10.74	8.99
–4.00	9.27	19.28	12.04	9.14
–2.17	7.18	20.57	11.16	9.19
–5.23	7.93	20.32	11.37	8.59
–0.32	8.80	22.12	10.63	10.31
–1.05	6.36	19.75	10.58	8.91
–1.80	8.50	19.92	9.91	9.13
–1.46	7.85	21.28	10.14	9.45
–0.39	8.83	20.57	11.33	10.08
–0.98	8.07	19.88	10.92	9.47
–2.75	9.17	21.73	10.26	9.60
–3.16	5.94	19.81	10.05	8.16
–2.18	8.65	20.43	10.93	9.46
–2.72	7.83	19.53	10.28	8.73
–4.75	8.72	21.10	11.31	9.09
–1.33	7.22	19.99	10.68	9.14
–4.92	6.92	20.39	12.32	8.68
–3.73	8.27	19.70	9.19	8.36
–5.28	7.93	19.97	11.20	8.46
–4.25	8.35	19.69	10.28	8.52
–3.59	7.61	19.71	10.02	8.44
–2.65	7.09	20.86	10.04	8.83
–2.77	5.92	20.59	9.46	8.30
–4.36	8.49	20.29	11.01	8.86
–3.55	7.94	20.42	10.35	8.79
–4.95	7.85	20.52	11.50	8.73
–4.29	6.83	20.30	11.70	8.63
–2.35	7.00	19.71	9.13	8.37
–2.09	8.83	21.40	10.97	9.78
–2.03	8.16	20.07	9.50	8.93
–1.32	7.54	20.64	11.37	9.56
–2.77	8.90	20.26	8.53	8.73
–5.72	9.99	20.04	10.70	8.75
–5.10	7.09	20.21	9.86	8.02
–4.36	8.98	20.02	10.97	8.90
–2.58	8.36	20.66	9.79	9.06
–3.80	8.82	20.47	9.58	8.77
–4.44	7.74	19.14	10.89	8.33
–1.01	8.14	21.02	10.95	9.77
–2.68	6.57	20.69	10.59	8.79
–2.30	9.25	19.64	11.38	9.49
–3.51	9.41	19.77	9.89	8.89
–2.70	9.20	20.76	9.94	9.30

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Southern Piedmont

BACKGROUND

Principal investigators
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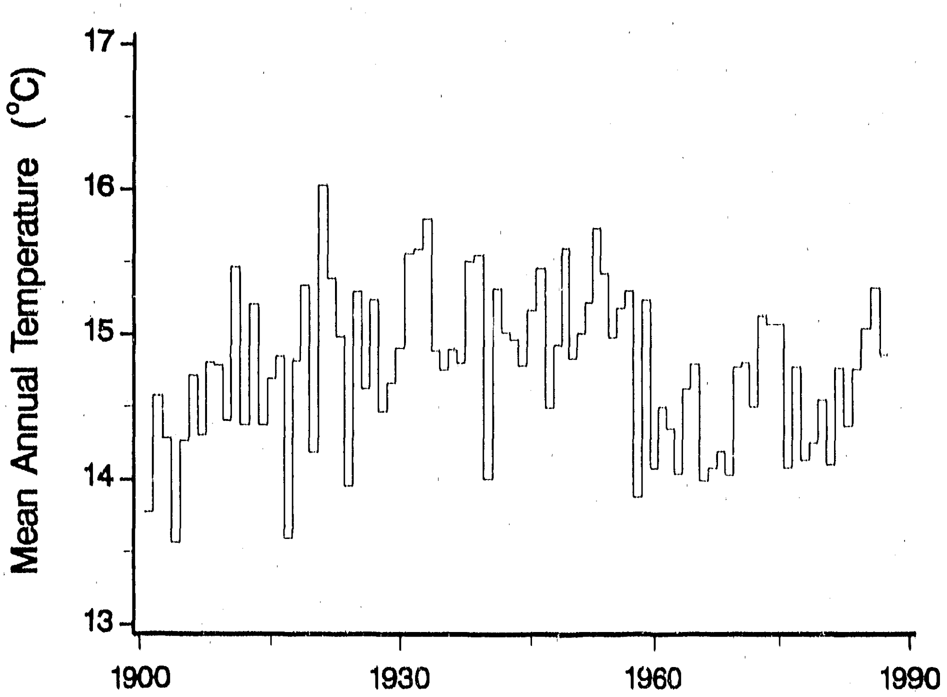
Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

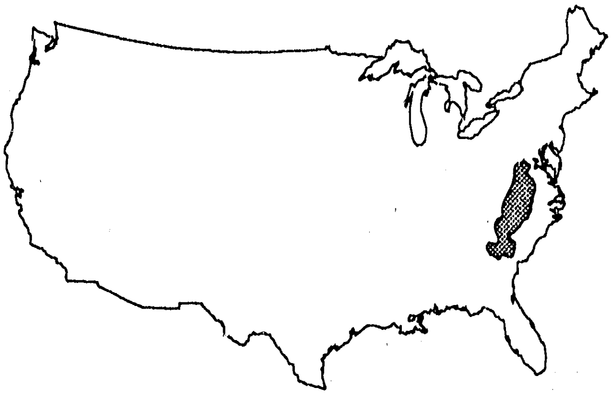
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Southern Piedmont

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated East region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a warm epoch from the early 1920s to the mid 1950s, preceded and followed by periods during which temperatures were generally at or below the mean for the century.

Southern Piedmont

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	13.77	3.73	13.09	24.89	13.72	13.86
1902	14.57	2.32	14.65	24.84	16.14	14.49
1903	14.28	4.45	15.40	23.94	14.21	14.50
1904	13.56	1.69	13.74	23.94	14.47	13.46
1905	14.26	1.51	15.30	24.39	15.54	14.19
1906	14.71	4.72	13.67	24.64	15.35	14.59
1907	14.30	5.39	13.82	23.66	14.43	14.33
1908	14.80	3.66	16.26	24.06	14.85	14.71
1909	14.78	6.94	14.15	24.18	15.11	15.09
1910	14.40	3.40	15.44	23.69	15.27	14.45
1911	15.46	5.05	14.17	25.26	15.75	15.05
1912	14.37	2.97	14.59	24.16	15.97	14.42
1913	15.20	6.78	14.87	24.39	14.76	15.20
1914	14.37	4.77	13.92	25.20	14.66	14.64
1915	14.69	4.34	13.47	24.14	16.46	14.60
1916	14.84	5.58	14.58	24.00	15.00	14.79
1917	13.59	5.06	13.67	24.19	13.04	13.99
1918	14.81	1.86	15.67	24.23	14.97	14.18
1919	15.33	5.90	14.94	24.39	17.31	15.63
1920	14.18	3.31	13.29	23.97	15.70	14.07
1921	16.02	5.50	16.19	24.90	16.97	15.89
1922	15.38	5.74	15.26	24.35	16.04	15.35
1923	14.98	5.51	14.13	24.63	14.98	14.82
1924	13.95	5.17	12.97	24.37	14.51	14.25
1925	15.29	5.59	14.75	25.43	15.70	15.37
1926	14.62	4.77	12.96	24.86	15.55	14.54
1927	15.23	6.30	14.78	23.15	16.69	15.23
1928	14.46	4.86	13.45	24.48	15.12	14.47
1929	14.66	4.55	15.50	23.66	14.90	14.65
1930	14.90	6.10	14.44	24.62	15.27	15.11
1931	15.55	4.39	12.74	25.15	17.85	15.03
1932	15.58	9.26	13.52	25.30	15.00	15.77
1933	15.79	6.89	15.08	24.84	15.96	15.69
1934	14.88	4.82	13.96	25.82	16.03	15.16
1935	14.75	4.56	14.95	24.99	15.75	15.07
1936	14.89	1.55	15.09	25.36	15.96	14.49
1937	14.80	6.61	13.89	25.19	13.88	14.89
1938	15.50	5.69	15.86	24.55	15.80	15.47
1939	15.54	6.16	14.87	25.03	15.75	15.45
1940	14.00	2.83	13.26	24.50	14.97	13.89
1941	15.31	4.59	14.36	24.88	17.56	15.35
1942	15.01	4.47	15.44	24.93	16.09	15.23
1943	14.96	5.20	14.25	25.79	14.31	14.89
1944	14.78	5.27	14.65	24.72	15.20	14.96

Year	Ann*
1945	15.16
1946	15.45
1947	14.49
1948	14.92
1949	15.59
1950	14.83
1951	15.00
1952	15.21
1953	15.72
1954	15.41
1955	14.97
1956	15.17
1957	15.29
1958	13.87
1959	15.22
1960	14.07
1961	14.49
1962	14.34
1963	14.03
1964	14.61
1965	14.78
1966	13.98
1967	14.07
1968	14.18
1969	14.02
1970	14.76
1971	14.79
1972	14.49
1973	15.11
1974	15.05
1975	15.05
1976	14.07
1977	14.76
1978	14.12
1979	14.24
1980	14.53
1981	14.09
1982	14.75
1983	14.35
1984	14.74
1985	15.02
1986	15.30
1987	14.84

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
3.98	16.44	24.45	16.03	15.22
4.34	15.69	23.63	16.33	15.00
5.36	13.59	24.07	15.89	14.73
3.54	15.66	24.59	15.16	14.74
8.09	14.31	24.83	15.34	15.64
7.71	13.76	23.98	15.01	15.11
4.58	14.08	24.90	15.28	14.71
6.77	14.45	25.60	14.55	15.34
6.23	15.52	25.22	15.65	15.65
6.14	14.55	25.33	16.09	15.53
4.52	16.12	24.46	15.07	15.05
4.62	14.11	24.70	14.95	14.60
7.76	15.12	24.39	15.11	15.59
3.21	13.59	24.39	15.58	14.19
4.21	15.11	24.81	15.64	14.94
4.95	12.52	24.31	15.77	14.39
3.44	13.48	23.79	16.32	14.26
4.78	14.32	23.85	14.96	14.48
2.33	15.23	23.94	15.27	14.19
2.85	14.71	24.11	14.97	14.16
5.36	14.76	23.71	15.44	14.82
4.00	13.70	24.17	14.54	14.10
4.45	14.50	23.15	13.29	13.85
3.61	14.39	24.57	15.42	14.50
3.25	13.85	24.52	14.44	14.01
2.87	14.63	24.38	16.23	14.53
4.71	12.88	24.04	16.38	14.50
6.82	13.82	23.25	14.80	14.67
5.28	14.57	24.59	16.72	15.29
6.91	15.38	23.41	14.42	15.03
6.15	13.96	24.09	16.23	15.11
5.54	15.12	23.38	12.88	14.23
1.77	16.18	25.05	15.62	14.66
1.67	13.67	24.56	15.98	13.97
3.28	14.85	23.44	15.54	14.28
4.12	14.05	25.04	15.21	14.60
3.80	14.11	24.56	14.44	14.23
3.37	14.68	23.82	15.45	14.33
5.24	13.47	24.90	15.35	14.74
4.20	13.28	24.09	15.45	14.26
5.17	15.64	23.90	17.30	15.50
4.28	15.05	25.26	16.03	15.16
4.21	14.34	25.65	14.82	14.76

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Coastal Northeast

BACKGROUND

Principal investigators
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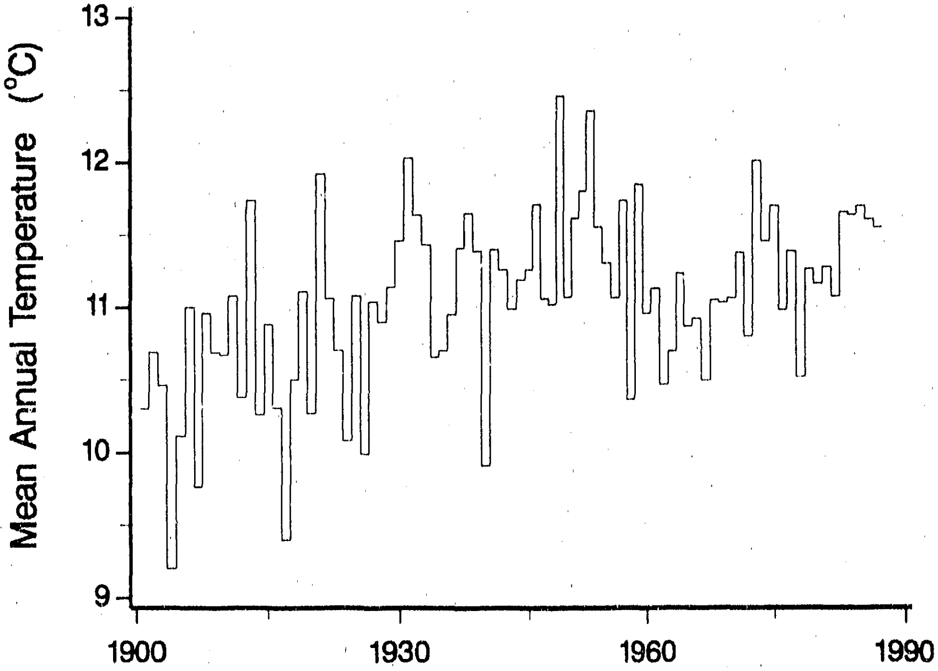
Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

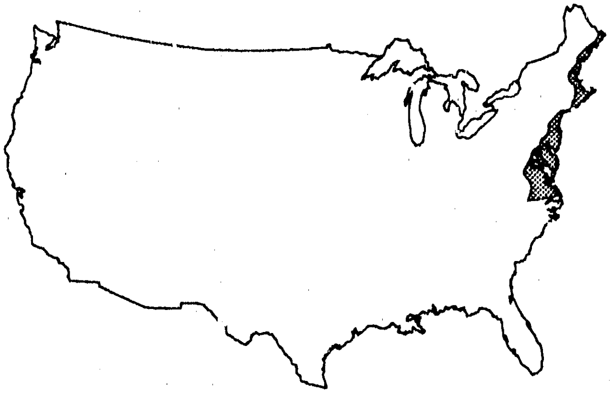
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Coastal Northeast

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated East region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a warm epoch from the early 1920s to the mid 1950s, preceded and followed by periods during which temperatures were generally at or below the mean for the century.

Coastal Northeast

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	10.30	–1.32	8.97	22.35	11.31	10.33
1902	10.69	–1.44	10.39	20.76	13.27	10.74
1903	10.46	–0.15	11.22	19.77	11.49	10.58
1904	9.20	–3.44	8.99	20.74	10.83	9.28
1905	10.11	–3.55	9.75	20.91	11.84	9.74
1906	11.00	1.19	8.92	21.70	12.63	11.11
1907	9.76	–1.29	8.17	20.01	11.51	9.60
1908	10.96	–0.13	10.47	21.44	12.44	11.05
1909	10.69	1.63	9.23	20.75	11.96	10.90
1910	10.67	–0.77	10.94	20.83	12.14	10.78
1911	11.08	–0.69	9.27	21.82	11.89	10.57
1912	10.38	–1.43	9.56	20.75	12.87	10.44
1913	11.74	2.08	10.74	21.33	12.81	11.74
1914	10.26	–0.14	8.86	21.10	12.37	10.55
1915	10.88	0.54	9.23	20.55	12.95	10.81
1916	10.31	0.02	8.26	20.81	12.10	10.30
1917	9.40	–0.75	8.21	21.50	9.97	9.73
1918	10.50	–3.79	10.63	20.89	12.05	9.94
1919	11.11	1.44	10.27	21.04	13.19	11.49
1920	10.27	–2.62	8.68	20.79	12.93	9.95
1921	11.92	1.33	12.15	21.51	13.27	12.07
1922	11.06	–0.29	10.49	21.25	12.76	11.05
1923	10.70	–1.05	9.02	21.21	12.20	10.35
1924	10.08	1.10	8.47	20.74	11.51	10.46
1925	11.08	0.71	10.09	21.85	11.54	11.05
1926	9.99	–0.23	8.18	20.86	11.94	10.19
1927	11.04	–0.01	9.49	19.85	13.65	10.74
1928	10.90	0.80	8.81	21.67	12.33	10.90
1929	11.14	0.38	10.96	21.11	12.36	11.20
1930	11.46	1.20	9.80	22.07	13.04	11.53
1931	12.03	0.42	9.45	22.09	14.87	11.71
1932	11.64	3.96	8.88	21.72	12.62	11.80
1933	11.43	2.54	9.97	21.72	12.23	11.61
1934	10.66	–1.84	9.37	22.17	12.89	10.64
1935	10.70	–0.80	9.58	21.90	12.86	10.89
1936	10.95	–2.72	10.70	21.81	12.45	10.56
1937	11.41	2.85	9.45	22.41	11.66	11.59
1938	11.65	0.74	10.59	22.07	12.82	11.55
1939	11.39	1.40	9.77	22.24	12.15	11.39
1940	9.91	–1.31	8.08	21.12	11.36	9.81
1941	11.40	0.12	9.90	21.47	14.13	11.41
1942	11.26	0.13	11.31	21.79	13.11	11.58
1943	10.99	–0.30	9.38	22.81	11.89	10.94
1944	11.19	0.09	9.98	22.31	12.49	11.21

Year	Ann*
1945	11.26
1946	11.71
1947	11.06
1948	11.02
1949	12.46
1950	11.07
1951	11.61
1952	11.80
1953	12.35
1954	11.55
1955	11.30
1956	11.06
1957	11.73
1958	10.36
1959	11.84
1960	10.95
1961	11.12
1962	10.46
1963	10.69
1964	11.27
1965	10.86
1966	10.91
1967	10.49
1968	11.04
1969	11.02
1970	11.05
1971	11.36
1972	10.79
1973	11.99
1974	11.44
1975	11.68
1976	10.97
1977	11.37
1978	10.51
1979	11.25
1980	11.15
1981	11.26
1982	11.06
1983	11.64
1984	11.62
1985	11.68
1986	11.59
1987	11.53

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May; Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
–1.07	11.87	21.37	13.28	11.36
–0.34	11.12	20.57	14.01	11.34
1.17	9.17	21.52	13.29	11.28
–1.57	10.06	21.60	13.21	10.82
3.12	10.52	22.99	13.03	12.42
2.74	8.50	21.14	12.67	11.26
1.32	10.24	21.63	12.59	11.44
2.14	10.03	22.82	12.33	11.83
2.63	10.95	21.99	13.34	12.23
2.30	10.13	21.48	13.12	11.76
0.27	10.99	22.50	12.49	11.56
–0.15	8.43	21.34	12.45	10.51
1.56	10.74	22.02	12.93	11.81
0.12	9.50	21.29	12.59	10.87
–1.20	10.90	22.27	13.64	11.40
1.72	8.98	21.70	12.94	11.34
–1.52	9.14	21.77	14.20	10.90
–0.37	10.18	20.98	11.66	10.61
–1.81	10.38	21.52	13.07	10.79
–0.75	10.31	21.36	12.45	10.84
0.12	9.65	21.30	12.33	10.85
0.22	9.18	22.24	12.33	10.99
0.63	8.29	21.43	11.38	10.43
–0.94	10.27	22.14	13.35	11.20
–0.45	9.98	22.13	12.39	11.01
–1.31	9.53	21.98	13.83	11.01
–0.45	9.03	21.81	13.89	11.07
1.59	9.15	21.04	11.66	10.86
1.29	10.68	22.70	13.44	12.01
1.62	10.58	21.55	12.07	11.45
2.06	9.48	22.04	13.59	11.79
1.21	11.06	21.84	10.78	11.22
–2.30	11.85	22.05	13.16	11.19
–1.84	9.12	21.83	12.42	10.38
–0.94	10.96	21.32	13.40	11.19
0.43	10.44	22.51	12.42	11.43
–0.29	10.58	22.35	11.94	11.17
–0.79	9.82	21.03	13.04	10.76
1.96	10.07	22.65	13.33	11.99
0.49	8.96	22.31	13.09	11.21
1.16	11.57	21.51	14.22	12.11
–0.07	11.02	21.96	12.68	11.40
0.33	10.64	22.61	12.43	11.50

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Karl, T.R., R.G. Baldwin, M.G. Burgin. 1988a. *Time series of regional seasonal averages of maximum, minimum, and average temperature, and diurnal temperature range across the United States: 1901–1984*. Historical Climatology Series 4-5. National Climatic Data Center. National Oceanic & Atmospheric Administration. National Environmental Satellite, Data, and Information Service. Asheville, North Carolina.

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Karl, T.R., C.N. Williams, Jr., and F.T. Quinlan. 1990. *United States Historical Climatology (HCN) serial temperature and precipitation data*. NDP-019/R1. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Coastal Southeast

BACKGROUND

Principal investigators
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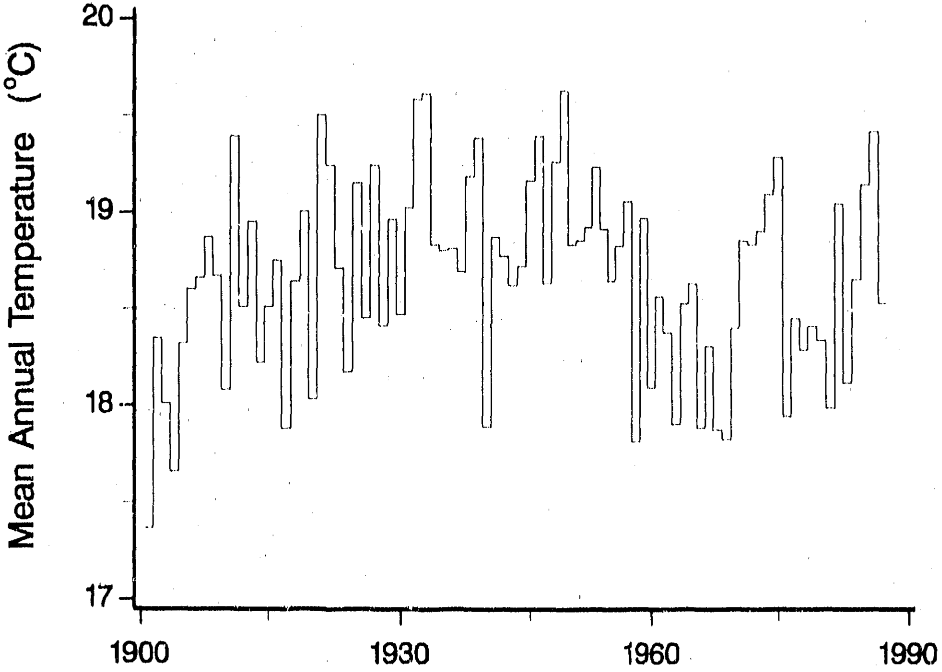
Sponsoring agencies
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
U.S. Department of Energy
Carbon Dioxide Research Program

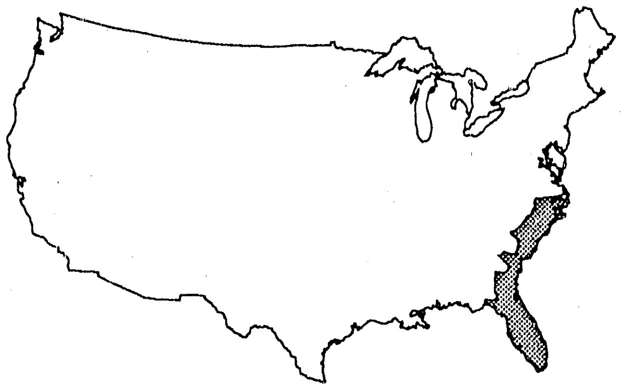
Period of record – 1901–1987.

Method – After comparing each station's data in the 1219-station Historical Climatology Network (HCN) (Karl et al. 1990) to data from its twenty nearest neighbors, stations were selected based on confidence, missing data, and consistency criteria. All data were adjusted for time of observation biases, station and instrument changes, and urban heat island biases. Twenty-three regions were formed by subjectively considering the climate characteristics across the country, the terrain, the continentality, and the vegetation. As an additional constraint, each region was required to have boundaries coinciding with NCDC's climate divisions. For further details see Karl et al. (1988a).

Data availability – These data are available from NCDC and CDIAC. The complete HCN data set (Karl et al. 1990) is available from CDIAC.



Annual calendar year average temperature.



Coastal Southeast

TRENDS

On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed over the recent century but that the changes have not been monotonic for the most part. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. Karl et al. (1988a) also found a considerable amount of detailed information for each regional time series but reported that their salient features often could be summarized in time series plots for three aggregated regions: West, Central, and East. For the aggregated East region, which includes this subregion, Karl et al. (1988a) reported that the annual average temperature time series can be divided into three epochs: a warm epoch from the early 1920s to the mid 1950s, preceded and followed by periods during which temperatures were generally at or below the mean for the century.

Coastal Southeast

Year	Ann*	Win	Spr	Sum	Fall	Ann†
1901	17.37	9.39	16.69	25.81	17.88	17.44
1902	18.35	8.36	18.06	26.33	20.12	18.22
1903	18.01	10.99	18.49	25.80	17.97	18.31
1904	17.66	8.12	17.73	25.44	18.52	17.45
1905	18.32	8.46	19.02	25.97	19.72	18.29
1906	18.60	10.55	17.79	26.21	19.64	18.55
1907	18.66	11.44	18.26	25.85	19.06	18.65
1908	18.87	9.96	20.04	25.89	18.97	18.71
1909	18.67	12.67	18.30	25.97	19.14	19.02
1910	18.08	9.49	18.58	25.45	19.06	18.14
1911	19.39	10.94	18.09	26.35	20.49	18.97
1912	18.51	9.71	18.91	25.82	19.70	18.53
1913	18.95	13.19	18.60	25.74	18.60	19.03
1914	18.22	10.62	17.40	26.54	18.83	18.35
1915	18.51	10.49	16.87	26.20	20.72	18.57
1916	18.75	11.47	17.83	25.71	19.32	18.58
1917	17.88	11.58	18.05	25.85	17.56	18.26
1918	18.64	8.80	18.84	25.77	19.25	18.16
1919	19.00	11.26	18.40	25.61	21.31	19.15
1920	18.03	10.02	17.10	25.65	19.34	18.03
1921	19.50	11.28	19.22	26.09	20.77	19.34
1922	19.24	11.89	19.13	25.76	19.89	19.17
1923	18.71	12.03	18.16	25.83	18.69	18.67
1924	18.17	11.14	17.10	26.38	18.63	18.31
1925	19.15	12.31	18.41	26.45	20.21	19.34
1926	18.45	10.38	16.71	26.21	19.64	18.23
1927	19.24	12.75	18.75	25.60	20.37	19.37
1928	18.41	10.58	17.42	26.14	19.50	18.41
1929	18.96	11.41	19.52	25.46	19.52	18.98
1930	18.47	11.86	18.00	25.73	19.02	18.65
1931	19.02	9.57	16.58	26.47	20.99	18.40
1932	19.58	15.49	17.51	26.77	19.27	19.76
1933	19.61	13.29	19.03	26.10	20.00	19.60
1934	18.83	11.41	17.95	26.78	20.23	19.09
1935	18.80	10.97	19.41	26.25	19.81	19.11
1936	18.81	8.50	18.58	26.47	20.00	18.39
1937	18.69	13.21	17.67	26.37	18.27	18.88
1938	19.18	11.13	19.68	25.96	19.60	19.09
1939	19.38	12.48	18.84	26.53	19.63	19.37
1940	17.89	8.58	16.99	26.41	18.84	17.71
1941	18.87	10.40	17.42	26.64	21.18	18.91
1942	18.77	10.19	18.43	26.70	20.25	18.89
1943	18.62	11.27	18.10	26.99	18.41	18.69
1944	18.72	11.16	18.70	26.40	19.26	18.88

Year	Ann*
1945	19.16
1946	19.39
1947	18.63
1948	19.26
1949	19.63
1950	18.83
1951	18.85
1952	18.92
1953	19.23
1954	18.91
1955	18.64
1956	18.82
1957	19.05
1958	17.81
1959	18.96
1960	18.09
1961	18.56
1962	18.37
1963	17.90
1964	18.52
1965	18.62
1966	17.88
1967	18.30
1968	17.87
1969	17.82
1970	18.39
1971	18.84
1972	18.82
1973	18.89
1974	19.08
1975	19.27
1976	17.94
1977	18.44
1978	18.28
1979	18.40
1980	18.33
1981	17.98
1982	19.03
1983	18.11
1984	18.64
1985	19.13
1986	19.40
1987	18.52

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*Calendar year mean (Jan–Dec).

†Season year mean (Win = Dec–Feb; Spr = Mar–May, Sum = Jun–Aug; Fall = Sep–Nov).

Average Temperature (°C), 1901–1987

Win	Spr	Sum	Fall	Ann†
10.19	20.02	26.21	20.09	19.13
10.71	19.18	25.63	20.61	19.03
11.66	17.78	25.63	20.09	18.79
10.30	19.69	26.44	19.85	19.07
14.37	18.39	26.38	19.66	19.70
14.05	17.63	26.06	19.04	19.20
9.93	17.81	26.60	19.52	18.46
12.56	18.27	27.11	18.77	19.17
11.45	19.45	26.23	19.23	19.09
11.86	18.18	27.00	19.38	19.10
9.91	19.43	25.85	19.28	18.62
10.37	17.94	26.30	18.97	18.40
13.52	18.53	26.04	19.34	19.36
8.16	17.43	26.43	19.83	17.96
10.43	18.46	26.28	20.14	18.83
10.29	16.72	26.13	20.14	18.32
9.40	17.87	25.89	19.89	18.26
11.38	17.93	26.06	18.94	18.58
8.49	18.82	25.96	18.89	18.04
8.55	18.57	25.84	19.35	18.07
11.30	18.53	25.62	19.60	18.76
9.76	17.47	25.46	19.13	17.96
10.27	18.81	25.22	17.83	18.03
9.48	17.98	26.31	19.08	18.21
8.96	17.17	26.35	18.80	17.82
8.29	18.52	26.10	19.69	18.15
10.89	16.93	26.05	20.32	18.55
13.15	17.87	25.45	19.55	19.00
10.85	18.62	26.20	20.70	19.09
12.88	19.19	25.40	18.76	19.06
12.43	18.52	26.11	20.20	19.32
10.81	18.79	25.38	17.19	18.04
7.78	19.35	26.67	19.69	18.37
7.76	17.95	26.34	20.42	18.12
9.79	18.55	25.84	19.90	18.52
9.71	18.18	26.61	19.29	18.44
8.65	17.94	26.82	18.54	17.99
10.35	18.65	26.13	19.47	18.65
10.74	17.14	26.39	19.38	18.41
10.11	17.74	25.93	19.39	18.29
10.90	19.21	26.25	21.80	19.54
10.40	18.36	26.94	21.08	19.20
10.35	17.61	27.03	19.06	18.51

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Karl, T.R., R.G. Baldwin, M.G. Burgin. 1988a. *Time series of regional seasonal averages of maximum, minimum, and average temperature, and diurnal temperature range across the United States: 1901–1984.* Historical Climatology Series 4-5. National Climatic Data Center. National Oceanic & Atmospheric Administration. National Environmental Satellite, Data, and Information Service. Asheville, North Carolina.

Karl, T.R., H.F. Diaz, and G. Kukla. 1988b. Urbanization: its detection and effect in the United States climate record. *Journal of Climate* 1:1099–1123.

Karl, T.R., C.N. Williams, Jr., and F.T. Quinlan. 1990. *United States Historical Climatology (HCN) serial temperature and precipitation data.* NDP-019/R1. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Oak Ridge, Tennessee.

Appendixes

Appendix A

Carbon Dioxide Information Anal

The Carbon Dioxide Information Analysis Center (CDIAC), located within the Environmental Sciences Division of Oak Ridge National Laboratory, has been in operation since 1982. CDIAC provides information support to the international research, policy, and education communities for evaluation of complex environmental issues associated with elevated levels of atmospheric CO_2, including potential climate change. CDIAC activities include obtaining and evaluating data, articles, and reports; producing digital numeric data and computer model packages (NDPs and CMPs); distributing CO_2-related reports; and producing the newsletter, *CDIAC Communications*, which has a worldwide distribution of over 5500 subscribers in 151 countries. To date, 38 NDPs and CMPs have been compiled, 12 issues of *CDIAC Communications* have been distributed, and CDIAC has responded to more than 16,000 information requests.

CDIAC is funded by the U.S. Department of Energy (DOE) to support its Carbon Dioxide Research Program (CDRP). The goal of CDRP is to develop sound scientific information for policy formation and governmental action in response to changes of atmospheric CO_2. CDRP's thrust during the past decade has been to (1) elucidate the processes that control the global carbon cycle

is Center

and provide predictions of future atmospheric CO_2 change; (2) develop data and models of the processes by which changes in the Earth's radiative balance may change climate at global and regional scales and predict rates of potential climate change; and (3) develop the data and models required to define and predict the combined effect of climate and CO_2 on plants, crops, and ecosystems.

In 1989, CDRP moved from DOE's Office of Basic Energy Sciences into the Office of Health and Environmental Research. At the same time, it was combined with other atmospheric research activities under the Atmospheric and Climate Research Division, which is directed by Ari Patrinos. The CDRP managers (and their areas of responsibility) are Roger C. Dahlman (global carbon research, vegetation research, and education), Michael R. Riches (climate research, quantitative links, oceans research, and resource analysis), and Thomas J. Gross (information and integration, including responsibility for CDIAC).

The mailing address for the program is:

Carbon Dioxide Research Program
Atmospheric and Climate Research
Division (ER-76)
U.S. Department of Energy
Washington, DC 20545, U.S.A.

Appendix B

Numeric Data Packages

Detailed descriptions of data sets [CDIAC Numeric Data Packages (NDPs)] used to produce *TRENDS '90* are presented in the next several pages. To order these NDPs or inquire about other CDIAC information products, an order form is provided at the end of this appendix. Simply copy the order form, fill in the appropriate information, and return the completed form to CDIAC. If you have any questions about the availability of these NDPs, you may contact CDIAC by phone, FAX, or any of the telecommunication networks listed below:

Carbon Dioxide Information Analysis Center
Building 1000, MS-6335
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, Tennessee 37831-6335, U.S.A.

(615) 574-0390
624-0390 FTS
574-2232 FAX

BITNET: CDP@ORNLSTC
OMNET: CDIAC
INTERNET: CDP@STC10.CTD.ORNL.GOV

Atmospheric CO_2 Concentrations — Mauna Loa Observatory, Hawaii, 1958–1986. C. D. Keeling, Scripps Institution of Oceanography. **CDIAC NDP-001/R1** (Rev. 1986)

Since 1958, air samples have been continuously collected at Mauna Loa Observatory and analyzed by infrared spectroscopy for CO_2 concentrations. Data are averaged to give monthly and annual atmospheric CO_2 concentrations.

These data represent the longest continuous record of atmospheric CO_2 concentrations in the world. This precise data record covers a single site, Mauna Loa Observatory, Hawaii, which is a reliable indicator of the regional trend in the concentration of atmospheric CO_2 in the middle layers of the troposphere and thus is critical to CO_2-related research. The data are in one file (2.5 kB).

Global Surface-Air Temperature Variations: 1851–1984. P. D. Jones, S. C. B. Raper, P. M. Kelly, and T. M. L. Wigley, University of East Anglia. **CDIAC NDP-003/R1** (Rev. 1986)

Anomalies in monthly and annual surface-air temperatures in relation to the 1951–1970 mean surface-air temperature were calculated for several periods: 1851–1984 for the Northern Hemisphere, 1858–1984 for the Southern Hemisphere excluding Antarctica, and 1958–1984 for the Southern Hemisphere including Antarctica. These estimates are derived from land-based meteorological station data and fixed-position weather-ship data interpolated onto a 5° latitude by 10° longitude grid. The data are in three files, one for the anomalies in Northern Hemisphere temperatures (10 kB) and two for the anomalies in Southern Hemisphere temperatures (9 kB and 2 kB).

Atmospheric CO_2 Concentrations — The NOAA/GMCC Flask Sampling Network. T. J. Conway and P. Tans, National Oceanic and Atmospheric Administration. **CDIAC NDP-005/R1** (Rev. 1990)

Flask air samples are collected approximately once per week at 29 stations scattered around the globe. The earliest samples were taken in 1968, but the period of record varies from station to station. The samples are analyzed for atmospheric CO_2

concentration on a nondispersive infrared gas analyzer apparatus at the NOAA/GMCC laboratory in Boulder, Colorado. The measurements are directly traceable to the primary CO_2 standards of the World Meteorological Organization. Each sample is characterized by station, year, sampling date and time, flask identification number, CO_2 concentration, date and time of analysis, and quality indicators. The data are in 30 files: one file that contains data through 1981 (946 kB) and one file for each of 29 sites with data from 1981 through 1986 (ranging from 3.6 to 55.8 kB).

Production of CO_2 from Fossil-Fuel Burning. R. M. Rotty and G. Marland, Oak Ridge Associated Universities. **CDIAC NDP-006** (1984)

Global CO_2 emissions for 1950 through 1982 were estimated by Marland and Rotty from fuel production data from the U.N. *Energy Statistics Yearbook* (1983, 1984). Data before 1950 came from C. D. Keeling. Fuel-production data were used in these calculations because they appeared to be more reliable on a global basis than fuel-consumption data. The data given are the year and annual global CO_2 emissions (annual global total; cumulative global total since 1860; and annual global emissions from solid fuels, liquid fuels, natural gas, gas flaring, and cement manufacturing). These data provide the only pre-1950 estimates of the amount of carbon emitted to the atmosphere from fossil-fuel burning. The CO_2 emission record since 1950 has been updated and revised several times, with the most recent estimates published by Marland et al. The data are in one file (7.5 kB).

Atmospheric CO_2 Concentrations – The CSIRO (Australia) Monitoring Program from Aircraft for 1972–1981. D. J. Beardsmore and G. I. Pearman, Commonwealth Scientific and Industrial Research Organization. **CDIAC NDP-007** (1984)

From 1972 through 1981, air samples were collected in glass flasks from aircraft at a variety of latitudes and altitudes over Australia, New Zealand, and Antarctica. The samples were analyzed for CO_2 concentrations by using a nondispersive infrared gas analysis. The resulting data contain the sampling dates, type of aircraft, flight number, flask identification number, sampling time, geographic sector, distance in kilometers from the listed distance measuring equipment station, station number of the radio navigation distance measuring equipment, altitude of the aircraft above mean sea level, sample analysis date, flask pressure, tertiary standards used for the analysis, type of analyzer used, and CO_2 concentration. These data represent the first published record of CO_2 concentrations in the Southern Hemisphere expressed in the 1981 CO_2 Calibration Scale of the World Meteorological Organization and provide a precise record of atmospheric CO_2 concentrations in the troposphere and lower stratosphere over Australia and New Zealand. The data are in one file (263 kB).

Annual and Seasonal Global Temperature Anomalies in the Troposphere and Low Stratosphere, 1958–Summer 1986. J. K. Angell and J. Korshover, National Oceanic and Atmospheric Administration. **CDIAC NDP-008/R1** (Rev. 1987)

For 1958 through 1986, anomalies in annual and seasonal temperatures in relation to a 1958–1977 mean (expressed in degrees Celsius) were calculated for the surface, troposphere (850–300 mb), tropopause (300-100 mb), and low stratosphere (100-50 mb and 100-30 mb) layers on the basis of region, hemispheres, and the globe. Most of the values are column-mean temperatures obtained from the differences in the heights of constant-pressure surfaces at individual radiosonde stations. The pressure-height data before 1980 were obtained from published values in *Monthly Climatic Data for the World*. These temperature anomalies may be used to analyze long-term temperature trends for a layer of the atmosphere (i.e., surface, troposphere, tropopause, and low stratosphere), a region (i.e., polar, temperate, subtropical, and equatorial regions), a hemisphere, or the globe. The data are in one file (64.5 kB).

Atmospheric CO_2 Concentrations – The CSIRO Monitoring Program: Surface Data for Cape Grim, Tasmania. D. J. Beardsmore, G. I. Pearman, and R. C. O'Brien, Commonwealth Scientific and Industrial Research Organization. **CDIAC NDP-010** (1985)

From 1976 through 1983, air samples collected from a high-volume general intake 10 m above the roof of the laboratory at Cape Grim, Tasmania, were dried and analyzed for CO_2 concentrations with a nondispersive infrared gas analyzer. This baseline CO_2 record from Cape Grim indicates the CO_2 concentrations in large maritime air masses devoid of vegetative influences in this region of the Southern Hemisphere. The data available on each sample are sampling date; daily, monthly, and annual CO_2 concentrations; standard deviation associated with each concentration; number of hours of data used to calculate the CO_2 values; and the analyzer used. The data are in three files: daily (17 kB), monthly (3 kB), and annual (310 B).

United States Historical Climatology Network (HCN) Serial Temperature and Precipitation Data. T. R. Karl, C. N. Williams, Jr., and F. T. Quinlan, National Oceanic and Atmospheric Administration. **CDIAC NDP-019/R1** (Rev. 1990)

Extending through 1987, this data base contains information on monthly total precipitation and temperatures from 1219 stations in the contiguous United States. To be included in the Historical Climatology Network (HCN), a station had to be currently active (1987), have at least 80 years of monthly temperature and precipitation data, and have experienced few station changes. These data were derived from a variety of sources, including the National Climatic Data Center archives, state climatologists, and published literature. The data base contains several hundred variables, including state number, station number, monthly temperatures (minimum, maximum, and mean), total monthly precipitation, and time of observation. This is probably the best monthly temperature and precipitation data set available for the contiguous United States because station moves, instrument changes, urbanization effects, and time-of-observation differences have been considered and, where necessary, the data have been corrected. The data are in 13 files (one station inventory file, one station history file, six temperature files, one precipitation file, one time-of-observation correction file, and two quality-assessment files). The file sizes range from 5 kB to ~50 MB and are available on nine-track magnetic tape only.

A Global Grid Point Surface-Air Temperature Data Set: 1851–1984. P. D. Jones, S. C. B. Raper, B. S. G. Cherry, C. M. Goodess, T. M. L. Wigley, B. Santer, and P. M. Kelly, University of East Anglia; R. S. Bradley, University of Massachusetts; H. F. Diaz, National Oceanic and Atmospheric Administration. **CDIAC NDP-020** (1986)

For 1851 through 1984, this data base presents anomolies in monthly surface-air temperatures for both hemispheres, in relation to a 1951–1970 reference period, on a 5° latitude by 10° longitude global grid. The basis of the data set is derived from the *World Weather Records* published by the Smithsonian Institution and the U.S. Weather Bureau. Additional data were added from meteorological archives. The records include the year, month, latitude, longitude, surface air temperature anomaly, number of stations used to calculate each gridded anomaly, and the mean value of the inverse of the great circle distance between the station and the grid point. The data are in two files (Northern and Southern hemispheres), each 19.63 MB in size and on nine-track magnetic tape only.

Global and Hemispheric Annual Temperature Variations between 1861 and 1988. P. D. Jones, T. M. L. Wigley, and P. B. Wright, University of East Anglia. **CDIAC NDP-022/R1** (Rev. 1990)

This data set contains estimates of variation in global and hemispheric annual temperatures in relation to a 1950–1979 reference period, for 1861 through 1988. The estimates are based on corrected land and ocean data. Land data were derived from meteorological data and fixed-position weather-ship data that were corrected for nonclimatic errors, such as station shifts and/or instrument changes. The marine data were from the compilation of the Comprehensive

Ocean-Atmosphere Data Set (COADS), which with updates extends to 1986. Updates to 1988 were made with hemispheric sea-surface temperature estimates produced by the U.K. Meteorological Office. Each record includes year and six annual temperature variations: one estimate each for the globe, the Northern Hemisphere, and the Southern Hemisphere and another estimate each that reflects an adjustment to account for the influence of El Niño/Southern Oscillation events. The data are in one file (kB).

Estimates of CO_2 Emissions from Fossil-Fuel Burning and Cement Manufacturing, Based on the U.N. Energy Statistics and the U.S. Bureau of Mines Cement Manufacturing Data. G. Marland, T. A. Boden, P. Kanciruk, S. F. Huang, and T. R. Nelson, Oak Ridge National Laboratory; R. C. Griffin, Kentucky Wesleyan College. **CDIAC NDP-030** (1989)

For 1950 through 1986, global and national annual estimates of CO_2 emissions from fossil-fuel burning and cement production were calculated from energy statistics compiled by the U.N. Statistical Office and from cement-manufacturing data compiled by the U.S. Bureau of Mines. The resulting data base contains the annual amounts of global CO_2 emissions and estimates of national CO_2 emissions for more than 200 countries. Among many variables, these data include total emissions; emissions from gas, liquid, and solid fuels; and emissions from cement production. The data are in six files (three for the U.N. statistics, one for the Bureau of Mines data, one for global CO_2 emission estimates, and one for the national CO_2 emission estimates) ranging in size from 427 bytes to 4.85 MB and are available on nine-track magnetic tape only.

Atmospheric CO_2 Concentrations – The Canadian Background Air Pollution Monitoring Network. N. B. A. Trivett, Environment Canada. **CDIAC NDP-034** (1989)

Flask air samples collected at roughly weekly intervals at three Canadian sites [Alert, Northwest Territories (July 1975 through October 1987); Sable Island, Nova Scotia (June 1975 through October 1987); and Cape St. James, British Columbia (May 1979 through October 1987)] were analyzed for CO_2 concentration with the measurements directly traceable to the primary CO_2 standards of the World Meteorological Organization (WMO). Each record includes the date, atmospheric CO_2 concentration, and flask classification code. They provide an accurate record of CO_2 concentrations in Canada during the past decade. Because these data are directly traceable to WMO standards, this record may be compared with records from other Background Air Pollution Monitoring Network stations. The data are in three files (one for each of the monitoring stations) ranging in size from 3.2 to 12.8 kB.

Appendix B

Ordering CDIAC NDPs

To order these NDPs, complete and return a copy of this form to CDIAC.

Additional CDIAC NDPs are described in detail in the *Catalog of Data Bases and Reports* (*ORNL/CDIAC-34*), also available from CDIAC.

Return completed form to:

Carbon Dioxide Information Analysis Center
Building 1000, MS-6335
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, Tennessee 37831-6335, U.S.A.

(615) 574-0390
624-0390 FTS
574-2232 FAX

BINET: CDP@ORNLSTC
OMNET: CDIAC
INTERNET: CDP@STC10.CTD.ORNL.GOV

Order Form for CDIAC Numeric Data Packages

NDP Number	Documentation Only	Documentation & Floppy Diskette		Documentation & Magnetic Tape*
		5 1/4"	3 1/2"	
NDP-001	☐	☐	☐	☐
NDP-003	☐	☐	☐	☐
NDP-005	☐	☐	☐	☐
NDP-006	☐	☐	☐	☐
NDP-007	☐	☐	☐	☐
NDP-008	☐	☐	☐	☐
NDP-010	☐	☐	☐	☐
NDP-019	☐	☐	☐	☐
NDP-020	☐	☐	☐	☐
NDP-022	☐	☐	☐	☐
NDP-030	☐	☐	☐	☐
NDP-034	☐	☐	☐	☐

*Magnetic tapes are nine-track only. The following information **MUST** be completed if a magnetic tape is requested:

Density	Label	Character Set
☐ 1600 BPI	☐ Nonlabeled	☐ EBCDIC
☐ 6250 BPI	☐ Standard	☐ ASCII

Please list special computer limitations or requirements:

Please send me additional information about CDIAC information products:

☐ *CDIAC Communications* (newsletter), ☐ Additional Numeric Data Packages

☐ *Catalog of Data Bases and Reports (ORNL/CDIAC-34)*

☐ Please note change of name or address:

Name: ______________________________

Organization: ______________________________

Mailing Address: ______________________________

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Telephone: ____________ FAX: ____________ eMail Address: ____________

Appendix C

A.D.	*anno Domini*
AO	air over
Ann	annual
AES	*Atmospheric Environment Service* (Downsview, Ontario, Canada)
BAPMoN	Background Air Pollution Monitoring Network (W.M.O.)
BP	before present
CDIAC	*Carbon Dioxide Information Analysis Center* (Oak Ridge, Tennessee, U.S.A.)
CH_4	methane
CIRES	*Cooperative Institute for Research in Environmental Sciences* (Boulder, Colorado, U.S.A.)
CMDL	*Climate Monitoring and Diagnostics Laboratory* (Boulder, Colorado, U.S.A.)
CMP	computer model package
CNRS	*Centre National de la Reserche Scientifique* (Paris, France)
CO_2	carbon dioxide
COADS	Comprehensive Ocean-Atmosphere Data Set
CSIRO	*Commonwealth Scientific and Industrial Research Organization* (Aspendale, Australia)
DOE	*U.S. Department of Energy* (Washington, D.C.)
ENSO	El Niño-Southern Oscillation
ESD	*Environmental Sciences Division* (Oak Ridge National Laboratory)
F.R.G.	Federal Republic of Germany
GMCC	Geophysical Monitoring for Climate Change (NOAA)
HCN	*Historical Climatology Network* (Asheville, North Carolina, U.S.A.)
INSTARR	*Institute of Arctic and Alpine Research* (Boulder, Colorado, U.S.A.)
IOS	*Institute for Ocean Science* (Sidney, British Columbia, Canada)
ITCZ	Intertropical Convergence Zone
kyr	kiloyear (one thousand years)

MAT	marine air temperatures
MLO	*Mauna Loa Observatory* (Hawaii, U.S.A.)
MSL	mean sea level
NASA	*National Aeronautic and Space Administration* (U.S.A.)
NCDC	*National Climatic Data Center* (Asheville, North Carolina, U.S.A.)
NDIR	nondispersive infrared gas analyzer
NDP	numeric data package
NOAA	*National Oceanic and Atmospheric Administration* (U.S.A.)
ORNL	*Oak Ridge National Laboratory* (Oak Ridge, Tennessee, U.S.A.)
PIREN	*Programme Interdisciplinaire de Reserche en l'Environnement* (Toulouse, France)
PPB	parts per billion
PPBV	parts per billion by volume
PPM	parts per million
PPMV	parts per million by volume
PRC	*People's Republic of China*
SIO	*Scripps Institution of Oceanography* (La Jolla, California, U.S.A.)
SPO	*South Pole Observatory* (Antarctica)
SST	sea surface temperature
TAFF	*Terres Australes et Antarctiques Francaises*
U.K.	United Kingdom
U.N.	*United Nations*
UNEP	*United Nations Environment Programme*
U.S.A.	United States of America
U.S.S.R.	Union of Soviet Socialist Republics
WMO	*World Meteorological Organization*
yr	year

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