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Atmospheric carbon dioxide measurements at Barrow, Alaska, 1973–1979

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ABSTRACT

The U.S. National Oceanic and Atmospheric Administration has operated a program to continuously measure atmospheric CO_2 concentrations at Barrow, Alaska, since July 1973. This report describes the basic operational program and reports the data through 1979. Analysis of the data shows a large-amplitude annual CO_2 cycle of 15.2 p.p.m., which is similar to that at other Northern Hemisphere high-latitude locations. The annual cycle is asymmetric with a maximum in late April and minimum in late August. Largest day-to-day variability of the the full data set occurs during summer. The long-term CO_2 trend is highlighted by a slight ($\simeq$0.1 p.p.m.) decrease in absolute concentrations in 1976 compared to 1975; overall, concentrations rose about 4 to 5 p.p.m. Tentative pressure-broadening corrections were applied to express results in mole fractions so that the Barrow measurements could be directly compared to those at Mauna Loa, Hawaii. Referenced to January 1, 1974, CO_2 values at Barrow averaged about 2.5 p.p.m. greater than at Mauna Loa. The Barrow–Mauna Loa interstation difference was greatest (more than 6 p.p.m.) during December and January. The difference reverses during summer when it is less than −6 p.p.m. in August. For 1979 CO_2 at Barrow averaged 336.9 p.p.m.

1. Introduction

The modern record of carbon dioxide in the atmosphere centers on the systematic measurements begun in 1958 by C. D. Keeling, using a continuously operating analyzer at Mauna Loa Observatory, Hawaii (Keeling et al., 1976). Those measurements document an increasing atmospheric CO_2 trend, ascribed to burning fossil fuels. As worldwide economy expands, CO_2 emissions to the atmosphere are expected to increase. Numerous scientists (e.g., Manabe and Weatherald, 1980), using mathematical simulations of climate, have suggested that the higher CO_2 levels will lead to significant changes in climate throughout the world.

CO_2 was first measured at Barrow, Alaska, by Kelley and co-workers from the University of Washington during the 1960's (Kelley, 1969; 1974). Their measurements with a continuously operating infrared analyzer began in July 1961 and are nearly continuous through 1967. They documented year-to-year CO_2 increases and described the annual and diurnal CO_2 cycles at Barrow. The Air Resources Laboratories of NOAA established a program of continuous CO_2 measurements at Barrow, Alaska, in 1973 (Komhyr and Harris, 1977). Analyses of the NOAA data for within-year variability (Peterson et al., 1980a), dependence on air mass trajectories during winter (Peterson et al., 1980b), and summertime variability related to meteorological conditions (Halter and Peterson, 1981) have been completed. Harris and Herbert (1980) graphically described the monthly variation of CO_2 concentrations with wind speed and direction. The present paper reports an updated set of the NOAA Barrow CO_2 measurements results through 1979, a selected data set with periods of local influence removed, and a description of the year-to-year and within-year variability of CO_2 concentrations at Barrow.

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2. Site

The NOAA Observatory (71.3° N., 156.6° W.) near Barrow, Alaska, is located within 2 km of the Chukchi Sea to the northwest and the Beaufort Sea to the northeast (Fig. 1). Point Barrow is the northernmost location in the United States. The surrounding terrain is flat tundra with numerous ponds and lakes stretching to the foothills of the Brooks Range more than 100 km to the south. Observatory elevation is 9 m. To the north the Arctic Ocean stretches beyond the North Pole.

There are several local anthropogenic sources of CO_2 at Barrow; the village of Barrow to the southwest of the Observatory (1970 population—2100) and the Naval Arctic Research Laboratory (NARL) to the west (population—about 200). During summer there are occasional hunters and tourists on the spit of land to Pt. Barrow. To the south, exploration for oil and gas has increased in recent years, but human activity is minimal during summer because of the difficulty of travel on the tundra. Therefore, air arriving at the Observatory from north through south-east is generally uncontaminated by anthropogenic CO_2. Air arriving from other directions may be slightly contaminated, especially if it has passed directly over Barrow village.

Although anthropogenic CO_2 sources are not extensive in the Barrow region, there are significant natural sources and sinks. These are most pronounced in summer when the tundra thaws, vegetation grows, and sea ice melts for up to 100 km from the shore. According to Kelley and Gosink (1979) tundra plants are a modest CO_2 sink, soil and lakes a modest source, and the thawed ocean surface a strong CO_2 sink. During winter there is practically no CO_2 exchange through the frozen tundra, but significant amounts of CO_2 do filter through (less than year old) sea ice to the atmosphere. Halter and Peterson (1981) described the influence of the summertime natural sources and sinks on the Barrow ambient CO_2 measurements.

Barrow has a distinctly arctic climate. The coldest month, February, has a mean temperature of −28 °C. The snow typically melts in early June. The mean daily temperature first exceeds freezing on June 13, reaches a maximum of only 4 °C in late July, and falls to freezing by September 12. The near-shore seas are free of ice from early July through September.

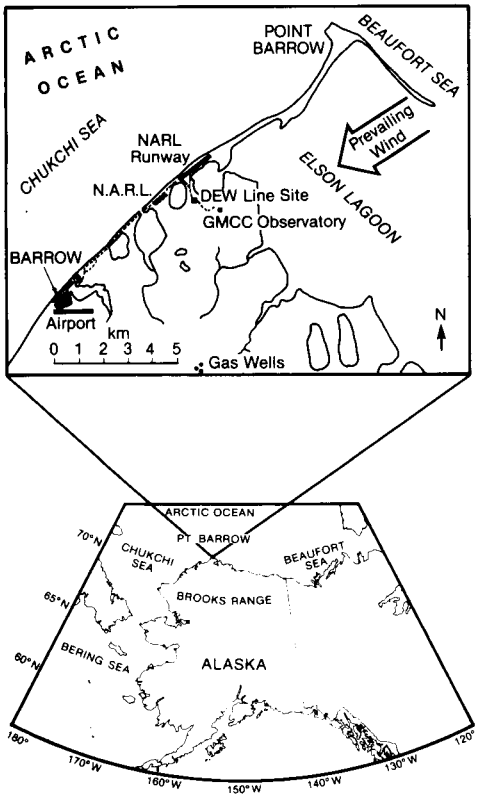

Fig. 1. Map of the Barrow, Alaska vicinity (top) and Alaskan area (bottom).

3. Experimental methods

Komhyr and Harris (1977) describe in detail the experimental methods for the Barrow program. Only a general outline and description of recent changes will be presented here. Initially (July 1973) an aluminum sampling line was installed with the inlet 16 m above ground. In May 1977, a sampling stack similar to those in use at other NOAA observatories was installed with an inlet 10 m above ground (Komhyr, 1980). Ambient air CO_2 is measured continuously with a non-dispersive infrared analyzer. Three analyzers have been used at Barrow; a UNOR-2 (manufactured by H.

Maihak, Hamburg, F.R.G.[1]) from July 1973 to August 1975; another UNOR-2 through July 1976; the original UNOR-2 to August 15, 1978; and a URAS-2T (Hartmann and Braun, A.G., Frankfurt, F.R.G.) to the present.

The infrared analyzer output voltage is scaled to CO_2 concentrations by using reference gases of known concentrations. Currently, gas from each of two working reference tanks with a CO_2 concentration difference of about 10 to 15 p.p.m. is cycled through the analyzer for 5 min each hour. Before June 1976, the working gases were cycled every half hour. Concentration values are assigned to these tanks at the NOAA laboratory at Boulder, Colo., based on comparisons with standard tanks from the Scripps Institution of Oceanography (SIO). Approximately 4 pairs of working reference tanks were used at Barrow each year. Once a week at Barrow, gas from each of three secondary standard tanks, with concentrations determined by SIO, is cycled through the analyzer for additional calibration of the working tank gases and a check on analyzer linearity. Two sets of secondary standard tanks were used at Barrow, with the changeover in January 1976.

The ambient air CO_2 concentrations reported here are based on the originally assigned calibrations of the working reference tanks. A preliminary check of these original assignations versus those determined from the weekly comparisons with the secondary standards at Barrow showed differences generally less than 0.25 p.p.m. Thus, when a formal analysis of the weekly calibrations is completed, adjustments to the Barrow data set of this magnitude may be necessary.

Scripps Institution of Oceanography (SIO) reported a drift in their primary CO_2 reference standards of 0.06 p.p.m. yr^{-1} through 1974 (Keeling et al., 1976). Our data are directly tied to the SIO standards, but we have not yet applied a drift correction. This will be done when SIO specifies the drift correction through 1979. Consequently, our final data set probably will show slightly greater year-to-year increases than those reported below.

All reference gases used at Barrow were mixtures of CO_2 in nitrogen rather than CO_2 in air. However, infrared analyzers respond differently to CO_2 in N_2 than to CO_2 in air because of pressure-broadening effects on the CO_2 infrared absorption lines. Thus, the indicated concentrations (when using CO_2 in N_2 calibration standards) are relative and must be corrected to be considered absolute (Pearman, 1977). This pressure-broadening correction is usually similar for instruments from the same manufacturer but is quite different for analyzers of different design. For our analyzers, a UNOR typically yields CO_2 concentrations about 5 p.p.m. greater than those obtained with a URAS instrument when CO_2 in N_2 calibration gases are used (Pearman, 1977). During August, 1978, pressure-broadening corrections for the Barrow analyzers were tentatively determined by intercalibrating the analyzers with CO_2 in N_2 and CO_2 in air calibration gases.

Herein, we will report dry-air atmospheric CO_2 concentrations in relative and absolute scales. The *relative* scale is the 1959 SIO adjusted index scale (J) (Keeling et al., 1976). Since we changed analyzers in August 1978 from UNOR to URAS, we adjusted the URAS measurements to be consistent with those of the UNOR in the adjusted index scale. We also present data in *absolute* mole fractions (X), the WMO 1974 CO_2 Calibration Scale (also known as the 1974 SIO CO_2 in air mole fraction scale). For this we first convert values in the adjusted index scale (J) to the WMO 1974 CO_2 in N_2 scale (W) by

$$W = C_0 + C_1 \cdot J + C_2 \cdot J^2 + C_3 \cdot J^3, \quad (1)$$

where $C_0 = 76.582$, $C_1 = 0.584910$, $C_2 = 3.1151 \cdot 10^{-4}$, and $C_3 = 7.3225 \cdot 10^{-7}$. Our tentative pressure-broadening correction is then applied to give mole fraction values (X) from

$$X = W - 135.872 + 0.77618 \cdot W - 0.00112585 \cdot W^2. \quad (2)$$

This nonlinear correction ranges from −2.53 p.p.m. at 325 p.p.m. to −2.10 p.p.m. at 345 p.p.m., the approximate range of the Barrow measurements. Following the nomenclature of Keeling et al. (1976) we refer to our data in these two scales as CO_2 adjusted index (J) and mole fraction (X) values in units of parts per million by volume (p.p.m.).

[1] Mention of company or product names should not be considered an endorsement by the U.S. Dept. of Commerce.

4. Data processing

When the program began at Barrow the voltage output from the analyzers was recorded on stripcharts. Since April 1975, the primary record has been obtained digitally on magnetic tape, with the stripcharts serving as backup. The analyzer voltage is interrogated each second, averaged by minute and hour, converted to concentrations (p.p.m. by volume), and recorded on magnetic tape (Herbert et al., 1980).

At Boulder the Barrow data tapes are converted to a master computer file of hourly CO_2 concentrations. Obviously erroneous values (usually caused by equipment malfunction) are deleted from the file and those hours with significant within-hour variation, based on corresponding stripchart information, are so coded. The Barrow CO_2 sampling system generally performed well except for several periods when a leaky pump diaphragm allowed air from inside the Observatory to contaminate the ambient air intake line. Major data losses occurred frequently from mid-February to mid-March 1975 and from January through April 1976.

The resulting data set includes many hours of measurement when local sources or sinks affected the record. Thus, to obtain a data set representative of larger space-scale conditions, we must select out the locally affected measurements. Since we do not yet understand the causes of all CO_2 variability at Barrow, we could not employ a physically-based selection method. Consequently, we used an objective statistical selection scheme that probably deletes most locally contaminated values. The underlying philosophy of the method is that a homogeneous air mass free of local contamination has small within-hour and hour-to-hour CO_2 concentration changes. Specifically, when the hour-to-hour change exceeded 0.25 p.p.m., values for both hours were deleted from the data set. Similar criteria have been used by Lowe et al. (1979) and Keeling et al. (1976). A much smaller group of values was also deleted, based on the within-hour variability coding. Finally, after these criteria were applied, a few remaining outlying values (representing far less than 1% of the data) were subjectively deleted.

The impact of data selection on the Barrow record strongly depends on season (Peterson et al., 1980a). Fig. 2 shows 1977 daily average CO_2 concentrations based on the complete data set, and can be compared to Fig. 3e (in Section 5 below) where data have been selected. For example, during May CO_2 variability is at a minimum and few values are selected out of the record. In contrast, the mid-summer period from late July into September exhibits the greatest variability and our selection scheme removed about 60% of the hourly data. August monthly averages for selected and complete data sets differ by more than 1.5 p.p.m.

5. Results

Fig. 3a–g, plots of daily average concentrations obtained from hourly values of the selected data set, illustrate several features of the Barrow CO_2 record. First, CO_2 concentrations gradually increased over the long term, most rapidly since 1976. Second, the annual cycle shows a rapid concentration decrease in July followed by rapidly rising levels from September to December. Third, maximum day-to-day variation often occurs late in the year in contrast with the complete data set (see Fig. 2) where day-to-day variation is greatest during August and September. Fourth, variation with periods of about 15 to 30 days often occurs from January into April. Peterson et al. (1980b) showed a relation between such variability and north–south large-scale atmospheric circulation changes. Interestingly, variations of

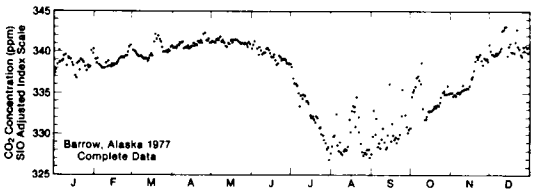

Fig. 2. Daily average CO_2 concentrations at Barrow, Alaska during 1977 using all available data.

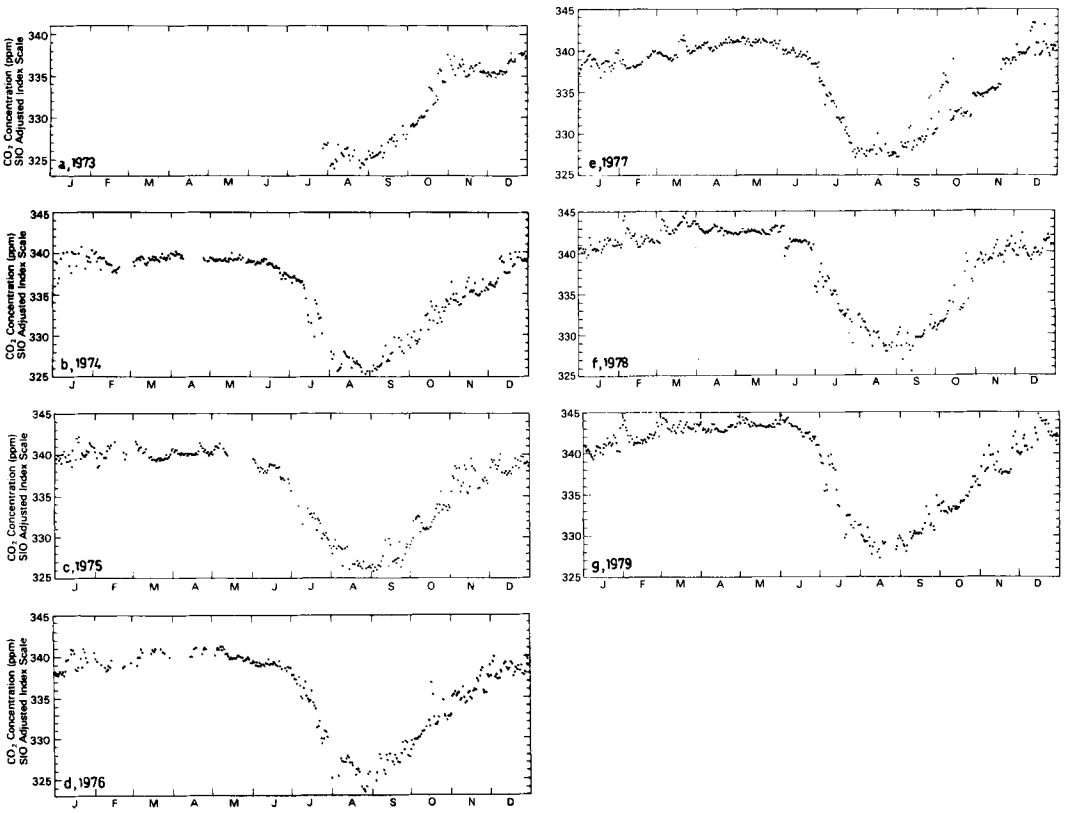

Fig. 3a–g. Daily average CO_2 concentrations (p.p.m.) at Barrow, Alaska, 1973–1979, using selected data only. SIO adjusted index scale.

similar period have been reported for Mauna Loa (Pearman, 1980). Fifth, the record is most steady in May.

To focus on the longer time scale Barrow CO_2 variability the data were smoothed by averaging the selected hourly values over 5-day periods (dots in Fig. 4). In addition, cubic spline functions (Wold, 1974) with knots (the points where adjacent cubic functions join) every 20 days were fitted by least squares to the 5-day average points over the full measurement record (thin continuous line in Fig. 4). This line clearly shows both the annual cycle and some shorter term variability with periods of 1 to $1\frac{1}{2}$ months. The latter is most evident during the winter half-year. The thick continuous line in Fig. 4 is a cubic spline function designed to show interannual and the long-term CO_2 secular change. It is fitted to monthly averages with knots once a year.

Daily CO_2 concentrations (Fig. 3) were combined to yield monthly averages, from which annual averages were obtained. These results are presented in Table 1 in the adjusted index scale and in mole fractions.

A main feature of Fig. 4 is the leveling off and decreasing trend of the long-term curve during the middle of the Barrow record. The slope of that curve is negative from May 1975 to July 1976. The 1976 annual average (Table 1) is 0.1 p.p.m. less than that for 1975. Taken by itself, such a CO_2 decrease is unexpected and might even cast suspicion on the data. At Mauna Loa (3.4 km elevation, 19° 29′N latitude), for example, since 1958 no calendar year has had an average concentration less than that of the previous year (Keeling et al., 1976; Keeling, 1980). However, recent analysis of the Ocean Station P (50° N, 145° W) CO_2 measurements (Hanson et al., 1981)

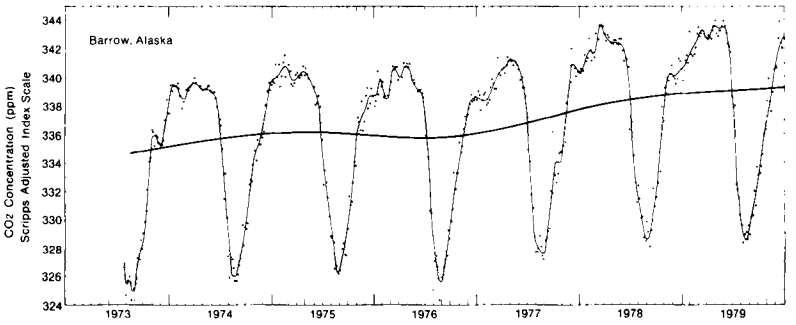

Fig. 4. Five-day average CO_2 concentrations (dots) at Barrow, Alaska, 1973–1979, using selected data only. The continuous curved lines are cubic spline functions showing short-term (thin line) and long-term (thick line) CO_2 variations.

Table 1. *Monthly and annual average CO_2 concentrations of selected data from Barrow, Alaska. The number of days per month (N) with at least one hour of valid data are listed along with the concentrations (p.p.m.) in the 1959 SIO adjusted index scale (J) and as mole fractions (X)*

	1973			1974			1975			1976		
	N	J	X	N	J	X	N	J	X	N	J	X
January				20	339.14	337.21	30	340.18	338.31	25	339.21	337.29
February				19	338.75	336.80	15	340.10	338.23	12	338.98	337.04
March				30	339.32	337.40	26	340.05	338.18	13	340.41	338.56
April				14	339.59	337.69	30	340.28	338.42	8	340.70	338.87
May				29	339.23	337.31	10	340.46	338.61	29	340.13	338.26
June				30	338.37	336.39	27	338.08	336.09	28	339.02	337.08
July				23	334.53	332.31	20	331.33	328.91	29	333.86	331.60
August	25	325.10	322.28	23	326.67	323.95	23	327.40	324.73	22	325.99	323.23
September	24	326.56	323.83	23	327.56	324.90	25	327.60	324.94	24	327.54	324.88
October	28	331.81	329.42	27	331.83	329.44	30	332.15	329.78	27	331.84	329.45
November	27	335.86	333.73	28	335.22	333.05	26	337.07	335.01	30	336.03	333.91
December	29	336.31	334.21	30	338.32	336.34	29	338.67	336.71	30	338.41	336.44
Annual					335.71	333.57		336.11	333.99		336.01	333.88

	1977			1978			1979		
	N	J	X	N	J	X	N	J	X
January	31	338.62	336.66	30	340.83	339.00	30	340.90	339.08
February	25	338.69	336.73	28	341.85	340.09	28	342.05	340.30
March	30	339.92	338.04	30	343.17	341.49	31	343.21	341.53
April	29	340.82	338.99	30	342.72	341.01	30	343.05	341.36
May	30	341.07	339.26	31	342.54	340.82	31	343.53	341.87
June	29	339.54	337.64	30	341.24	339.44	29	342.66	340.95
July	31	332.42	330.07	29	334.47	332.25	25	334.96	332.77
August	24	327.83	325.19	23	329.97	327.46	22	329.11	326.55
September	28	329.67	327.14	24	329.63	327.10	26	330.80	328.35
October	30	334.17	331.93	24	333.90	331.64	30	334.41	332.19
November	29	336.70	334.62	28	339.80	337.91	28	338.98	337.04
December	31	340.53	338.69	29	340.36	338.51	25	342.25	340.51
Annual		336.67	334.58		338.37	336.39		338.83	336.88

showed a 1975 to 1976 trend similar to that described for Barrow. They ascribed the Station P CO_2 dip to an anomalously cold region of sea surface temperatures in the North Pacific to the west of Station P. The agreement between the sea level North Pacific and Alaskan measurements, despite their disagreement with the high altitude Hawaiian data, lends support to the validity of an actual CO_2 decrease at Barrow during 1976.

The long-term CO_2 concentration change, as indicated by the annual averages in Table 1, was a 3.31 p.p.m. increase from 1974 to 1979. However, this value should be interpreted very cautiously. As we indicated earlier, a correction for the drift of the SIO primary calibration system has not yet been applied. Based on experience (Keeling et al., 1976) we anticipate that this correction will add 0.06 to 0.10 p.p.m. per year to the measured increase. Also, the Barrow record is affected by CO_2 sources and sinks. Even our fairly stringent data selection scheme did not remove all locally affected measurements. Thus, during periods when local sources or sinks are particularly effective, the Barrow data may not be representative of large-scale hemispheric processes, and computations of longer term changes will be biased. This bias is evidenced by the results obtained from different methods of computing the long-term CO_2 change. At Barrow, May is the month with least day-to-day and hour-to-hour variability, a feature indicative of minimal local influence. Only by the very end of May does the spring snowmelt begin in earnest. Thus, May measurements probably reflect best the larger scale CO_2 regime. From May 1974 to May 1979, concentrations increased 4.56 p.p.m., a measure more than a part per million greater than that obtained from the annual averages. By using these May statistics and a Scripps drift correction, the 1974–1979 increase will average nearly 1 p.p.m. per year.

A composite annual cycle of CO_2 concentrations at Barrow was computed from the data of Fig. 4. The spline function fit to the 5-day average points (thin line of Fig. 4) was detrended using the long-term function (thick line of Fig. 4) to adjust all data to a reference of January 1, 1974. The $6\frac{1}{2}$ yr data set was then averaged through the calendar year over each 5-day interval. The resulting mean 5-day concentrations (referenced to January 1, 1974), converted from adjusted index to mole fraction scale, are presented in Fig. 5. Mid-month, maximum, and minimum values, obtained from the Fig. 5 data, are given in Table 2 in both adjusted index and mole fraction scales. For comparison, we include in Fig. 5 monthly averages from Mauna Loa (Keeling, 1980), detrended and referenced to January 1, 1974. These values, also in the mole fraction scale, were obtained from 1973 and 1974 measurements to represent the typical Mauna Loa annual cycle.

The Barrow CO_2 annual cycle has an amplitude of 15.2 p.p.m. (absolute mole fraction units) and is very asymmetric. The amplitude compares well with that from other high-latitude measurements: 15.0 p.p.m. for 1 to 3 km altitude over Scandinavia (Bolin and Bischof, 1970) and about 14 to 15 p.p.m. from Ocean Station P (Wong, 1978). The asymmetry is evidenced by the average date for the maximum on April 28 with the minimum just 4 months later on August 26. These features of the annual variation of CO_2 in the atmosphere are generally ascribed to biospheric processes of CO_2 uptake by photosynthesis and release by respiration and biologic decay (Pearman and Hyson, 1980).

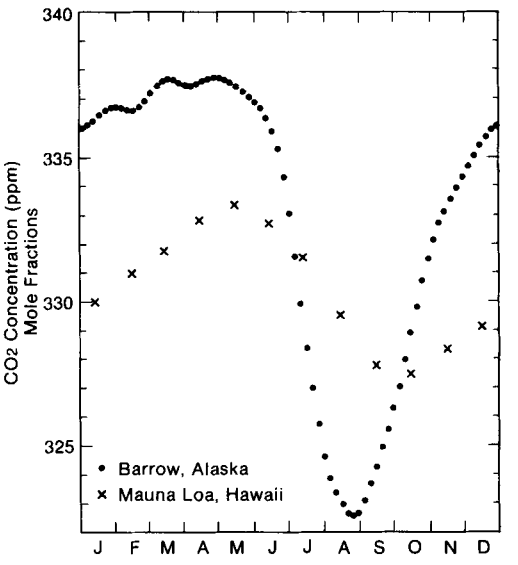

Fig. 5. Composite average annual CO_2 concentration at Barrow, Alaska. Each dot represents a 5-day average. Monthly average concentrations at Mauna Loa, Hawaii, (crosses) from Keeling (1980). Data are referenced to January 1, 1974, and are expressed in absolute mole fraction units with pressure-broadening corrections applied.

Table 2. CO_2 *concentrations at Barrow, Alaska representing a smoothed, composite annual cycle, referenced to January 1, 1974*

Date	CO_2 concentration (p.p.m.)	
	1959 Adjusted index	Mole fraction
January 15	338.34	336.36
February 15	338.59	336.62
March 15	339.55	337.65
April 15	339.56	337.66
April 28 (maximum)	339.64	337.74
May 15	339.42	337.51
June 15	338.11	336.12
July 15	331.40	328.98
August 15	325.80	323.02
August 26 (minimum)	325.36	322.55
September 15	326.98	324.28
October 15	331.31	328.89
November 15	335.41	333.25
December 15	337.51	335.48

The composite annual cycle of Fig. 5 was computed by averaging six or seven yearly values for each 5-day interval. Consequently, a standard deviation (sd) can be computed about each mean 5-day value to yield information on the variability of the annual cycle through the year. By this measure smallest year-to-year variation (sd = 0.2 to 0.3 p.p.m.) about the mean annual cycle occurs in late August and early September, when the CO_2 concentration itself is at an annual minimum. Another period of low variability (sd $\cong$ 0.5 p.p.m.) occurs from March to mid-June. Variability is greatest (sd $\cong$ 1.7 p.p.m.) when the CO_2 concentreation is decreasing rapidly with time (July). Large variability (sd $\cong$ 1.2 p.p.m.) also occurs from late October through mid-November. At this time of year abnormally high concentrations occurred in 1973, 1975, and 1978 with low values in 1977 (see Fig. 3).

Comparison of the Barrow and Mauna Loa average annual cycles in Fig. 5 shows distinct differences in both amplitude and phase. The low latittude, high altitude Hawaiian measurements have much smaller amplitude (less than 6 p.p.m.) a more symmetric annual cycle, and a phase lag of about $\frac{1}{2}$ month at the spring maximum and nearly 2 months at the autumn minimum in comparison to the Barrow record. Some of these differences would be reduced if the elevation differences between sites were considered (Bolin and Bischof, 1970). The Fig. 5 data also show the annual variation of the north–south CO_2 interstation gradient. The absolute value of these gradients and associated concentrations should not be taken too literally, however, since the pressure-broadening corrections (discussed above) used to convert each data set to the absolute mole fraction scale are not definitive. Moreover, we do not imply that the gradients are linear over the 50° of latitude between the sites. The Barrow values have their greatest margin over Mauna Loa (more than 6 p.p.m.) during December and January. From then, the gradient slowly decreases through June. In summer the gradient reverses, with its largest value exceeding 6 p.p.m. in August. These gradients are qualitatively similar to those originally described by Bolin and Keeling (1963), but do have greater absolute values. The only major discrepancy is for October when they reported Barrow CO_2 to be some 5 p.p.m. greater than that at Mauna Loa.

Averaging the Fig. 5 data over the year gives a Barrow annual mean about 2.5 p.p.m. greater than that at Hawaii. This contrasts with a Barrow–Mauna Loa difference of about 1.2 p.p.m. reported by Bolin and Keeling (1963). Why does the mean CO_2 concentration at Barrow exceed that at Mauna Loa? Among possible reasons are anthropogenic CO_2 release centered in Northern Hemisphere mid-latitudes north of Hawaii; natural (i.e., oceanic and/or biospheric) mean CO_2 sources north of Mauna Loa or natural sinks to the south; and the interaction of seasonal changes in the meridional CO_2 gradient coupled with those of the mean meridional atmospheric circulation. Cautious acceptance of the approximate doubling of the mean Barrow–Mauna Loa concentration difference over some 15 years (the 1957–1962 data of Bolin and Keeling versus January 1974 herein) suggests that the first or anthropogenic reason for sustaining the difference may be important. During this period, worldwide emissions of CO_2 increased by 80% (Rotty, 1978).

As more CO_2 data from additional locations become available, intercomparison of averages, gradients, annual cycle amplitudes and phases, etc., should provide fundamental information on the global carbon cycle. However, latitudinal gradients, for example, are often small (Bolin and

Keeling, 1963), and very accurate measurements will be necessary for site-to-site comparisons. Our analyses point out several additional factors to be considered. First, data sets should be as free as possible of local contamination. According to the measurements of Kelley and Gosink (1979) and data analyses of Halter and Peterson (1981), the Chukchi and Beaufort Seas have marked undersaturation of CO_2 during summer and air flowing over them will experience some depletion of CO_2. These findings suggest that our annual cycle at Barrow may not be solely representative of large-scale hemispheric processes and is to some as yet undetermined extent locally influenced. Second, the amplitude of the annual cycle, as well as the absolute value of the measurement, depends on the scale used. Both Tables 1 and 2 show that the Barrow annual amplitude is almost 1 p.p.m. greater for the mole fraction than the adjusted index scale. About half of this change arises from the adjusted index to the 1974 WMO CO_2 in N_2 scale conversion and about half from application of the pressure broadening correction. A third factor is whether monthly averages or more detailed analyses (as done herein) are used to compute an annual cycle. Comparison of Tables 1 and 2 shows that the annual amplitude is about 0.7 p.p.m. greater for the detailed analysis. Finally, measurements taken continuously may not yield the same statistics as those taken intermittently with flasks. The latter are obtained much less frequently, usually once or twice a week.

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