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ATMOSPHERIC CARBON DIOXIDE MONITORING
IN NEW ZEALAND, 1971 - 1985

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ABSTRACT

This paper has two main objectives. Firstly to present the results of 14 years monitoring of atmospheric CO₂ concentration in New Zealand; and secondly to give an assessment of the major sources of error in the data together with an estimate of overall precision.

KEYWORDS

Atmospheric Composition
Baring Head
Carbon Dioxide
Infra-red analysis

1 INTRODUCTION

Monitoring of atmospheric CO₂ concentration in New Zealand was started in 1970 by staff of the Institute of Nuclear Sciences and of Scripps Institution of Oceanography (SIO). Space does not permit a list of the many people from both these organizations who have been involved since that time, however we would like to acknowledge the work of Dr D. C. Lowe who was largely responsible for running the project prior to 1979, and to Drs C. D. Keeling and P. R. Guenther of SIO who have provided considerable support and encouragement throughout. Since 1982 the New Zealand Meteorological Service has helped to meet operating costs and has installed meteorological instruments at Baring Head and their assistance is also gratefully acknowledged.

The monitoring program has used continuously running non-dispersive infrared (NDIR) gas analysers calibrated with gas mixtures whose concentrations are determined by SIO. Starting in December 1970 measurements were made at a site (Makara) near the western coastline in the Wellington region, and this early work has been described by Lowe (1974). Monitoring at Makara was discontinued in March 1972 as it was clear by then that sampled air was seldom free from the influence of surrounding grassland. In December 1972 monitoring was re-established at Baring Head east of the Wellington harbour mouth, on a cliff top with a southerly aspect. This site provides 50 to 60 southerly wind episodes per year which appear to be representative of oceanic air to the south of New Zealand.

Early data from the project were published by Lowe et al (1978a, 1978b, 1979) but is presented again here in the WMO 1985 calibration scale with a correction for carrier gas effects. Over recent years, data have been published in the WMO series of provisional data reports and some minor corrections have now been made to that data. Flask sampling has also been carried out at Baring Head since 1977. These flasks are analysed independently at SIO and thus provide an important validation of our analyser data.

The gas analyser is housed in a small building close to the cliff edge. Normally the entire system runs continuously and unattended, but is visited about once a week by staff from our institute. In addition the lighthouse keeper at Baring Head is available to perform simple maintenance and to take flask samples during southerly winds.

Two different gas analysers have been used in the project up to the end of 1984. Prior to January 1976 the data presented are from a URAS-1 analyser while subsequent data are from a URAS-2T. Most operational procedures have remained the same or very similar throughout the project, and we believe the

entire data set is a consistent record of baseline atmospheric CO₂ concentrations.

For data after January 1980 our estimate of the precision of measurement relative to the WMO 1985 scale is 0.3 ppmv (standard deviation). Prior to this our more tentative estimate of precision is 0.5 ppmv. It is important to realise, however, that the major contributions to errors in the data are systematic in nature and persist for periods of several months to a few years. In order to provide some understanding for this, the next two sections cover briefly the procedures used and the sources of error.

2 GAS ANALYSER OPERATION

Air to be sampled is pumped through a gasline with an intake approximately 10 metres above the ground, and 5 metres from the edge of a cliff which drops about 80 metres to the beach below. Prior to November 1976 a single polyethylene gasline was used and the flow rate was about 0.5 litre per minute. At this time comparison with new gaslines of polyethylene and stainless steel showed that the original line was contaminated. Since November 1976 two stainless steel lines have been sampled alternately, and the flow rate has been maintained at about 2 litres per minute. Note that the flow rate through the analyser is lower, and has ranged from 0.5 to 0.2 litre per minute at different times, with lower values being used in recent years as the gas plumbing system has improved.

The air intake contamination just mentioned, is the most serious uncertainty in our data. Measurements at the time the contaminated airline was replaced showed a contamination effect of approximately 1.5 ppmv. Subsequent careful inspection of selected air data showed a jump upwards of about 1.1 ppmv on or about the 20th of August 1975 and this has been taken as the start of the contamination although there is no other evidence for any contaminating event at this time. The data presented below have been corrected downwards by 1.1 ppmv in this period judged to be contaminated.

The air is dried cryogenically before being analysed. In June 1976 the type of freezer used was changed and the effective dew point of the air analysed was reduced from about -30 C to about -50 C. Although both analysers are sensitive to water vapour this change is believed not to have effected the data significantly as it has always been our practice to pass both calibration and sample gases through the cryogenic drier so that these are analysed at a similar dew point. This means the water vapour effect in the analyser is a constant offset in the analyser response which is removed in the calibration process.

In order to track the continually drifting calibration scale of the

analyser, a programmed sequence of calibration gases is alternated with the sampled air. We have used three calibration gases in a "minor calibration" every 24 hours to determine the analyser sensitivity (rate of change of analyser output with concentration), and one of these gases every hour to determine the drifting baseline (analyser output at a fixed concentration). The philosophy behind this was that the baseline drifted more rapidly than the sensitivity.

In fact careful retrospective analysis of the analyser output shows that the sensitivity changes more rapidly than the baseline. However as the true zero of the instrument is well off scale, a change in sensitivity does appear similar to a shift in baseline. In practice this is seen as a strong positive correlation between sensitivity and baseline. This fact has been used to infer small changes in sensitivity between minor calibrations using the hourly measurements of the single calibration gas.

Estimates of the error due to drift in the analyser calibration scale can be made by comparing the results of a minor calibration period using a best fit sensitivity, with those using a sensitivity interpolated from best fit sensitivities at the neighbouring calibration periods. Such an analysis shows that calibration drift errors are typically 0.05 ppmv and are less than 0.1 ppmv for more than 95% of the time.

3 CALIBRATION

In addition to the fixed program of minor calibrations described above, a "major calibration" involving typically 6 to 12 calibration gases is performed about once a month. The purpose of these major calibrations is threefold.

Firstly, the analyser output is not strictly linear with gas concentration and it is necessary to estimate a small quadratic curvature coefficient. For the URAS-2T the quadratic curvature correction to air concentrations, amounts to a few tenths of a ppmv, however for the URAS-1 the correction was an order of magnitude larger. We have found that the curvature coefficient normally changes significantly only when analyser components are removed and replaced, the reference gas (against which air and calibration gases are compared) is changed, or similar major changes are made.

Secondly, we use major calibrations to check the calibration gases against each other, and to detect drift in a particular gas. In general we have little problem with drifting calibration gases, and it suffices to interpolate linearly for each gas cylinder between the values assigned at SIO before and after the gas is used in New Zealand, these assignments normally being within 0.2 ppmv of one another.

However in a few cases special treatment is called for. One of the most extreme cases of drift is shown in Figure 1 for cylinder number 181 used extensively in 1983. A cluster of calibration values from SIO is shown in mid 1982 and another in late 1984 these being averaged to provide the SIO assignments. A very large drift occurs between these, and linear interpolation between the two SIO assigned values is not consistent with the calibrations done in New Zealand in 1983.

The values that would have been assigned to this gas in our major calibrations during 1983 and early 1984 are also shown in figure 1. Clearly the drift is non-linear. In fact it would appear that a small drift took place until December 1984, at which time the cylinder pressure had dropped from 2200 psi to about 500 psi. From then on the drift occurred much more rapidly, although the pressure did not drop much more. This case and two other less dramatic ones have been treated by using an intermediate concentration assignment, at about the point where the drift suddenly increases, based on our major calibrations.

Thirdly, the analyser output is different for CO₂ in air mixtures than for CO₂ in nitrogen mixtures at the same concentration. This is the "carrier gas effect", and as our normal calibration gases are CO₂ in nitrogen mixtures, a carrier gas correction (CGC) must be made for sampled air. This correction is several ppmv in magnitude. Our major calibrations since 1977, but with a gap including all of 1979, have included air mixtures and thus provide estimates of the CGC. As the URAS-1 was still operational in 1977 corrections are available for both instruments.

It is normal practice to assume that the CGC term is proportional to concentration, and we have done this for the URAS-1 and for the URAS-2T prior to October 1981. A theoretical analysis of the carrier gas effect (e.g. Griffith, 1982), gives a correction depending on the optical properties and size of the gas sample cells in the analyser.

However, for our URAS-2T analyser, the CGC drifted almost linearly in time between October 1981 and July 1982. The correction at a concentration of 340 ppmv, changed from 5.5 ppmv to 3.2 ppmv. During this period virtually all components, except the twin sample cells, were replaced in turn without reversing the change. In fact replacing the infra-red radiator actually increased the rate of drift for a short time. Furthermore swapping around the twin optical cells (one for analysed gas and one for reference gas) made no significant change either. The authors have no convincing explanation for this mysterious change in CGC, but fortunately we were able to track it in detail by performing major calibrations to estimate the correction about every two weeks during the critical period.

Individual estimates of the CGC are shown in Figure 2, and a piecewise linear approximation to these points has been used in calculating the air data given here.

A further problem that arises in estimating the carrier gas correction is the apparent lack of consistency in air calibration gases available to us from various sources. Figure 3 shows a summary of the deviations of individual air gases from the constant CGC mentioned above, taken from all our major calibrations in the three years 1982 to 1984. The spread in these values about a best fit straight line is disturbingly high, and appears to be related to the source of the gas cylinder (see figure caption for details):

This leads us to infer that the behaviour of our analyser with respect to the various constituents of the carrier gas, which presumably vary from one gas supplier to another, is appreciably different to that of the SIO analyser on which the WMO scale is based. We have used an equal weighting of all air gases analysed in estimating the CGC, whereas if we were for example to use just the gases from the National Bureau of Standards alone, our air values would shift downward by 0.2 ppmv. In our view this lack of consistency in air calibration gases is a major source of error, both for the precision of a single station such as ours that uses gases from various sources, and more particularly for the monitoring network as a whole.

4 STEADY INTERVAL SELECTION

The aim of the New Zealand monitoring program is to make "baseline" measurements representative of oceanic air to the south of New Zealand. To this end we use as a primary selection criterion, steadiness in measured concentration over a number of hours. Steadiness over several hours indicates the lack of a daily cycle and therefore that the air mass has been isolated from the terrestrial biosphere for a period that is long relative to dispersive mixing times.

Prior to March 1978 data analysis was performed manually and the criterion applied to select steady periods was that the maximum and minimum values of half-hour average values be within 0.1 ppmv for the whole period. Since March 1978 data analysis has been performed by computer programs and the criterion used is that the standard deviation of minute by minute values of concentrations be less than 0.1 ppmv in any 6 hour subperiod. The latter criterion appears to be more stringent.

It is observed that strong northerly winds can produce steady intervals as defined above. Because of this we select periods of southerly winds only. In 1976 a wind vane was installed at Baring Head and this is used to monitor

local wind direction. Prior to this time, wind records from Wellington airport (about 10 km away) were used.

Even with both these selection criteria applied, data can be included from wind trajectories that have passed across the South Island of New Zealand. This is revealed by wind trajectory analyses performed for us by Dr N. Gordon of the NZ Meteorological Service. For example figure 4 shows a "good" trajectory, and figure 5 shows a "bad" one for a similar time of year. These events cannot be discriminated clearly on the basis of steadiness or local wind direction, and so a further selection criterion has been sought.

Several wind trajectories that have been calculated for Baring Head confirm the observation that when regional air flows are from the south or southeast, surface air pressures are greater in Christchurch on the east side of the South Island than in Hokitika on the west. When the air flow is from the southwest this regional pressure index changes sign. This is an orographic effect due to the Southern Alps, a large mountain range running down the length of the South Island. Hourly pressure records are available from the two sites mentioned for the entire period covered by our data and it has been relatively easy to use these to obtain the east-west pressure index across the South Island for steady intervals selected according to the first two criteria mentioned above. The third criterion then imposed is that the pressure at Christchurch must be at least 1 mBar higher than that in Hokitika throughout the steady period.

It should be noted that the "bad" trajectory shown in figure 5 is for a period during the 1982/3 El Nino Southern Oscillation (ENSO) anomaly, and that during 1983 New Zealand experienced a much more pronounced westerly air flow than normal. Selection on the basis of the South Island pressure index given above causes a larger systematic effect on the data in 1983 than in other years, reducing the monthly mean values for some winter months by as much as 0.3 ppmv. It would therefore appear then that this type of selection is important in ensuring consistent sampling.

5 SUMMARY OF THE DATA

The data for all selected southerly steady air periods, as described above, are tabulated in Appendix I, and shown in Figure 6a. They clearly show a consistent secular trend and annual cycle in atmospheric CO₂ concentration.

The data that have been corrected to compensate for air intake contamination are indicated on the figure, however there are no other significant breaks in the data. In particular the change over from the URAS-1 to the URAS-2T analyser is smooth and this results directly from independent calibrations

including separate CGC terms for both instruments. No adjustments have been made on the basis of continuity of the air data.

To summarize the various sources of error mentioned above, we estimate error terms of 0.05 ppmv due to drift in analyser calibration; 0.10 due to actual variability in air concentrations throughout the selected steady period; 0.10 due to uncertainty in the nitrogen calibration gases; and 0.20 due to uncertainty in the air calibration gases (CGC term). This leads to a total precision of about 0.3 ppmv. However prior to 1980 the carrier gas correction is less well established, so for this earlier period we believe a precision of 0.5 ppmv is more realistic.

The results of analyses carried at SIO on flask samples from Baring Head, are given in Appendix II. Unfortunately there has not always been good agreement among duplicate and triplicate flasks taken at Baring Head, particularly during earlier years, and there is some resulting lack of confidence in the flask data. Furthermore many of the better flask samples are not coincident with a steady interval in the analyser data. If comparison is restricted to sets of flasks that agree to better than 0.2 ppmv, and are strictly coincident with analyser steady intervals, then the means and standard deviations of the analyser minus flask differences over recent years is as follows:

	Mean	Standard-deviation	Number
1977	0.00	0.65	4
1978	-0.17	0.17	4
1979	-1.15	0.28	3
1980	+0.06	0.20	5
1981	-0.15	0.24	6
1982	+0.39	0.21	5
1983	+0.22	0.26	6
1984	+0.14	0.11	7

6 TRENDS IN THE DATA RECORD

In order to show the secular trend in the New Zealand data, and minor variations in the rate of increase of CO₂ concentration, figure 7 gives monthly mean data with the annual cycle removed. For this purpose the annual cycle was treated as a sinusoid with a period of 12 months, but other ways of determining the annual cycle do not produce significantly different results. The annual cycle has an amplitude of 0.92 ppmv peak-to-peak and the secular trend averages 1.33 ppmv per annum over the period shown.

It appears that the rate of increase in concentration dropped appreciably during the 1982/3 ENSO event, and this was followed by an increase in the rate similar to the "bounce back" pattern described by Gammon et al (1984). It can be seen from figure 7 that the decycled data deviate from a constant increase during the January 1982 to December 1984 period. This difference reaches a peak of 0.6 (+/- 0.2) ppmv in January 1983.

Space does not permit a detailed comparison with other southern hemisphere data on CO₂ concentrations, however a few simple comparisons should be made. We will refer to data from Cape Grim, Tasmania, (Beardsmore et al 1984) as CGO; to the Australian aircraft data (Pearman and Beardsmore, 1984), as AUS; to the recent data from Amsterdam Island (Ascencio-Parvy et al, 1984) as AMS; and to the data presented here as BHD. Taking the differences in monthly mean values between these data sets and those from the SIO South Pole program (Keeling et al, private communication) referred to as SPO, for as many months as are available gives the following comparisons:

AUS - SPO	AMS - SPO	BHD - SPO	CGO - SPO
1972 - 81	1981 - 83	1973 - 83	1976 - 82
0.54 ppmv	0.47 ppmv	0.37 ppmv	-0.56 ppmv

Clearly the Cape Grim data differ significantly from other measurements at similar latitudes, being about 1 ppmv lower. Otherwise it would appear that the CO₂ concentration at 40 to 50 degrees south is higher than at the South Pole by about 0.4 ppmv.

7 FUTURE DEVELOPMENTS

As a result of our experience over the last few years, we believe that instrumental precision in atmospheric carbon dioxide measurements can be controlled at levels below 0.1 ppmv. At Baring Head we have recently installed a microprocessor which dynamically controls the use of up to 12 calibration gases according to air steadiness and other factors. During southerly winds an air sample can be alternated with calibration gases close in concentration and a data precision equal to the pooled precision of the set of calibration gases used, can be achieved without difficulty.

The limit to station precision and more particularly to network precision is at present set by the precision (0.20 ppmv) of the secondary standard gases supplied by the WMO central calibrating laboratory. We believe there are also unresolved questions over the consistency of CO₂-in-air gases and that this may be worse than 0.20 ppmv, as discussed above, although the gas

mixtures used in the New Zealand program may not be typical in this regard.

At present improving the precision of NDIR measurements reveals noise in the calibration gas system rather than improving the precision of atmospheric CO₂ concentration data. In order to improve this situation it is essential to improve the quality of the calibration standards.

REFERENCES

- Ascencio-Parvy, J.M., A.Gaudry, and G.Lambert (1984). Year to Year CO₂ variations at Amsterdam Island in 1980-83. Geophysical Research Letters, 11: 1215-1217.
- Beardsmore, D.J., et al (1984). Division of Atmospheric Research, CSIRO, Technical paper no 6, (Appendices 2b and 3b).
- Gammon, R.H., W.D.Komhyr, L.S.Waterman, T.Conway and K.Thoning. Estimating the natural variation in atmospheric CO₂ since 1860 from interannual changes in tropospheric temperature and the history of major El Nino events. Abstr: Chapman Conference on Natural Variations in Carbon Dioxide and the Carbon Cycle, Tarpon Springs, Florida 1984.
- Griffith, D.W., C.D.Keeling, J.A.Adams, P.R.Guenther and R.B.Bacastow (1982). Calculations of carrier gas effects in non-dispersive infrared analyzers. I and II. Tellus 34: 376 - 397.
- Lowe, D.C. (1974). Atmospheric Carbon Dioxide in the Southern Hemisphere. Clean Air. 8: 12-15.
- Lowe, D.C., C.D.Keeling, and P.R.Guenther (1978a). Baring Head New Zealand Carbon Dioxide Project Data Report 1972 - 1975. INS-R-245. Institute of Nuclear Sciences, New Zealand.
- Lowe, D.C., C.D.Keeling, and P.R.Guenther (1978b). Baring Head New Zealand Carbon Dioxide Project Data Report 1976 - 1978. INS-R-250. Institute of Nuclear Sciences, New Zealand.
- Lowe, D.C., P.R.Guenther and C.D.Keeling (1979). The Concentration of Atmospheric Carbon Dioxide at Baring Head, New Zealand. Tellus. 31: 58-67.
- Pearman, G.I., and D.J.Beardsmore (1984). Atmospheric carbon dioxide measurements in the Australian region: ten years of aircraft data. Tellus 36B: 1 - 24.

FIGURE CAPTIONS

Figure 1. Drift in concentration for cylinder no 181 during 1982, 1983 and 1984. Circles denote concentrations measured at SIO and stars denote ones measured in New Zealand. The solid line shows the piecewise linear approximation used in calculating final values for air concentrations.

Figure 2. Measurements of the URAS 2T carrier gas correction term as it would affect a gas with a CO₂-in-air concentration of 340 ppmv. Stars denote individual measurements from calibration runs, and the solid line the piecewise linear approximation used to obtain final values for air concentrations.

Figure 3. Deviations in apparent concentrations of individual CO₂-in-air mixtures from the mean carrier gas correction inferred for a CO₂-in-air concentration of 340 ppmv. Each symbol denotes the mean value for a gas mixture and the vertical bar the standard deviation of individual measurements for that mixture. Circles denote gas mixtures obtained from Airco Industrial Gases, squares denote mixtures obtained from NBS, and triangles denote mixtures obtained from SIO. The solid line is the regression line fitting deviation as a function of concentration for all of the data.

Figure 4. Isobars and wind trajectory for air arriving at Baring Head during favourable baseline conditions. The thick lines show two overlapping wind trajectories at the 1000 mBar and 900 mBar levels for the 72 hours prior to arrival at Baring Head at 12 pm New Zealand Standard Time on the 7th of February 1984. The isobars are shown for a time 24 hours prior to the wind arrival at Baring Head. This wind trajectory and isobaric plot is taken from plots supplied courtesy of Dr N Gordon, New Zealand Meteorological Service, Wellington, New Zealand.

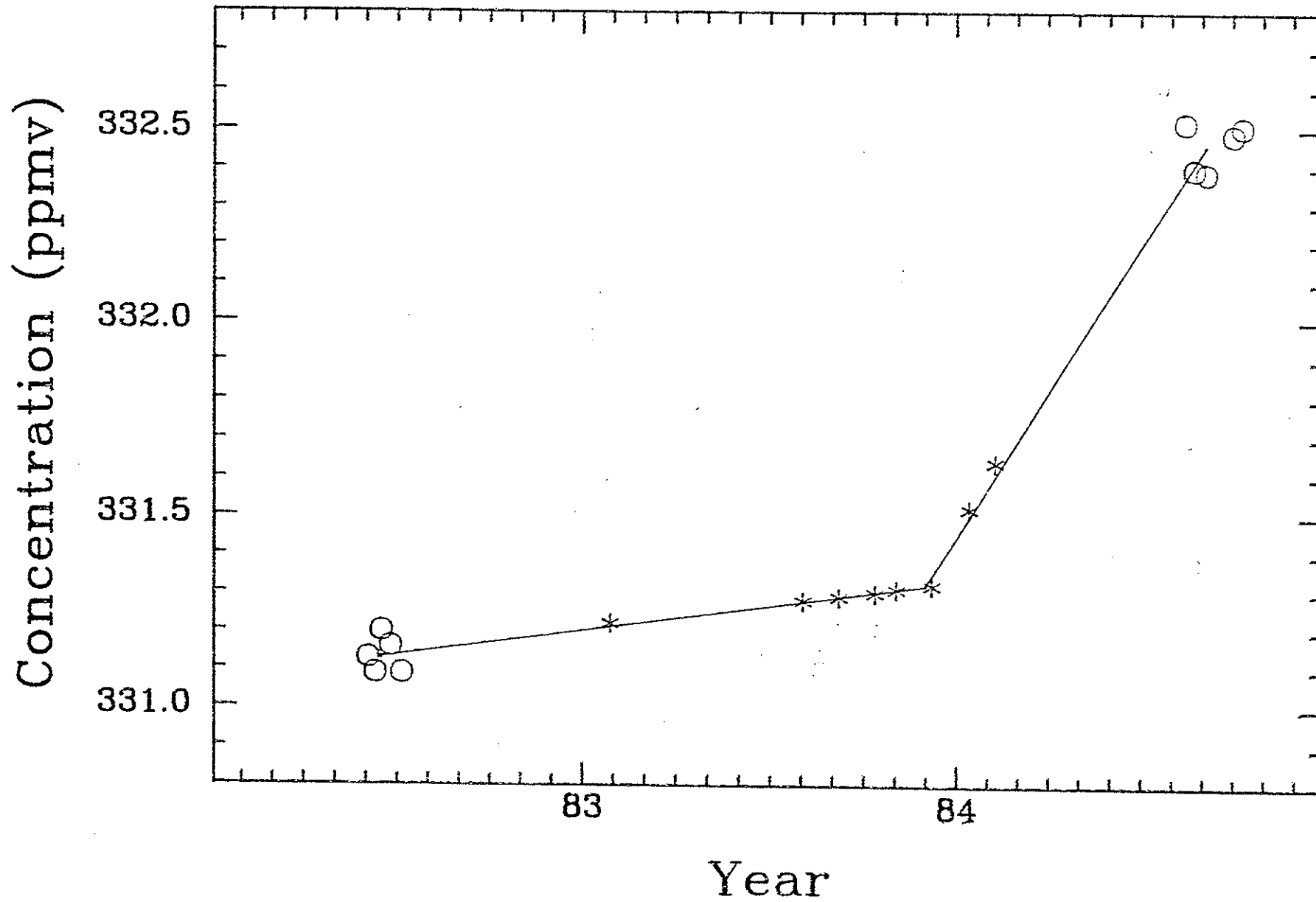
Figure 5. As for Figure 4, but for regional air flow conditions unfavourable for baseline measurements. In this case the arrival time at Baring Head is 12 pm New Zealand Standard Time on the 10th of February 1983.

Figure 6a. Atmospheric CO₂ concentrations measured by the URAS-1 and URAS-2T analysers at Baring Head and Makara for selected baseline periods. Stars denote monthly means of selected data from the early period at Makara, and crosses denote individual selected baseline periods at Baring Head. Data from the 20th of August 1975 to the 30th of November 1976 have been corrected downwards by 1.1 ppmv due to airline contamination (see text). These data are denoted by circles.

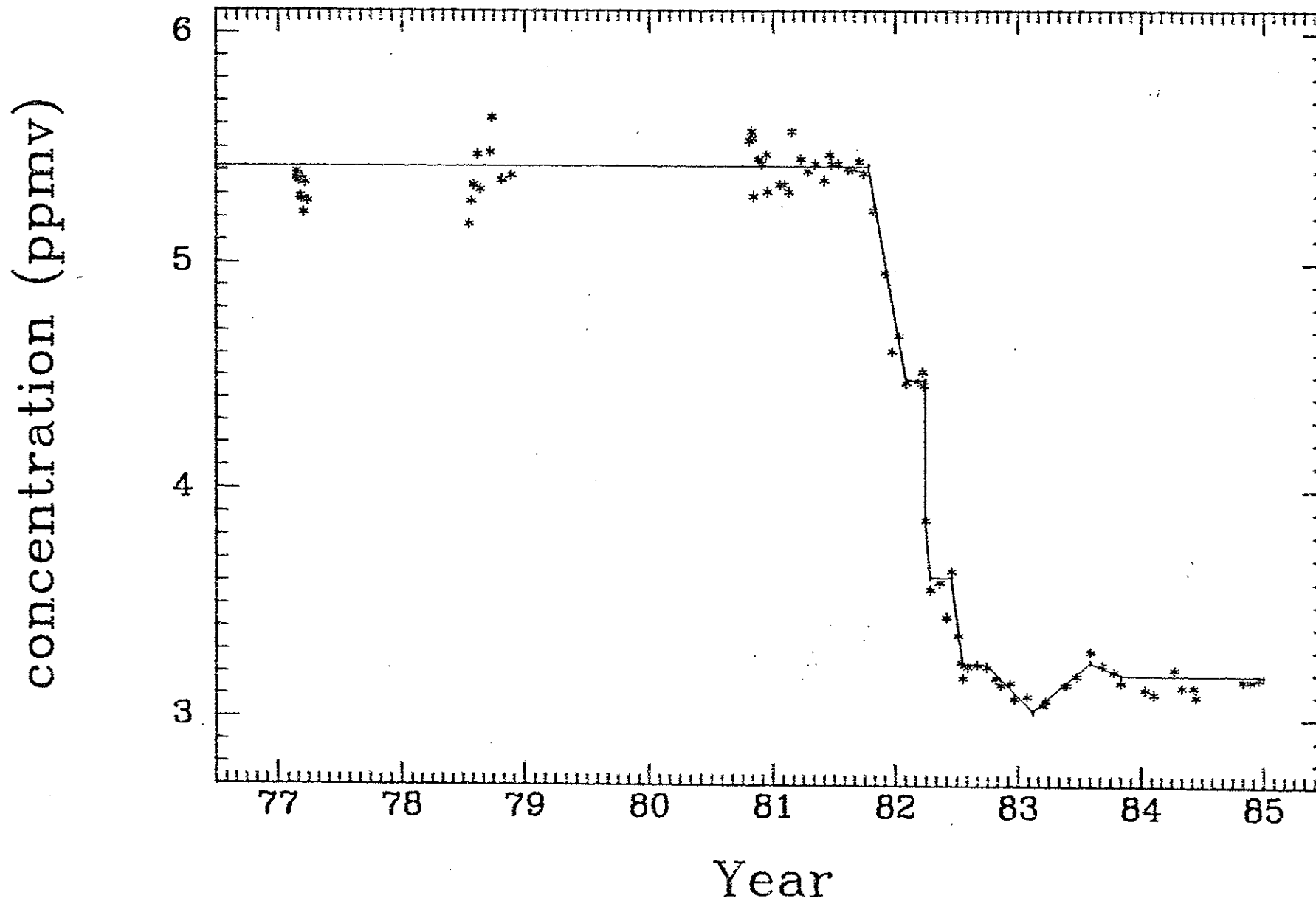
Figure 6b. Atmospheric CO₂ concentrations measured by the flask sampling program at Baring Head. These measurements were made at SIO on pairs of 2 litre flasks filled at Baring Head under southerly wind conditions. Obvious outlying values have been removed, but otherwise both flasks of a pair are shown.

Figure 7. Monthly mean atmospheric CO₂ concentrations measured at Baring Head and Makara after removal of a fixed annual cycle. The annual cycle was determined by fitting a linear term and a sinusoid with a period of 12 months to monthly means derived from the data shown in figure 6a. The resulting sinusoidal term was subtracted from the original data to produce the values shown here. Other ways of determining the annual cycle produce results that are not significantly different. The vertical bars show our estimated total error (standard deviation) between these measurements and the true air concentration on the 1985 WMO calibration scale.

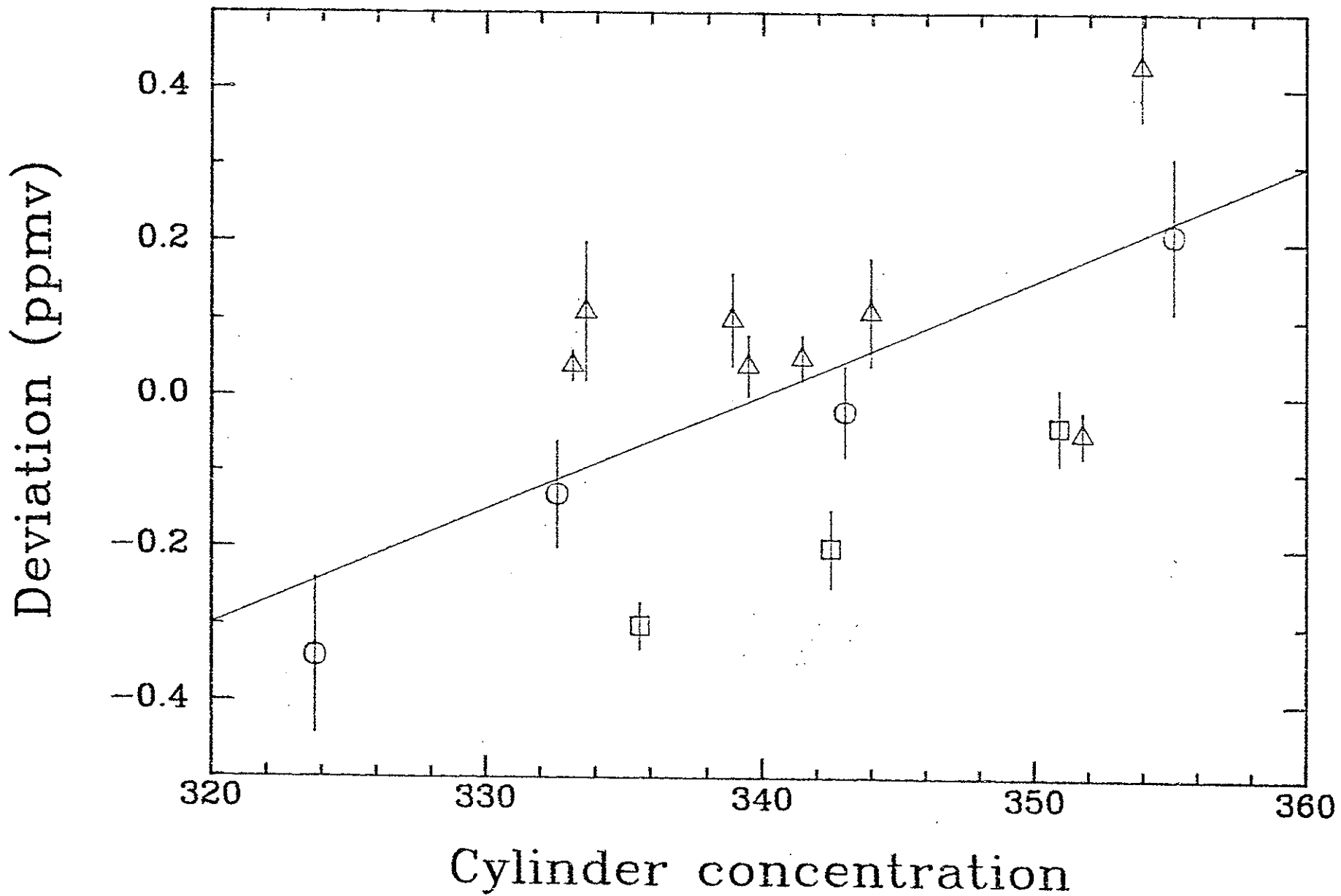
Cylinder 181 calibration history

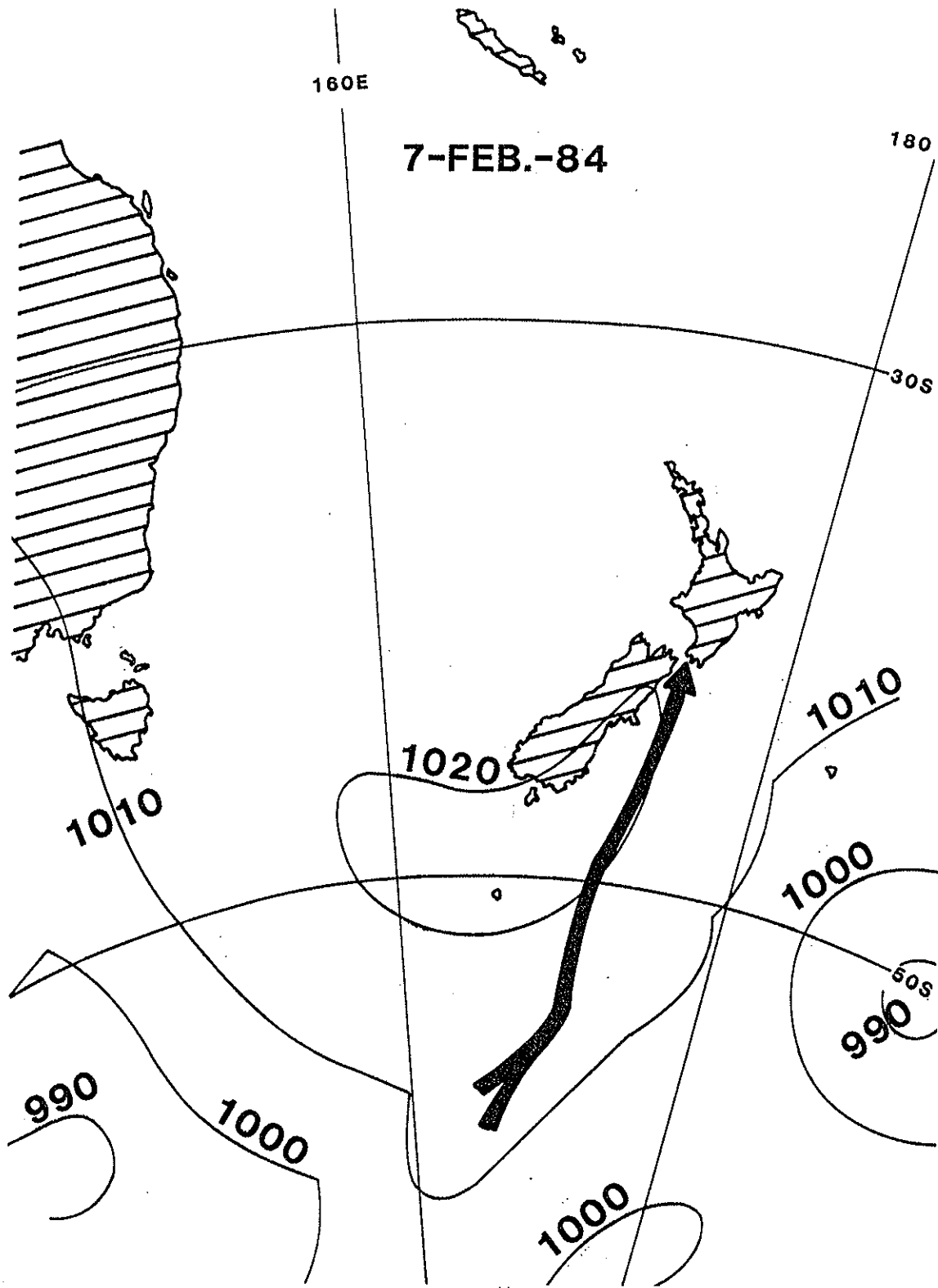


URAS-2T CGC at 340 ppmv

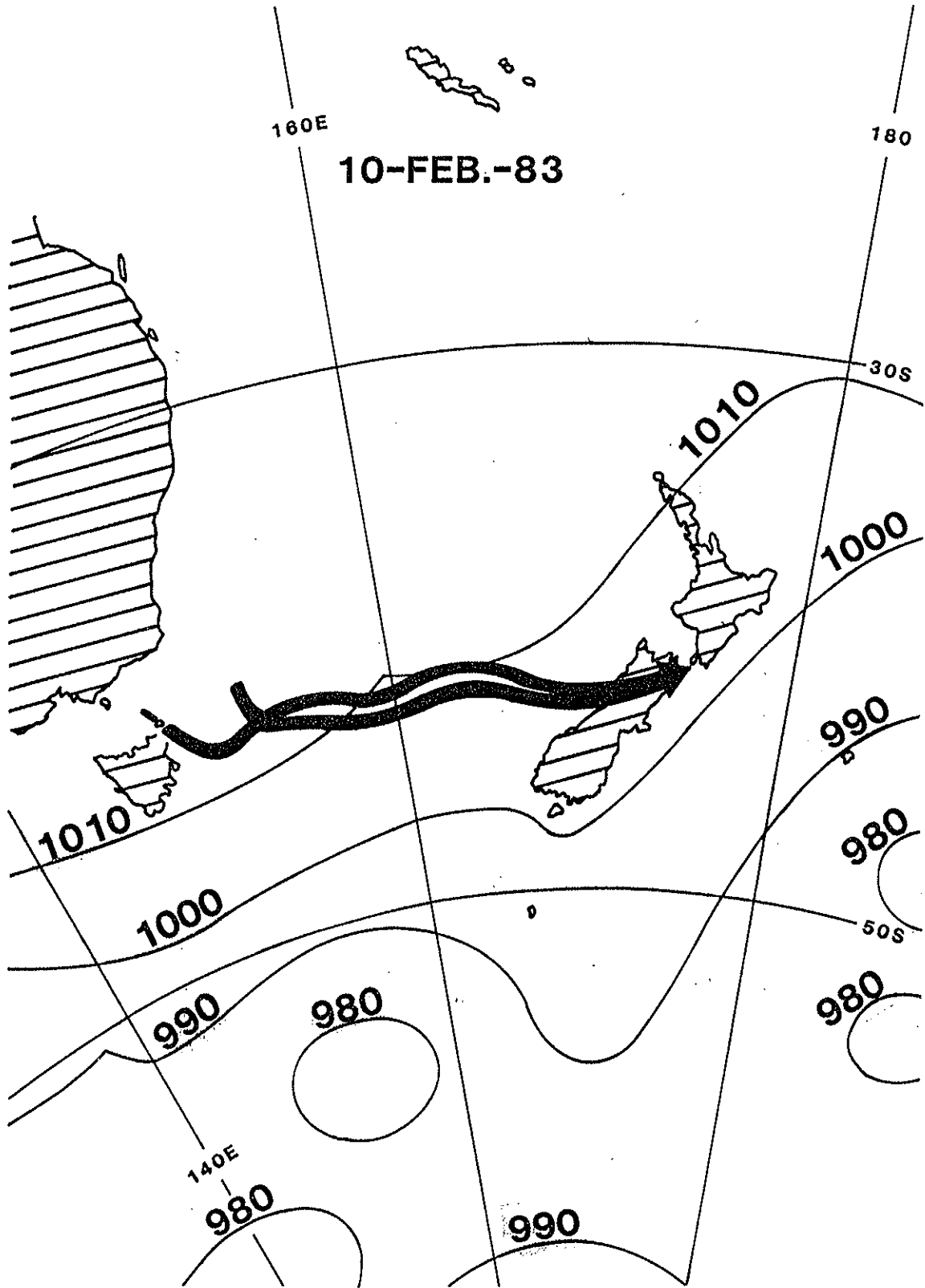


CGC deviations for individual cylinders

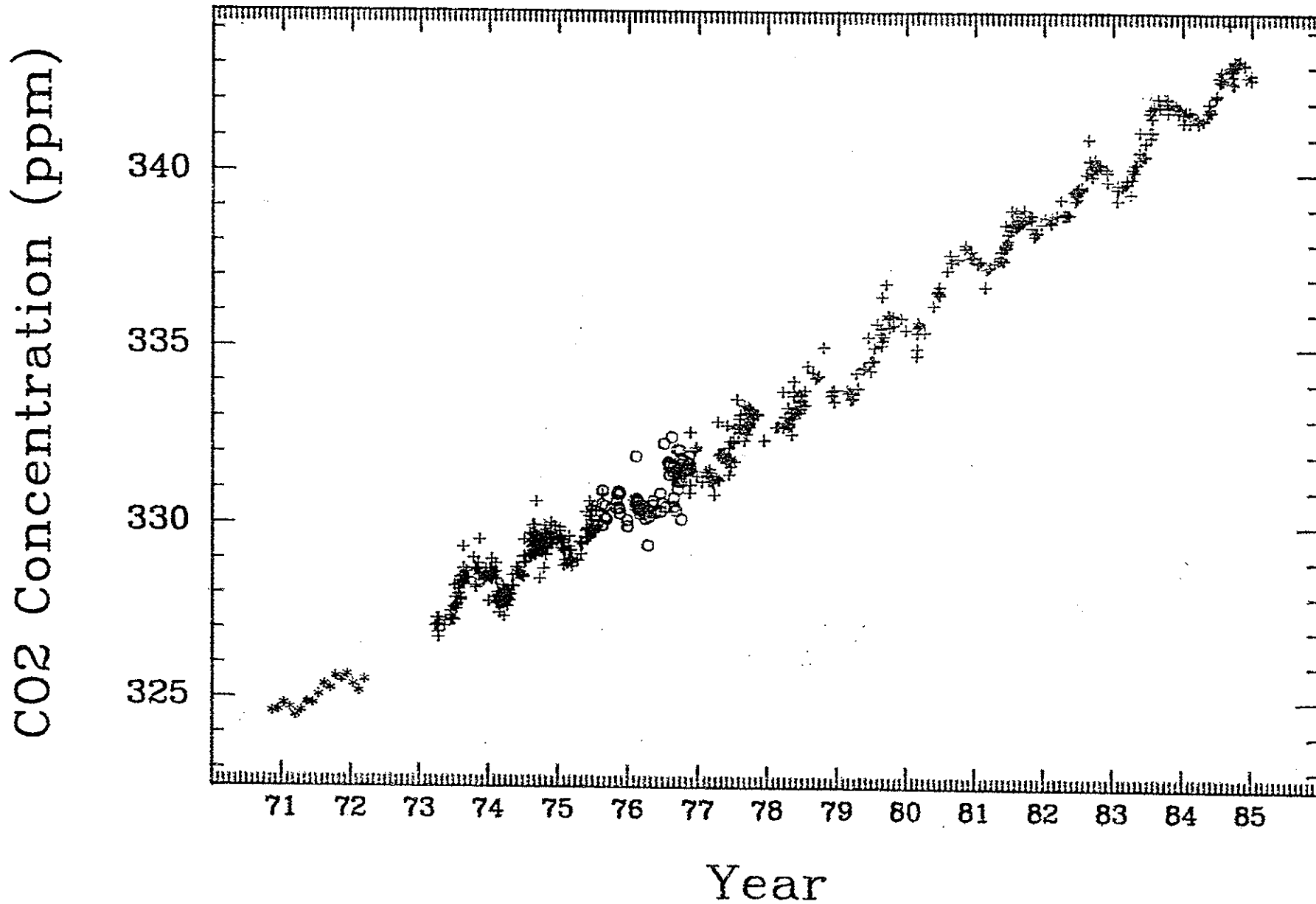




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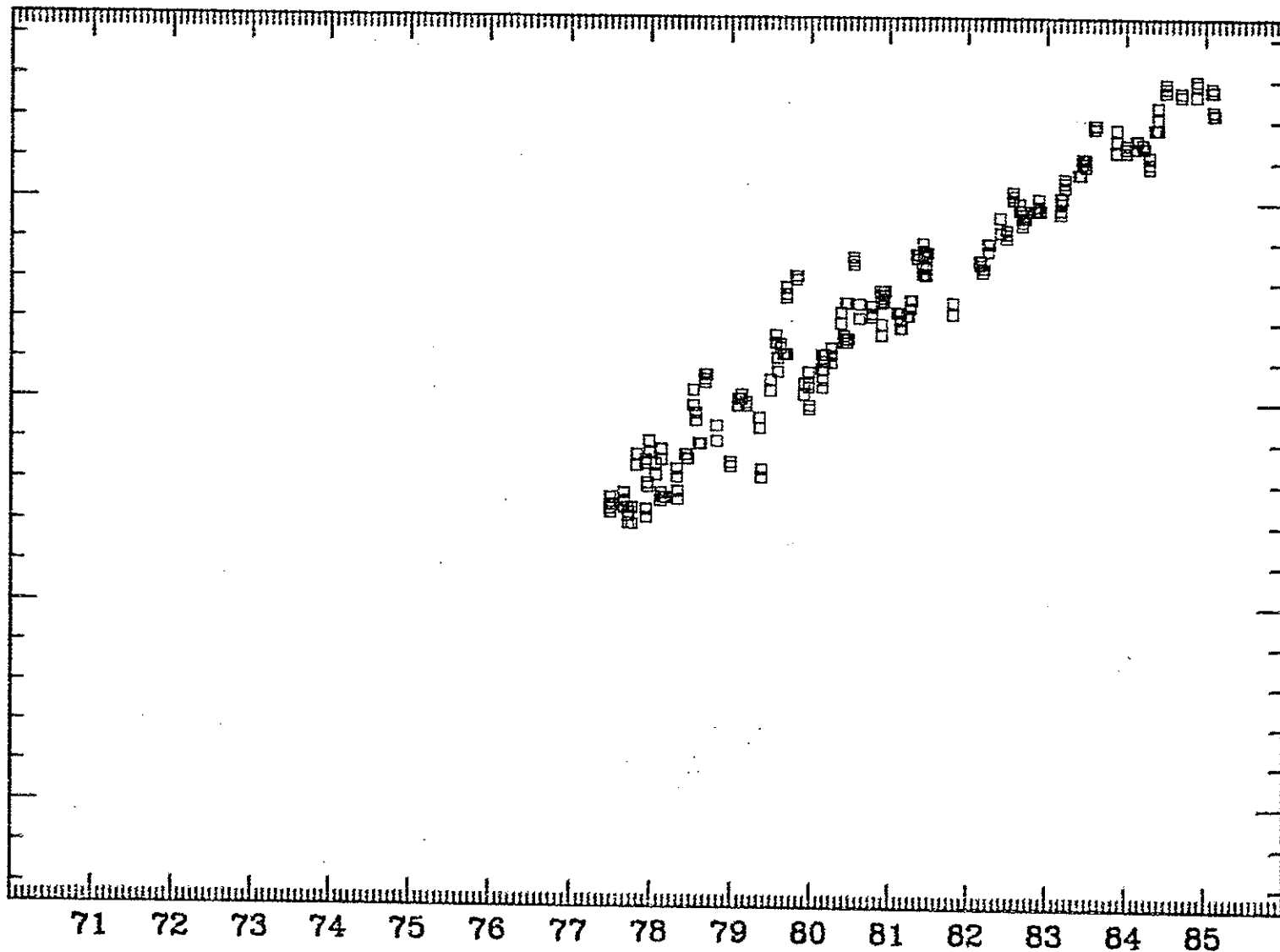


Baring Head Southerly Winds



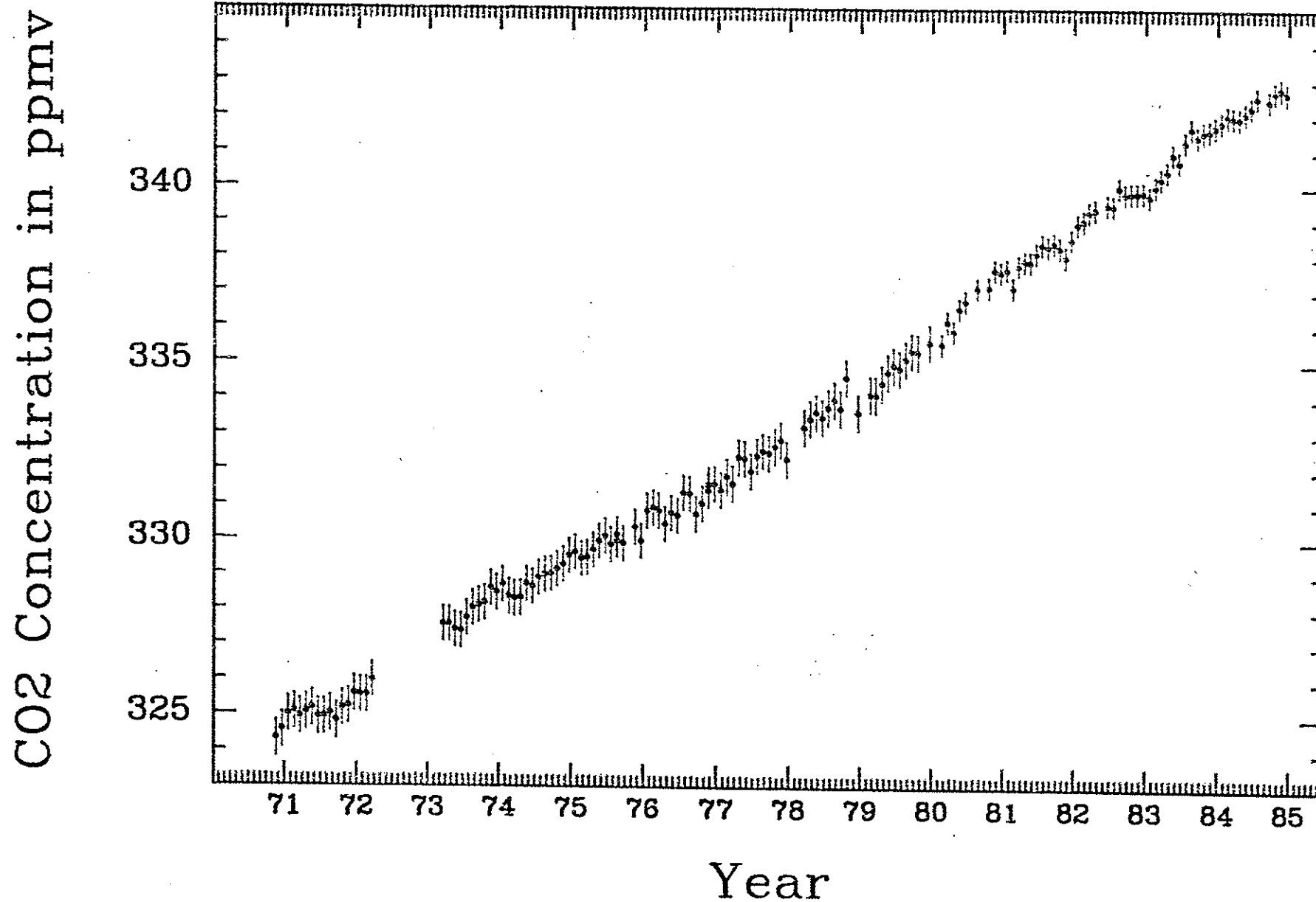
CO2 Concentration (ppm)

340
335
330
325



Year

BHD Decycled monthly mean values



Appendix I

Carbon Dioxide Concentrations of
Selected Steady Intervals from
the NDIR Continuous Analyser at
Baring Head, New Zealand

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1970

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in August 1985

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1													1
2													2
3													3
4													4
5													5
6												24.81	6
7													7
8												25.19	8
9													9
10													10
11												24.64	11
12													12
13													13
14												24.58	14
15												24.30	15
16													16
17												24.26	17
18													18
19												24.45	19
20													20
21													21
22												24.74	22
23													23
24												24.40	24
25											24.58		25
26													26
27											24.81		27
28													28
29												24.75	29
30											24.37		30
31												24.84	31

Monthly values

X										24.59	24.63	X
N										4	14	N
s										0.22	0.27	s

Annual mean 324.61 ppmv
(based on 2 monthly means)

X = average monthly concentration

N = number of Flasks selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1971

CORRECTED CO2 concentration values (in ppmv above 300.0)
Prepared in August 1985

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1	24.98			24.97				25.41				25.93	1
2			24.26					24.99		25.62		26.35	2
3		24.88		24.29					25.18		25.63	25.66	3
4							24.72	25.17		24.85		25.33	4
5	25.22					24.26	24.88			25.52		26.18	5
6	24.76		25.17		24.50		25.22			25.89			6
7			24.83		25.58		25.81				25.53		7
8		24.71								25.84			8
9	24.85									25.85			9
10	24.90	24.51			24.88					25.87		25.40	10
11	24.61								25.60			25.62	11
12		24.36				24.38	24.70			25.46	25.36		12
13		24.86			24.85		24.43	25.26				25.94	13
14		24.30		24.56		24.65							14
15			24.70			24.83	25.00	25.50			25.89		15
16						24.85			25.18	25.29			16
17		24.93	24.14			25.10	24.68			25.62	25.19	24.80	17
18				24.90									18
19		24.76						24.83		25.41			19
20					24.56					25.85	25.11		20
21		24.45	24.25			25.23			25.02				21
22		24.93		24.50						25.70	25.69	25.35	22
23			24.34			24.99	24.88					26.36	23
24		24.65					25.61	25.87					24
25		24.99			24.65	24.88	24.97		25.32				25
26	24.41			24.43				25.84				25.02	26
27		24.78	24.36				25.52						27
28			24.20		24.94	25.13			25.17			25.54	28
29							25.57	25.41			25.65		29
30							25.00						30
31					24.84								31

Monthly values

X	24.82	24.70	24.47	24.61	24.85	24.83	25.07	25.36	25.25	25.60	25.51	25.65	X
N	9	13	9	7	8	13	15	9	9	16	13	17	N
s	0.26	0.23	0.35	0.27	0.34	0.32	0.41	0.35	0.20	0.30	0.27	0.49	s

Annual mean 325.06 ppmv
(based on 12 monthly means)

X = average monthly concentration

N = number of Flasks selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1972

CORRECTED CO₂ concentration values (in ppmv above 300.0)

Prepared in ~~December 1972~~

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1	25.17	25.66	25.45										1
2													2
3	25.18	25.26	25.57										3
4		25.54											4
5		25.05											5
6	25.39	24.78											6
7		25.30											7
8	25.35	24.44											8
9													9
10		24.79											10
11	25.79												11
12	25.47	25.26											12
13		25.61											13
14		25.05											14
15													15
16		25.37											16
17													17
18													18
19	25.65	25.03											19
20		24.94										25.63	20
21												26.08	21
22												26.40	22
23	24.91												23
24	25.77	25.38											24
25	25.94												25
26	25.42												26
27	25.67	25.22										25.64	27
28	24.25	25.36											28
29													29
30													30
31													31

Monthly values

X	25.38	25.18	25.51									25.94	X
N	18	26	2									31	N
s	0.45	0.32										0.37	s

Annual mean 325.50 ppmv
(based on 4 monthly means)

X = average monthly concentration
N = number of Hours selected
s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1973

CORRECTED CO₂ concentration values (in ppmv above 300.0)

Prepared in ~~October 1985~~

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1				27.47			27.56	28.02					1
2				27.15			27.78		28.46				2
3				27.03									3
4				27.13									4
5		27.67		27.13									5
6	26.37	27.67	26.60	27.13			28.23	28.39				28.37	6
7			26.60				27.64	28.22	28.64				7
8		25.88						28.00	28.64				8
9	26.40		26.52	26.88				27.80			28.86	28.49	9
10			26.54				27.84				28.86		10
11		26.39		26.73			27.77					28.36	11
12	26.54	26.07	26.85				27.99					28.77	12
13	25.79	25.88	26.80	27.41	27.02	27.34	27.53						13
14		26.05		27.23	27.13	27.33	27.51				28.41		14
15					27.19	27.17	27.63				28.74		15
16	26.29					27.26		28.43	28.44		29.55		16
17	26.11	26.72	26.64			27.33		28.54		29.03			17
18		26.20						28.58				28.72	18
19								28.35				28.59	19
20												28.52	20
21		27.38	27.13					29.01				28.51	21
22		26.80						28.74					22
23		26.51						28.52		28.73			23
24			27.44					28.26		28.69			24
25			27.34				28.25			28.36			25
26			27.12				28.04						26
27			26.91				27.99			28.17			27
28							28.03						28
29							28.23						29
30							28.15						30
31							28.02						31

Monthly values

X	26.25	26.60	26.87	27.13	27.11	27.29	27.89	28.37	28.55	28.60	28.88	28.54	X
N	53	146	138	146	35	76	298	207	35	51	39	108	N
s	0.27	0.66	0.32	0.22	0.08	0.07	0.26	0.33	0.11	0.34	0.42	0.15	s

Annual mean 327.67 ppmv
(based on 12 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1974

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in August 1985

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1			27.44								29.66		1
2			27.44			28.75					29.76		2
3			27.88		28.13	28.54	29.06		29.61		29.55		3
4	27.77				28.26	28.61	29.09		29.43		29.28		4
5							28.86		29.28		29.30		5
6				27.92			28.87		29.28				6
7			27.69	27.96			28.92	29.25					7
8					28.54		28.91	29.10					8
9	28.72							29.73	29.57	29.19			9
10	28.45	28.87		27.63			29.55	29.15	30.63	29.66		29.56	10
11		28.16		27.86				29.16	29.61			29.46	11
12	28.71					28.46		29.10	29.71				12
13	28.63				28.21	28.56		29.06	29.60	29.57			13
14						28.56		29.08	29.58			29.94	14
15		27.71	28.34					29.11				29.74	15
16	28.31	27.88	28.21			28.56						29.51	16
17	28.51	27.89	28.07			28.49							17
18		27.91	28.04			28.62		29.47		28.73			18
19	28.41					28.36		29.52	29.06				19
20	28.99					28.53		29.05	29.25				20
21		28.03	28.14	27.80						30.73	29.65		21
22			27.70	27.81				29.34		29.90	29.51		22
23			27.81	27.75				29.58		29.34	29.42	29.52	23
24	28.54		27.34	27.79				29.68				29.52	24
25	28.65							29.41		29.36			25
26		27.72	27.76	28.20				29.59			30.03		26
27		27.72		28.02				29.38	28.43				27
28				27.84				29.61	29.45	29.83			28
29				27.94	28.56			29.24	29.53	29.11			29
30					28.76			29.24	29.39	29.66			30
31	28.63									29.73			31

Monthly values

X	28.53	27.99	27.84	27.88	28.41	28.55	29.04	29.33	29.46	29.57	29.57	29.61	X
N	130	112	124	217	46	180	146	264	197	116	93	44	N
s	0.30	0.36	0.32	0.15	0.25	0.10	0.24	0.22	0.44	0.50	0.24	0.17	s

Annual mean 328.81 ppmv
(based on 12 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1975

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in ~~August 1986~~

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1		29.23	29.21		29.27	29.94							1
2								30.06			30.52		2
3							30.05	30.06			30.43		3
4							29.88		30.17		30.65		4
5		28.98							30.37		30.65		5
6		28.98	29.02						30.70				6
7					29.42	29.84							7
8						29.84					30.83		8
9	29.79		29.25								30.83		9
10	29.74					29.64							10
11	29.70		28.79										11
12	29.90		28.90						30.13				12
13													13
14				28.96		30.64					30.91		14
15						30.20							15
16						30.32							16
17	29.54	28.84					30.36				30.44		17
18	29.31	28.92											18
19	29.31										30.84		19
20	29.29							29.75			30.84		20
21	29.29						29.97	30.41			30.28		21
22						29.86	29.82	30.31					22
23						29.71	29.95	30.78					23
24						30.11							24
25		28.95		29.49		30.30							25
26		29.41		29.49	29.64	29.91							26
27		29.56			29.60	29.70							27
28		28.98			29.82	29.80							28
29	29.53				30.03	30.49						30.10	29
30	29.25			29.09								30.10	30
31	28.97				29.80							29.92	31

Monthly values

X	29.47	29.09	29.03	29.26	29.65	30.02	30.01	30.23	30.34		30.66	30.04	X
N	96	108	60	26	59	154	81	56	59		108	50	N
s	0.27	0.25	0.20	0.27	0.26	0.31	0.19	0.35	0.26		0.21	0.10	s

Annual mean 329.80 ppmv
(based on 11 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1976

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in August ~~1986~~

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1		30.67		30.15									1
2			30.28	30.15						31.85			2
3			30.28							31.71			3
4										31.51			4
5			30.51					31.61		30.14			5
6								31.41					6
7		30.50						31.58	30.27				7
8		30.50					32.27		30.42				8
9		30.50	30.40										9
10			30.40		30.53								10
11					30.53								11
12		30.43			30.65					31.52	31.74		12
13		30.98			30.65						31.56		13
14		30.55		30.39						31.50	31.56		14
15		30.45							31.55	31.81	31.72	32.08	15
16		30.89		29.40			30.48	32.45	31.41		31.92		16
17		30.40		29.40				32.45	30.99				17
18						30.86						31.35	18
19									31.56	31.53	31.59		19
20				30.25		30.36			32.08		32.61		20
21				30.19	30.32							32.17	21
22				30.19	30.32				30.95			31.52	22
23					30.32				31.30	31.60		31.33	23
24						30.61						31.24	24
25						30.61							25
26		30.49								31.55			26
27		30.45	30.51					31.06	31.34				27
28								31.15	31.20				28
29													29
30													30
31	30.67		30.30				31.74						31

Monthly values

X	30.67	30.57	30.38	30.02	30.47	30.61	31.50	31.67	31.19	31.47	31.76	31.67	X
N	4	159	82	96	56	33	38	80	127	132	129	64	N
s		0.19	0.10	0.39	0.15	0.20	0.92	0.57	0.52	0.49	0.38	0.43	s

Annual mean 331.00 ppmv
(based on 12 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1977

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in August 1985

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1								32.82		33.25	33.13		1
2			31.26					32.86			33.13		2
3					31.68		32.34	33.00			33.10		3
4			31.21		32.00		32.30	32.87	32.67		33.10		4
5				31.32	31.84	31.69		32.59	32.68				5
6					31.90	31.97			32.70				6
7		31.50			32.12	31.59			32.70				7
8		31.50			31.79	31.91	31.77		33.00				8
9					32.02	31.89			32.79				9
10								33.10	32.74				10
11		31.28		32.89			32.71		32.55	33.08			11
12		31.65		32.89						33.08			12
13										32.98			13
14										32.98		32.37	14
15									33.20				15
16				31.40					33.07				16
17				31.29		32.35			33.23				17
18				31.29	31.88	31.83			33.02				18
19			31.26	31.96	31.88	31.70			32.85				19
20	31.11		31.16	32.21	31.87				32.81				20
21	31.18								33.28				21
22	31.50	31.37					33.53		33.44				22
23		31.37											23
24		31.48	30.84										24
25		31.38											25
26					31.74				32.75				26
27					31.78				32.75				27
28							32.54						28
29							32.58	32.37					29
30					32.79			33.35	33.12				30
31					32.79								31

Monthly values

X	31.26	31.44	31.15	31.91	32.01	31.87	32.54	32.87	32.91	33.07	33.12	32.37	X
N	45	79	42	99	160	125	94	99	267	34	35	14	N
s	0.21	0.11	0.18	0.70	0.35	0.23	0.53	0.30	0.25	0.11	0.01		s

Annual mean 332.21 ppmv
(based on 12 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1978

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in ~~December 1999~~

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1													1
2				32.86								33.64	2
3				33.04								33.66	3
4				33.04	33.18							33.77	4
5												33.77	5
6													6
7					33.01								7
8					32.54								8
9													9
10													10
11									34.14				11
12									34.14				12
13													13
14						33.61	33.41					33.80	14
15				32.84		33.36	33.78					33.47	15
16		32.75				33.36							16
17				33.30	33.74								17
18				33.30	33.39	33.16							18
19					34.05	33.30							19
20					33.63	33.46							20
21					33.19	33.49				35.01			21
22				32.77	33.21								22
23				32.84	33.21	33.27							23
24			33.29			33.27							24
25									34.20				25
26		32.77							34.20				26
27		32.77				33.65							27
28								34.30					28
29								34.30					29
30													30
31							34.48						31

Monthly values

X	32.76	33.29	33.00	33.31	33.39	33.89	34.30	34.17	35.01		33.68	X
N	20	16	65	143	135	31	13	35	6		72	N
s	0.02		0.21	0.42	0.16	0.54		0.04			0.12	s

Annual mean 333.68 ppmv
(based on 10 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1979

CORRECTED CO₂ concentration values (in ppmv above 300.0)

Prepared in August 1985

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1													1
2									35.33	35.90			2
3									35.33	35.75			3
4									35.33	35.59			4
5							34.64			35.59			5
6							34.62						6
7												35.85	7
8												35.85	8
9													9
10													10
11													11
12													12
13				34.28		35.31							13
14			33.54			35.31		35.41					14
15			33.55				35.01	35.41					15
16			33.71					35.41	36.83				16
17			33.71										17
18													18
19				33.85				35.55					19
20			33.69	33.85				35.55					20
21					34.40								21
22		33.80			34.40			35.07					22
23		33.74			34.45	34.60		35.07		35.90			23
24		33.72			34.45	34.60			35.84	35.64			24
25								36.47	35.85	35.64			25
26						34.34			35.95				26
27								35.21					27
28		33.75						35.21				35.51	28
29												35.51	29
30							35.69					35.51	30
31													31

Monthly values

X	33.75	33.64	33.99	34.43	34.83	34.99	35.44	35.78	35.72		35.65	X
N	51	67	18	27	28	50	89	61	70		78	N
s	0.04	0.08	0.25	0.03	0.45	0.50	0.40	0.54	0.14		0.19	s

Annual mean 334.82 ppmv
(based on 10 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1980

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in August 1985

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1			35.65										1
2			35.73										2
3			35.70										3
4										37.55			4
5													5
6												37.61	6
7													7
8								37.22			37.87	37.59	8
9											37.91	37.59	9
10				35.45							37.95	37.59	10
11				35.45								37.78	11
12													12
13													13
14													14
15													15
16						36.60							16
17						36.63							17
18						36.53							18
19													19
20								37.68					20
21													21
22													22
23													23
24						36.74							24
25						36.74							25
26													26
27		34.77			36.21								27
28		35.13						37.46					28
29		35.58											29
30													30
31													31

Monthly values

X	35.16	35.69	35.45	36.21	36.65		37.45		37.55	37.91	37.63	X
N	42	14	8	8	51		19		7	25	43	N
s	0.41	0.04			0.09		0.23			0.04	0.08	s

Annual mean 336.63 ppmv
(based on 9 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1981

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in August 1985

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1									38.61				1
2													2
3			37.27					38.59					3
4								38.56					4
5					37.52	37.87		38.60					5
6						37.90		38.91					6
7						37.90		38.49			38.33		7
8						37.89		38.49			38.32		8
9						37.89					38.22		9
10						38.17	38.38				38.25		10
11						38.01	38.38	38.67			38.31		11
12				37.44			38.38						12
13				37.44			38.73						13
14							38.52		38.82				14
15					37.63				38.82				15
16									38.98				16
17	37.42								38.98	38.81			17
18			37.32				38.60			38.76		38.57	18
19			37.32		37.77		38.60			38.70			19
20					37.55								20
21						38.09							21
22					37.50	38.09							22
23					37.50	38.21							23
24		36.75			37.50	38.28				38.46			24
25					37.50					38.46			25
26								38.60					26
27								38.63		38.81			27
28								38.72		38.81			28
29								38.72					29
30	37.49							38.69					30
31	37.49							38.65					31

Monthly values

X	37.47	36.75	37.30	37.44	37.56	38.03	38.51	38.64	38.84	38.69	38.29	38.57	X
N	15	6	44	25	92	181	77	145	25	94	65	6	N
s	0.04		0.03		0.10	0.15	0.14	0.11	0.15	0.16	0.05		s

Annual mean 338.01 ppmv
(based on 12 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1982

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in August 1985

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1									40.38			40.05	1
2		38.66		39.27					40.38	40.26			2
3		38.66		39.27						40.26		39.79	3
4							39.61						4
5													5
6										40.27			6
7										40.27			7
8	38.77												8
9	38.77					39.51							9
10		38.59				39.51							10
11		38.59											11
12		38.76							40.18				12
13		38.76				39.50							13
14			38.83			39.48		40.01	39.93				14
15			38.83	38.81		39.51		40.01	40.18				15
16				38.81		39.39			40.26				16
17						39.24							17
18						39.24				40.24			18
19						39.40							19
20				38.82		39.40	39.57		40.24				20
21				38.84			39.60		40.24				21
22				38.84			39.65						22
23				38.83									23
24				38.88									24
25						39.30							25
26						39.39		40.99					26
27									40.43				27
28													28
29											40.16		29
30											40.08		30
31													31

Monthly values

X	38.77	38.67	38.83	38.93		39.41	39.61	40.34	40.25	40.26	40.12	39.92	X
N	12	45	31	118		168	51	28	80	40	24	15	N
s		0.08		0.19		0.10	0.03	0.57	0.15				s

Annual mean 339.55 ppmv
(based on 11 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1983

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in August 1985

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1													1
2													2
3								41.91	41.89	42.12			3
4				39.44				41.91	41.89	42.12			4
5													5
6													6
7						40.53							7
8						40.53							8
9				39.87								41.74	9
10				39.87								41.82	10
11			39.73				41.73			41.88		41.85	11
12							41.22			42.06			12
13							41.22			42.05			13
14										42.00			14
15										41.75			15
16			39.84	40.15									16
17							41.84						17
18							41.11						18
19					40.63		41.20						19
20					40.70	40.61							20
21		39.66		40.07	41.20	40.89							21
22				40.07	40.44						41.90		22
23				40.07	40.44						41.89		23
24					40.44		41.59				41.93		24
25							41.59	42.12			41.95		25
26	39.55							42.12					26
27	39.59			40.28							41.86		27
28				40.28							41.86		28
29													29
30													30
31													31

Monthly values

X	39.57	39.66	39.79	40.01	40.64	40.64	41.44	42.01	41.89	42.00	41.90	41.80	X
N	29	9	14	99	80	34	104	28	7	55	48	24	N
s				0.26	0.30	0.17	0.28	0.12		0.13	0.04	0.06	s

Annual mean 340.95 ppmv
(based on 12 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means

Annual atmospheric carbon dioxide measurement report form

Programme at BARING HEAD

For the year 1984

CORRECTED CO2 concentration values (in ppmv above 300.0)

Prepared in August 1985

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1										43.12		42.72	1
2										43.17		42.72	2
3										43.04			3
4										43.04			4
5	41.71												5
6	41.56	41.76							42.94				6
7		41.63					42.73		43.64				7
8							42.73		43.02				8
9										43.15			9
10					41.74								10
11					41.74								11
12													12
13													13
14	41.71								42.91				14
15	41.71								42.92				15
16	41.78								42.93				16
17							42.61		42.85				17
18							42.61		42.75				18
19		41.65	41.59		41.97				42.55				19
20		41.65			41.79				42.54				20
21				41.53	41.82								21
22			41.53	41.53	41.86		42.89			43.19			22
23			41.53			42.17	42.73			43.19			23
24			41.49			42.17	42.65						24
25											43.08		25
26											43.08		26
27													27
28						42.23							28
29												42.80	29
30					41.77							42.71	30
31					41.77								31

Monthly values

X	41.69	41.67	41.54	41.53	41.81	42.19	42.71		42.91	43.13	43.08	42.74	X
N	42	47	57	45	100	24	67		108	49	11	50	N
s	0.08	0.06	0.04		0.08	0.03	0.10		0.31	0.06		0.04	s

Annual mean 342.27 ppmv
(based on 11 monthly means)

X = average monthly concentration

N = number of Hours selected

s = standard deviation (ppmv), based on daily means