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ATMOSPHERIC CO_2 CONCENTRATION AT A SUBURBAN LOCATION, KURASHIKI, DURING 1976/1977

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INTRODUCTION

Environmental CO_2 concentration is an important micrometeorological parameter. Vertical transport of CO_2 is controlled by the winds and CO_2 concentration in the surface layer. Above the vegetation, the diurnal or seasonal variation in CO_2 concentration reflects the variation in CO_2 assimilation or respiration of the vegetation (Huber 1950, 1952). Thus, any model of crop micrometeorology requires data on environmental CO_2 as an input (e.g., Goudriaan 1977).

Huber (1950) introduced the modern method of recording CO_2 in the field, using a nondispersive infrared gas analyzer URAS. More recently, atmospheric CO_2 has been measured for investigating CO_2 budget in the ecosystem (e. g., Spittlehouse and Ripley 1977) or monitoring the global background CO_2 in the climatological research (see review papers by Pearman 1980 ; Pearman et al. 1983 ; Fraser et al. 1983).

This paper reports on the measurements of atmospheric CO_2 concentration at a suburban location, Kurashiki, in the southwest district of Japan. Data were collected from 27 September 1976 to 13 November 1977.

METHOD

1. *The Site and Sampling Points*

Measurements were made in the grounds of the Institute (34. 6°N, 133. 8° E, 2 m above MSL) located at the southern border of the town of Kurashiki (Fig. 1). About 10 km southwest of the site, there is an industrial area, Mizushima, along the coast of Seto Inland Sea. In the region Kurashiki-Mizushima, the sea breeze prevails in warmer months. In winter, monsoonal NW winds are prevalent. Winds usually fall off at night throughout the year.

Fig. 2 shows sampling points 1 and 2. Air intake at point 1 was positioned at about 2 m above the roof of the phytotron ; the height above the ground was 5. 4 m. Intake at point 2 was mounted on the arm of a mast set up in a plot of the field. The plot was a wheat field from

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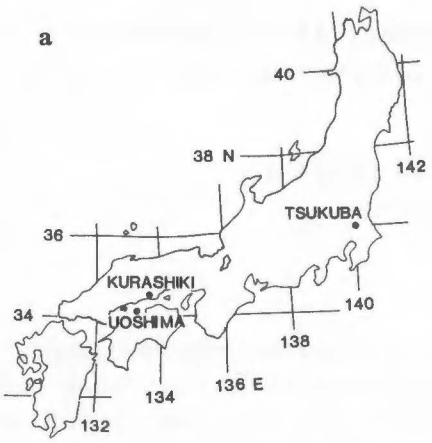

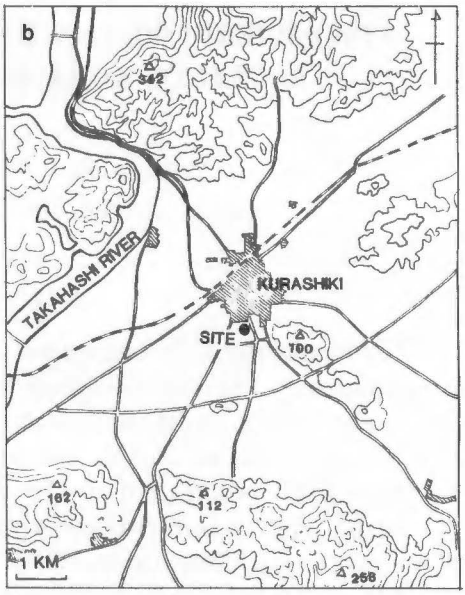

FIG. 1. The observation site. Locations of two other stations whose data are cited for comparison are also shown in Fig. 1a.

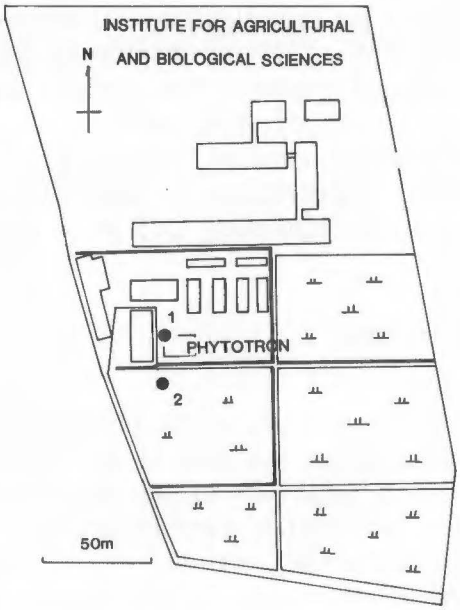

FIG. 2. Measuring points.

November to June, and a paddy from July to October. The height of intake at point 2 was varied with the crop growth so that it was situated about 0.1 m above the crop surface.

2. *Measuring System*

Measurements were made with a measuring system Hitachi-Horiba

ASSA–2; it consists of an infrared gas analyzer (Horiba LA–2), a sampling system, and a 6 point recorder.

The system ASSA–2 are described briefly. (1) Membrane pumps continuously draw in air samples from 6 measuring points through 6 independent paths. Solenoid valves sequentially connect one of the flow paths to the path leading to the measuring cell. The scanning interval is 1 min, so that one cycle of measurement is completed in 6 min. (2) The rate of flow through the measuring cell is specified at 0.5 *l*/min. At this flow rate, the recorder output becomes nearly steady in about 50 sec after the changeover between circuits. The recorder prints each data point just before the following interchange. (3) The sampled air is dehumified by a thermoelement cooler to a dew point of 1.5 ± 1°C before it is passed into the measuring cell. A filter unit is incorporated in front of the pump to remove coarse dust particles. (4) The measuring range is 0–600 ppm, which corresponds to 0–150 mm width on the recording paper.

The present experiment used only 2 paths of the 6 sampling paths. The conduits used were vinyl tubes about 50 m long with inner and outer diameters of 6 and 9 mm, respectively. Cotten wool was inserted into the tube at the intake as an additional dust filter. The travel time of the sampled air from the measuring point to the analyzer was about 40 sec. This estimate was made by injecting N_2 gas at the inlet and noting the time lag of the ensuing minimum in the recorder output.

3. *Calibration*

The record was read using the scale provided by the factory. The scale was nonlinear because the sensitivity of the analyzer decreased with increasing concentration. In reading the record, the calibration was approximated by the equation

$$Y = 2.869X/(1-1.92\times10^{-3}X)$$

where Y is the CO_2 concentration in ppm and X is the recorder output in mm. The sensitivity was about 5 ppm/mm in the usual range of 300–500 ppm. The resolution was thus about 1.5 ppm.

The scale referred to the standard gas mixture CO_2/N_2 prepared by Seitetsu Kagaku. The rated accuracy of the standard gas was within 1% of the concentration. The original scale was checked on 23 April 1977, using 6 flasks of standard gas of CO_2 cncentration: 0 (pure N_2), 42.5, 297, 341, 395, and 512 ppm, each supplied by Seitetsu Kagaku. At about 500 ppm, the original scale was found to give CO_2 values in good agreement with those given by the check. At lower CO_2 concentrations, the CO_2 values read by the original scale were about 1% lower than those given by the check. The measurement were not corrected for this discrepancy.

In the routine measurements, the zero point and span were checked every 2 to 3 days, referring to the standard N_2 gas and a standard gas CO_2/N_2 of 512 ppm, either supplied by Seitetsu Kagaku. The reading were corrected for the zero drift and span change. The zero drift and the span change in the interval between consecutive checks were linearly interpolated to be applied in the correction.

The zero drift tended to be negative; the mean value from 111 cases was -0.2 ± 0.6 ppm/day. The worst case yielded a drift of -2.5 ppm/day. No systematic drift was found in the span. The mean of the span change from 113 cases was 0.00 ± 0.72%/day. Thus, the frequency distribution was not skewed, but it was highly peaked near zero with about 95% of the cases falling within ±1.5%/day.

There are other factors affecting the accuracy of CO_2 measurement, e.g., interference of the residual water vapor in the air sample and the carrier gas error (Griffith 1982; Griffith et al. 1982). The water vapor effect was examined by Ohtaki (1983) for a similar instrumentation. His results indicated that the associated error is unlikely to be important. The carrier gas error was not considered in the present study.

We cannot specify the absolute accuracy of measurements, though discussions given above suggest some underestimate of CO_2 in the present measurements. However, the measurement was conducted according to a prescribed procedure and using the same flasks of standard gas. Thus, the internal inconsistency is presumed to have been kept minimal.

4. *Execution of Measurement*

The measurement was continued from 27 September 1976 to 13 November 1977 excepting the following periods of interruption: May 30 (10–20h); June 8 (11–17h) and June 9 (9–17h); June 24 (19–24h) and June 25 (0–24h). The interruption on May 30 was due to malfunction of the dehumifier, and that on June 24/25 was due to failure of the timing mechanism of the sampling system. Harvesting work on June 8 and 9 made impracticable the daytime measurements on the field on these days.

Another trouble encountered in the operation of the measuring system was dew deposit in the vinyl tube leading to the sampling point on the field. On June 10, condensed water vapor within the tube temporarily reduced the flow rate to 0.2 ℓ/min.

The adjustment of the zero and span took about 10 min. The resulting missing data were filled in by interpolation.

RESULTS AND DISCUSSIONS

Data were obtained every 6 min for each measuring point, i.e., for 5.4 m height at the phytotron and for 0.1 m on the field. The hourly

mean value was obtained by averaging 10 readings taken during the hour.

1. *Diurnal Variation*

Hourly CO_2 values in each hour of the day were averaged for each month to reveal the mean diurnal course of the CO_2 concentration for that month. The results are listed in Appendix. Fig. 3 illustrates the diurnal variation for February and August. The field site was a stubble field in February and a paddy in August.

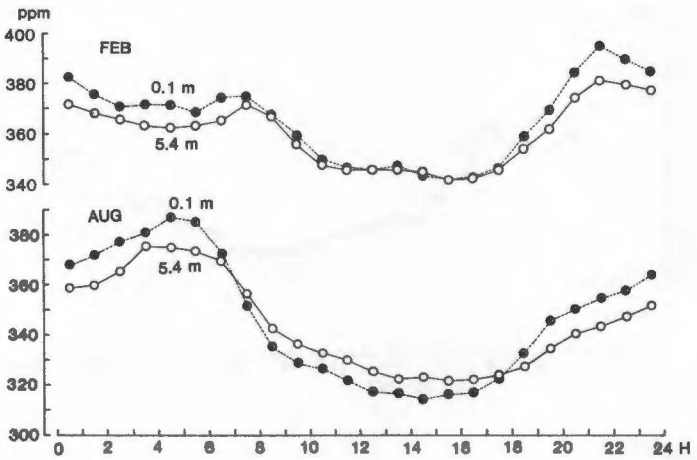

FIG. 3. Diurnal variations of CO_2 concentration in February and August, 1977 at Kurashiki.

The CO_2 concentration was fairly steady during midday. Daily minimum occurred around 15 h in both months. CO_2 rose rapidly in the evening. The nighttime variation in August differed from that in February. In August, CO_2 continued to increase until a maximum was attained before sunrise. In February, the increase in CO_2 concentration slackend in the late evening. CO_2 slightly decreased thereafter, and a secondary maximum appeared shorly after sunrise. The drop of CO_2 in the morning was sharp in both months.

The diurnal variation of CO_2, characterized by the high concentration at night and relatively low concentration in the daytime, is primarily controlled by diurnal variation of wind speed as mentioned above. In warmer months this feature is accentuated by daytime CO_2 assimilation and nighttime respiration of vegetation. The double peaks noted in the diurnal variation during the winter are presumed to be associated with the variation in the intensity of man-made sources.

The CO_2 difference between two heights 5.4 m and 0.1 m is a measure

of CO_2 gradient in the surface layer. In February, CO_2 generally decreased with height, i. e., the gradient was negative, though it became nearly zero in midday to early afternoon. In August, CO_2 in the daytime was lower at 0. 1 m than at 5. 4 m, i. e., the gradient was positive above the crop surface, reflecting the net CO_2 assimilation of the crop stand.

Fig. 4 illustrates short-period fluctuations superposed on the regular diurnal variation. The scatter is large near the surface, particularly at night when winds are usually light or calm.

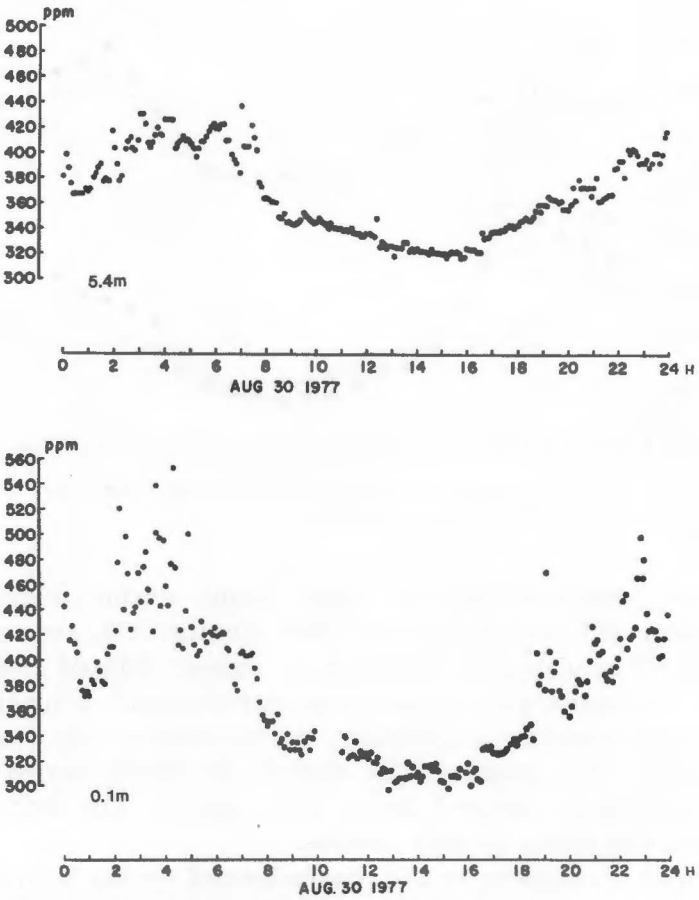

FIG. 4. Plot of individual CO_2 readings (at interval of 6 min) on a typical fair weather day in summer.

Though the daytime CO_2 variation was generally steady, it was found to be disturbed on some days. The example given in Fig. 5 shows that the CO_2 concentration began to increase between 11 h and 12 h with veering of wind from E to SW; it decreased as the wind direction

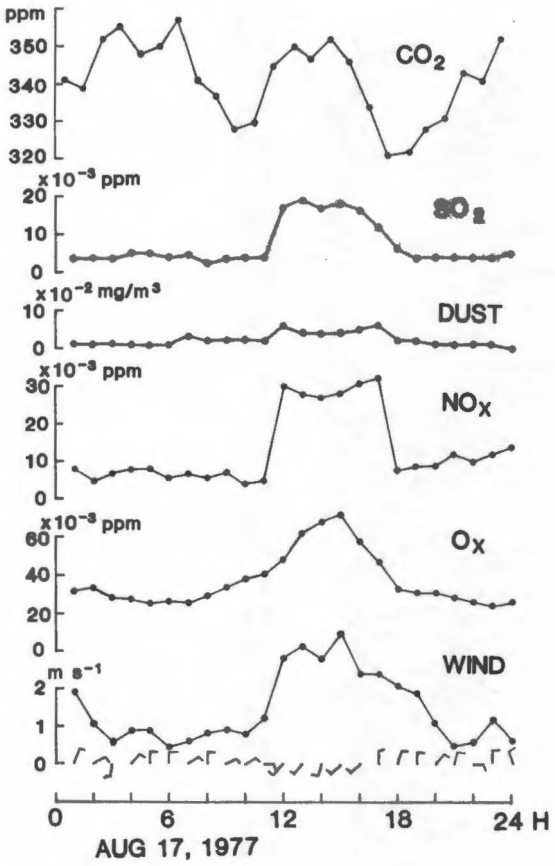

FIG. 5. An example of disturbed diurnal variation of CO_2. Pollution and wind data by courtesy of the Municipal Agency, Kurashiki.

changed from SW to N between 16 h and 17 h. A parallel variation was observed for air pollutants measured at the Air Pollution Monitoring Station Kurashiki.

2. *Interdiurnal and Synoptic-Scale Variations*

The daily maximum and minimum of hourly CO_2 concentrations are plotted in Fig. 6. The figure shows that the interdiurnal variations were remarkably large. The CO_2 concentration diminished after a rainfall. This is related to the advent of fresh air mass rather than to a scavenging effect of rain.

Power spectra calculated for autumn 1976, winter 1976/1977, spring and summer 1977 are shown in Fig. 7. The figure shows that the one-day period was predominant in the CO_2 variation. The half-day period, which explains asymmetry in the daily variation, was not negligible. In winter the contribution of half-day period was comparable with that of one-day period. The peak in a period of 4–5 days is associated with quasiperiodic variation in weather. This peak was obscured in summer

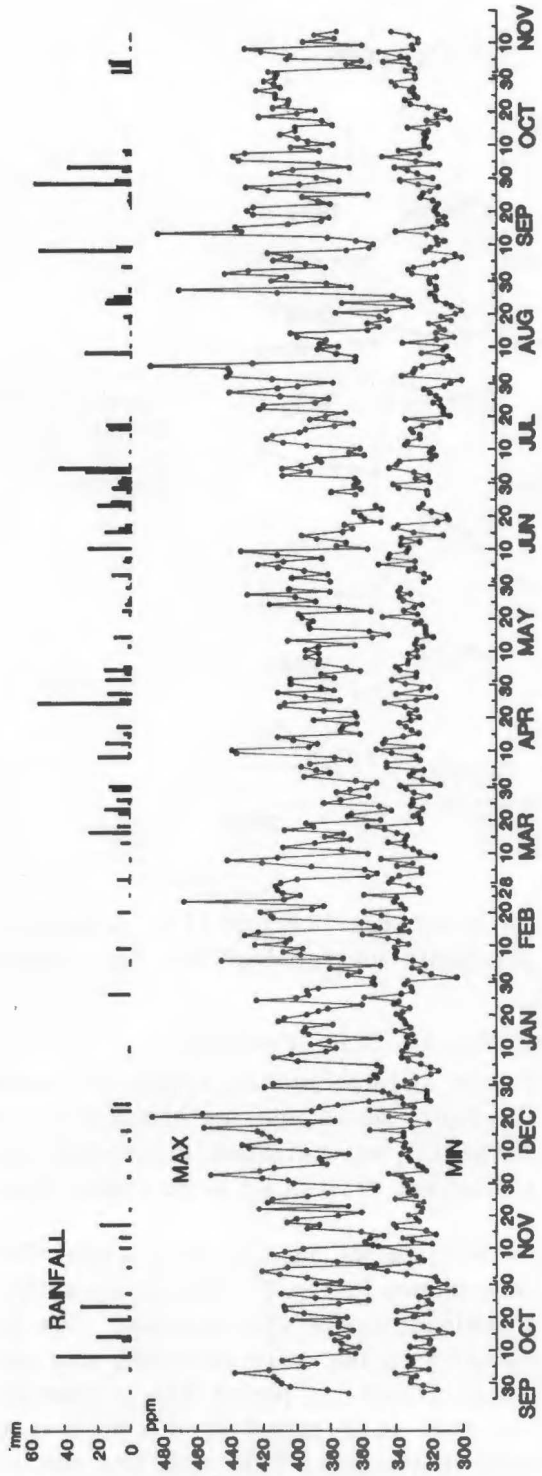

FIG. 6. Plot of daily maximum and minimum on successive days at Kurashiki in 1976/1977. Rainfall is given in daily sum by termini 9 h.

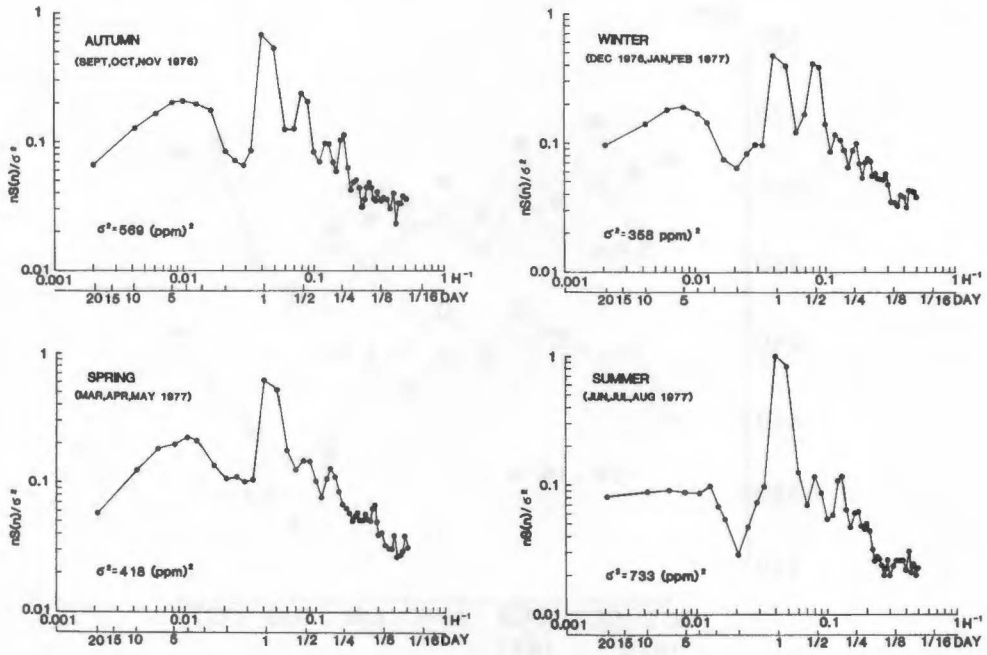

FIG. 7. Logarithimic power spectra $nS(n)$ normalized by variance σ^2 such that $\int_0^\infty nS(n)/\sigma^2\,dn=1$. n is the frequency in h^{-1}; $S(n)$ is the power spectrum density. Spectra were computed from hourly values of CO_2, using Blackman-Tukey's scheme. Measuring height is 5.4 m.

by the persistence of longer-period variations.

3. *Seasonal Variation*

Monthly mean values of CO_2 concentration derived from the daily means are plotted in Fig. 8. The values are somewhat scattered due to variability from month to month. However, CO_2 concentration was high during cold season and low in summer, thus exibiting a seasonal variation.

Monthly means of CO_2 during the hour 14 h to 15 h are also plotted in Fig. 8. Generally the daily minimum occurred around this hour when the vertical mixing is supposed to be most active. Hence, CO_2 measured during 14–15 h is presumed to represent fairly well the regional CO_2 concentration in the bulk of the planetary boundary layer. As is expected, the scatter from month to month was reduced and the seasonal variation became more well defined. It is seen from the figure that the minimum occurred in August. Data on individual days indicate that the annual minimum was attained in the later half of August; see the plot of daily minimum of CO_2 in Fig. 6. Maximum occurred at the end of winter. It is noted that in the annual course based on daily means (the

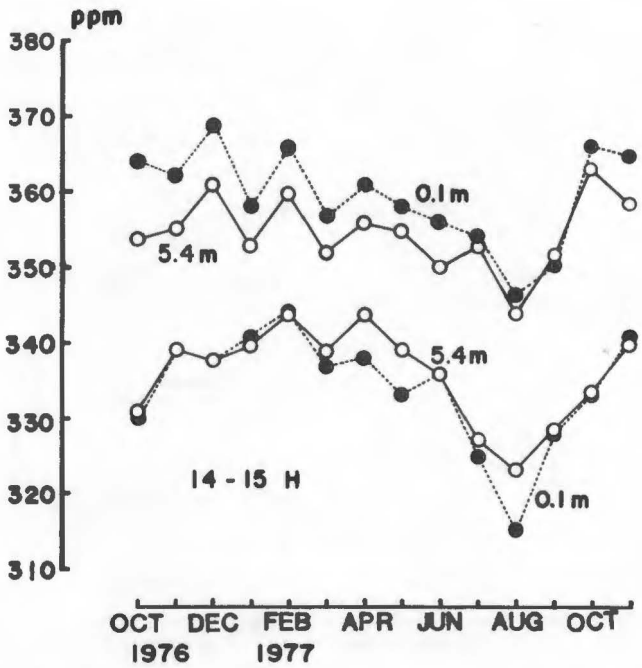

FIG. 8. Seasonal variation of CO_2 concentration at Kurashiki in 1976/1977.

upper portion of Fig. 8) the maximum occurred in midwinter.

The seasonal variation found here is broadly similar to that observed at other CO_2 monitoring stations. e. g., at Point Barrow (Peterson et al. 1982). It reflects the seasonal variation in plant activity. It is noted in this connection that CO_2 concentration in the hour 14–15 h was lower at 0. 1 m than at 5. 4 m during March to May over the wheat field and during July to September over the paddy field.

Fig. 9 compares the present measurement with two recent measurements: a measurement by Fushimi at Tsukuba in 1980/1981 (Fushimi 1982) and that by Ohtaki at Uoshima in 1979 (Ohtaki 1983). Data used in the figure for the land station Tsukuba represent daily minima

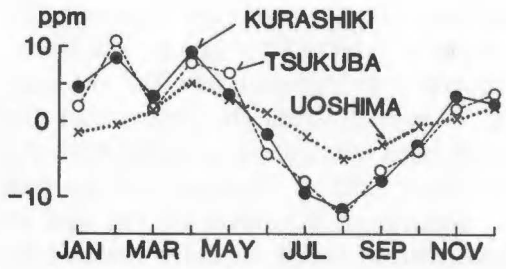

FIG. 9. Seasonal variation of CO_2 concentration at Kurashiki compared with those at Tsukuba in 1980/1981 and Uoshima in 1979.

averaged for each month. Uoshima data were taken at a small island in Seto Inland Sea located at about 60 km southwest of Kurashiki. Data free from any disturbance by nearby man-made sources were selected by Ohtaki to obtain representative CO_2 values over the inland sea. For locations of Tsukuba and Uoshima, see Fig. 1a.

The seasonal variation at Tsukuba station in 1980/1981 is apparently similar to the variation at Kurashiki in 1976/1977. At the island station Uoshima the amplitude of annual variation is small compared with those at the land stations.

4. *Secular Variation*

Annual mean CO_2 derived from CO_2 in the hour 14–15 h at Kurashiki was 335 ppm in 1976/1977. Ohtaki (1983) estimated the annual mean in 1979 at Uoshima at 340 ppm. Comparison of these values suggests a rate of CO_2 increase of about 2 ppm per year in the relevant area. It is noted that Uoshima and Kurashiki measurements were referred to the standard gas prepared by Seitetsu Kagaku.

Ohtaki argued that his value 340 ppm in 1979 is reasonable compared with the value 336.3 ppm* at Mauna Loa in the same year. A reduction of CO_2 measurements at Mauna Loa by Pearman et al. (1980) has given the annual mean of 332.2 ppm in 1976 and 333.8 ppm in 1977. Based on the same reasoning as in Ohtaki (1983) we consider that our value 335 ppm at Kurashiki in 1976/1977 is compatible with the background CO_2 measured at Mauna Loa.

CONCLUSION

The present measurements were made in the surface layer on a site of complex terrain and land uses. The results obtained are inevitably local in character. However, the measurements at Kurashiki demonstrated well-defined seasonal and diurnal variations in atmospheric CO_2. They also suggest that the secular change of regional CO_2 could be monitored provided care is take in data reduction.

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* A later estimate by Fraser et al. (1983) is 336.6 ppm.

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APPENDIX. Mean hourly values of CO_2 concentration for each month from 27 September 1976 to 13 November 1977 at Kurashiki.

5.4 m

MONTH:	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
0–1 h	365	367	363	373	356	371	360	367	367	357	368	357	374	382	365
1–2	368	368	362	373	356	368	358	367	368	360	373	359	373	382	365
2–3	367	368	362	368	354	365	356	368	370	364	378	365	376	381	369
3–4	366	370	360	365	353	363	356	369	371	367	381	371	378	382	372
4–5	367	370	358	364	353	362	355	371	374	367	383	372	381	383	369
5–6	375	372	360	362	355	363	357	369	376	367	385	373	383	386	371
6–7	377	374	363	365	358	365	360	366	370	362	378	370	376	390	379
7–8	371	369	366	372	368	372	360	361	361	355	364	355	359	380	377
8–9	354	357	360	373	367	368	355	354	354	350	351	342	345	361	364
9–10	341	346	350	360	355	356	350	349	350	348	343	336	335	350	353
10–11	333	337	342	350	347	349	347	348	346	346	342	332	332	342	349
11–12	332	337	340	344	343	346	344	347	345	345	339	331	328	337	346
12–13	334	334	338	340	339	346	340	345	340	342	335	327	325	332	342
13–14	331	333	339	339	338	347	338	345	337	339	332	324	327	330	341
14–15	330	331	339	338	340	344	339	344	339	334	327	324	328	333	340
15–16	333	333	337	338	338	342	340	344	338	333	325	322	329	335	340
16–17	330	333	339	344	340	343	339	341	335	333	326	322	332	339	339
17–18	336	340	350	356	346	345	343	341	337	335	328	324	335	345	348
18–19	356	352	362	369	353	354	350	346	343	338	333	328	346	361	354
19–20	369	359	366	375	357	362	355	353	349	341	339	335	349	368	355
20–21	369	363	367	377	360	374	360	357	355	347	350	340	354	373	360
21–22	381	366	369	378	363	381	360	361	361	352	358	344	358	379	360
22–23	381	365	368	376	363	379	360	365	364	354	363	348	360	381	359
23–24	376	364	367	376	359	376	360	366	365	356	366	351	366	385	360

0.1 m

MONTH:	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
0–1 h	387	390	376	385	367	382	373	381	379	371	374	366	365	388	381
1–2	391	388	374	385	367	376	370	389	383	380	376	371	364	388	378
2–3	387	386	370	380	361	371	371	386	383	390	380	377	365	385	384
3–4	401	388	368	377	361	372	367	392	385	390	381	380	367	385	383
4–5	391	392	368	374	362	372	369	389	388	386	385	384	372	386	380
5–6	398	388	371	370	364	369	369	384	382	380	386	384	377	386	381
6–7	394	386	373	374	368	374	366	364	366	365	377	369	372	391	388
7–8	367	368	369	378	376	376	360	354	357	356	363	351	359	380	380
8–9	350	353	360	375	370	368	352	345	348	354	349	336	346	360	365
9–10	338	342	350	360	358	356	347	340	343	349	342	329	338	349	354
10–11	328	335	342	351	348	349	344	339	340	347	341	326	334	340	350
11–12	327	335	341	344	344	346	341	337	338	346	337	323	331	335	347
12–13	328	331	339	340	340	346	337	336	333	343	335	319	326	331	344
13–14	325	332	339	340	338	347	336	337	331	340	331	315	327	330	342
14–15	325	330	339	338	341	344	337	338	333	336	325	316	328	333	341
15–16	328	332	338	339	339	342	338	338	334	335	325	315	329	335	341
16–17	329	335	342	346	340	343	338	338	333	335	324	318	332	340	344
17–18	345	351	359	364	348	346	344	340	336	336	328	322	334	349	359
18–19	389	366	371	382	359	359	356	351	346	341	333	332	346	369	361
19–20	399	374	373	389	364	371	362	362	356	346	341	345	352	376	362
20–21	386	384	381	393	367	388	372	374	365	357	356	349	353	385	366
21–22	413	392	383	393	371	396	367	383	371	362	364	355	355	391	368
22–23	409	385	380	390	372	392	370	384	376	364	367	358	358	393	369
23–24	393	382	381	389	367	385	373	385	379	365	369	363	361	390	373