SHORTER CONTRIBUTION

Space and time variations of tropospheric carbon dioxide in the southern hemisphere

By G. I. PEARMAN and J. R. GARRATT, *C.S.I.R.O. Division of Atmospheric Physics, Aspendale, Victoria, Australia*

(Manuscript received ?)

An atmospheric carbon-dioxide monitoring programme has recently been initiated at the C.S.I.R.O. Division of Atmospheric Physics, Australia. The primary objective of the programme is to provide high quality measurements of atmospheric CO_2 mixing ratios to complement the existing monitoring stations in the Northern Hemisphere. The programme is based on the collection of discreet air samples from aircraft, with subsequent analysis at the laboratory. The techniques are therefore similar to those of the Swedish CO_2 Programme described by Bischof (1970), but differ from those employed at the remote ground station at Mauna Loa and Antarctica (Pales & Keeling, 1965).

The aircraft used for the collection of flask samples during the period of interest consisted of a Fokker "Friendship" (Commonwealth Department of Civil Aviation), a Boeing-707 (Qantas Airways) and a Piper "Commanche" (Smithair, Melbourne). They were flown over South-East Australia and over the sea to the south-east of the continent (Bass Strait and the Tasman Sea).

In addition to the aircraft measurements data were obtained at two fixed ground stations. One is situated at Aspendale, 27 km south of Melbourne, where air from the 18 m level (sampled from an intake located above a roof) is analysed for CO_2 at regular intervals, at least once a week. The second is at Rutherglen, a small inland town in the north-east of Victoria, where measurements were made during 1971 of the CO_2 mixing ratio in air from 2 m above a wheat crop (Pearman & Garratt, 1972*a*).

All measurements were made with a UNOR 2 infra red gas analyser, relative to a primary reference gas, with an accuracy of ± 0.2 p.p.m. (parts per million by volume). The absolute value of CO_2 mixing ratio for the primary reference is not known accurately but will be determined relative to the "Scripp's" standard in the near future. The data are therefore presented with CO_2 values relative to a fixed reference.

The data reported here for the first 8 months of the programme are insufficient for a discussion of the secular trend in atmospheric CO_2. However, while measurements by Bolin & Bischof (1970) have indicated the extent of space and time variations in tropospheric CO_2 in the Northern Hemisphere, such measurements have not, until now, been available for the Southern Hemisphere. Differences in behaviour between the two hemispheres might be expected, because of the greater extent of ocean in the Southern Hemisphere and the far greater intensity of industrial and seasonal plant growth activity in the Northern Hemisphere.

In Fig. 1 we show all the data collected in the flask sampling programme thus far (March through October, 1972), averaged for each one km altitude layer. Included for each mean value are the standard deviation from the mean (horizontal bar) and the number of observations included in each mean. Also presented are the daytime (1 000–1 400 h inclusive) data for Aspendale & Rutherglen, plotted similarly, where each individual measurement for these two sites represents a 15 min (approximately) average.

The most significant feature of the flask sample data is the consistency throughout the first 8 months of observation, given that the individual observations were made on 30 sepa-

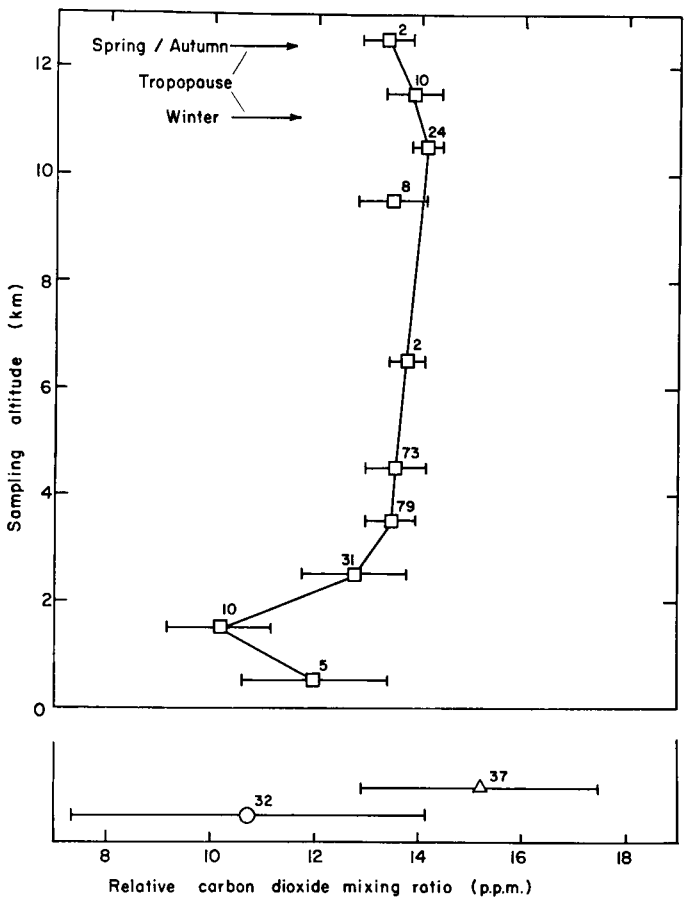

Fig. 1. Carbon dioxide mixing ratio in the Southern Hemisphere troposphere relative to a primary reference gas, as a function of height. Also indicated are the mean levels of the tropopause for Autumn, Winter and Spring for 40°S approximately. □, Mean of all individual flask samples collected from aircraft over South-East Australia, Bass Strait and the Tasman Sea. Numerals indicate number of observations included in each mean, while horizontal bars represent one standard deviation about the mean. △, Mean of measurements taken for air sampled at approximately 18 m above the ground at Aspendale, Victoria. ○, Mean of measurements taken for air samples at 2 m above a wheat crop,near Rutherglen, Victoria.

rate occasions over horizontal distances of ~2 000 km. The standard deviations of the individual observations about the mean for the lower troposphere (0.5–5 km) and the upper troposphere (5–10 km) were 1 and 0.3 p.p.m. respectively.

Although flask samples are few in number in the altitude range 10–12 km, there is an indication of a decrease in CO_2 mixing ratio and an increase in variability at these altitudes. This behaviour is consistent with that reported by Bolin & Bischof (1970) for the Northern Hemisphere. It results from the proximity of the tropopause to the sampling altitude, and in Fig. 1 we include the mean seasonal positions of the tropopause for the Southern Hemisphere mid-latitudes. Thus for the 10–12 km layer in particular the data will consist of both tropospheric and stratospheric samples, the difference in CO_2 mixing ratio between troposphere and stratosphere giving the increased variability.

In addition some comment is required on the increased variability, and relatively lower mean value, for the 9–10 km layer. This too results from the inclusion of both tropospheric and stratospheric samples, three of these samples being collected on a single day when the tropopause was abnormally low (about 8 km) ahead of a cold front moving eastwards across the south Tasman Sea (12.10.1972). The 3 samples

were most probably of stratospheric air and therefore of lower CO_2 content than the upper troposphere.

The observed variations of CO_2 in the atmosphere may be the result of several contributing factors, including an annual increase, seasonal variations, vertical and horizontal gradients and measurement inaccuracies. While a detailed analysis of these contributing factors is envisaged when additional data have been collected it is possible to make some preliminary comments. It is clear that on most occasions when samples are taken at altitudes above about 3 km, the variation between samples taken on the same day within 100 km of each other is no more than 0.2–0.3 p.p.m. At the moment we have little data for analysis over greater horizontal distances. On one occasion flasks were collected at an altitude of $\sim$10 km over a horizontal distance of 1 500 km. The horizontal difference in CO_2 content was $\sim$1 p.p.m. This is consistent with the results of Bolin & Bischof (1970). In the lower troposphere at least, most of the variation at a given altitude will thus result from temporal effects over a range of time scales greater than one day.

The mean decrease of CO_2 mixing ratio with decreasing altitude through the troposphere implies a surface sink for CO_2, and is discussed elsewhere (Garratt & Pearman, 1973). The increase of CO_2 on approach to the surface probably results from the local effect of terrestrial CO_2 sources. The five samples collected in the lowest 1 km were taken from a light aircraft over Aspendale, while the majority of the others were collected over the sea.

Considering the near-surface data, the mean of 37 day-time measurements made at Aspendale for the period August through October, 1972 is only 2 p.p.m. higher than the mean tropospheric value for the period March through October, 1972. The standard deviation of these data from the mean is some 2 p.p.m. Even more remarkable, the Rutherglen daytime data, for the period July through November, 1971, has a mean value only 3 p.p.m. less than the 1972 tropospheric mean, and a standard deviation of 3.4 p.p.m.

To summarise, the data obtained to date indicate relatively small space and time variations in the CO_2 content of the Southern Hemisphere troposphere. This covers the height range from a few metres above the surface to the tropopause. The variations are of the same order of magnitude as that of the secular trend observed in the Swedish and USA programmes ($\sim$1 p.p.m. per annum—see Pearman & Garratt, 1972*b*). Any long-term trend in CO_2 content should therefore be more readily evident in tropospheric measurements made in the Southern Hemisphere, over a period of only a few years.

The near-surface measurements further indicate at least for the Southern Hemisphere, that the day-time CO_2 mixing ratio in air sampled a few metres above the ground (over a crop or otherwise) is influenced to only a small degree by terrestrial sources and sinks for CO_2. Vertical mixing in the atmospheric boundary layer is evidently sufficiently intense to maintain the above-crop CO_2 mixing ratio close to the free atmosphere value, which varies little with time of year.

Acknowledgement

The authors acknowledge with gratitude the co-operation of D.C.A., Qantas and Smithair personnel.

REFERENCES

Bischof, W. 1970. CO_2 measurements from aircraft. *Tellus 22*, 545–549.

Bolin, B. & Bischof, W. 1970. Variations of carbon dioxide content of the atmosphere in the Northern Hemisphere. *Tellus 22*, 431–442.

Garratt, J. R. & Pearman, G. I. 1973. Large scale CO_2 fluxes in the Southern Hemisphere troposphere. Submitted to *Nature*.

Pales, J. C. & Keeling, C. D. 1965. The concentration of atmospheric carbon dioxide in Hawaii. *J. Geophys. Res. 70*, 6053–6076.

Pearman, G. I. & Garratt, J. R. 1972*a* Carbon dioxide measurements above a wheat crop 1. Observations of vertical gradients and mixing ratios. *Agric. Meteorol.* (in press).

Pearman, G. I. & Garratt, J. R. 1972*b*. Global aspects of carbon dioxide. *Search 3*, 67–73.