Tellus (1987), *39B*, 67–71

Seasonal variations of atmospheric CO_2 in the southern Indian Ocean

By PATRICK MONFRAY, ANDRÉ GAUDRY, GEORGES POLIAN and GÉRARD LAMBERT, *Centre des Faibles Radioactivités, Centre National de la Recherche Scientifique, Av. de la Terrasse, B.P. 1, 91190 Gif/Yvette, France*

(Manuscript received December 27, 1985; in final form April 2, 1986)

ABSTRACT

Atmospheric CO_2 recording at Amsterdam Island shows a 0.7 ppm seasonal effect, non-attributable to local causes and significantly different from the results obtained in other southern hemisphere stations. An attempt is made at comparing this seasonal variation to CO_2 models.

1. Introduction

Seasonal variations of the atmospheric CO_2 have been studied in several parts of the world. In the northern hemisphere, a maximum is observed in April–May and a minimum in August–October with peak-to-peak magnitudes from 5 to 15 ppm, according to the latitude (Peterson et al., 1982, Komhyr et al., 1985, Bacastow et al., 1985). Moreover the isotopic composition of CO_2 shows the dominant rôle played by the continental biomass in these seasonal variations (Mook et al., 1983).

In the southern hemisphere, a spring maximum is also observed in September–October and a fall minimum in March–April in several stations: Cape Grim, Tasmania (Beardsmore and Pearman, 1987), South Pole and Baring Head, New Zealand (Komhyr et al., 1985, Heimann, pers. comm.). However, the peak-to-peak magnitudes are less than 1.5 ppm and according to Mook et al. 1983, the contributions of the ocean and of the biomass are comparable. Most of the models represent these variations rather roughly (Pearman et al., 1983, Fung et al., 1983). More recently, Heimann (pers. comm.) obtained good agreement for the south pole but less satisfying results for the other stations of the southern hemisphere.

The seasonal variation of the atmospheric CO_2 recorded since 1980 at Amsterdam Island seems to be different from that found in the other southern hemisphere stations and a simple application of the models could not account for experimental data. The aim of this paper is first to determine the CO_2 seasonal variation non-attributable to local causes, and to compare different CO_2 components considered in models.

2. Measurements and data selection

Amsterdam Island (Territoire des Terres Australes et Antarctiques Francaises) is located in the southern Indian Ocean (37°47 S, 77°31 E) 3,400 and 5,000 km off Madagascar and South Africa, respectively, which are the nearest continental areas to be considered in these latitudes to leeward of westerly winds (Fig. 1). Detailed description of the site and of the CO_2 measurement technique were given by Gaudry et al. (1983). The CO_2 is continuously determined by a non-dispersive infrared device (URAS 2T). The CO_2 in N2 standards were directly certified by the Scripps Institution of Oceanography. A correction was made for CO_2 in air standards (Gaudry et al., 1987). The results obtained from October 1980 to October 1984 are expressed in

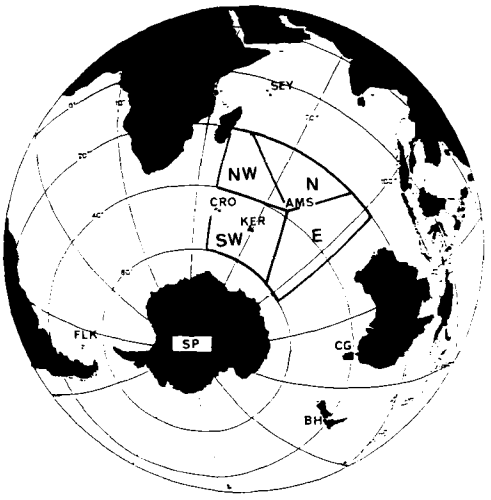

Fig. 1. Location of Amsterdam Island showing the air trajectory sectors utilised in the text.

the adjusted 1985 air mole fraction scale of the Scripps Institution of Oceanography. Despite its geographical isolation and scarce vegetation, the site might still be affected by local CO_2 contamination. Thus, very strict selective criteria were imposed to define a marine sector: wind direction between 300° and 040° with velocities greater than 5 m/s, and wind direction between 260° and 300° with velocities greater than 8 m/s. The efficiency of these criteria can be seen in Fig. 2 where the mean diurnal variations, calculated from a 4-year data set, with and without data selection are compared.

Monthly mean values of selected data are shown in Fig. 3, together with the corresponding 11-month running mean (5 months preceding and

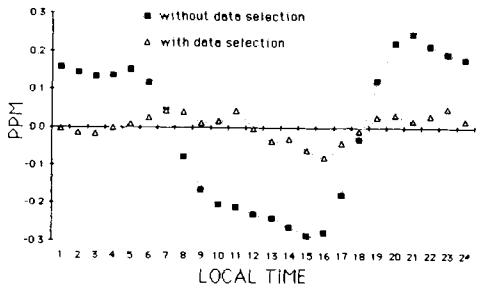

Fig. 2. Mean diurnal CO_2 variations for data without selection (squares) and for data corresponding only to the marine sector defined in the text (triangles).

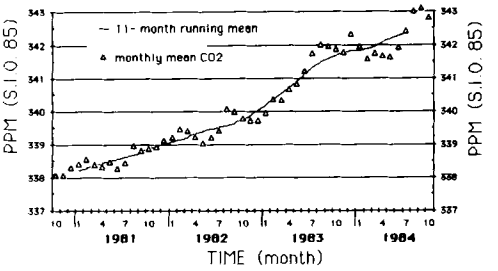

Fig. 3. Monthly mean CO_2 concentration after data selection (triangles) and 11-month running mean (black curve) at Amsterdam Island.

following the considered month). The general trend observed is an increase of CO_2 of the order of 5 ppm in 4 years, in agreement with most CO_2 data. However, this general increase is far from being regular and significant changes of the increase rate are observable. More especially, a relationship seems to exist between El-Niño events and CO_2 variations measured at Amsterdam Island (Ascencio-Parry et al., 1984; Gaudry et al., 1987). Systematic increases of CO_2 can be observed in June to August and to a certain extent in January–February.

To define a seasonal signal, this running mean was subtracted from each of the hourly mean values obtained during the considered month; then a monthly mean value of these seasonal signals is calculated by gathering the values relative to each calendar month. However, it is impossible to deduce directly from them the true seasonal effect, since the data selection resulted in keeping only 29% of the numerical values, which corresponded preferentially to particular meteorological conditions and therefore to air mass trajectories non-representative of the average conditions. In order to compensate for these non-stochastic effects, we have studied the effect of the air mass trajectories on the CO_2 variations.

Back trajectories at 850 mb were determined every 12 h at Amsterdam Island, from October 1980 to December 1983, by J. M. Miller from the N.O.A.A. – Air Resources Laboratories' trajectories model (private communication) according to a method described by Pack et al. (1978) and Harris (1982). Besides uncertain complex situations, 4 sectors were defined (see Fig. 1) from which the air masses originate: North (N), North-West (NW), South-West (SW) and East

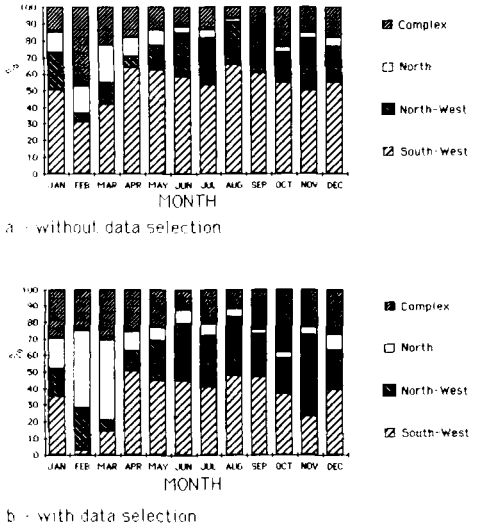

Fig. 4. Histogram of the air-mass trajectories without selection (a) and after data selection (b). The sectors (N, NW and SW) correspond to those defined in Fig. 1. The term "complex" refers to a situation where the origin is undetermined.

(E). In fact, practically, no air mass ever comes from this latter. The frequency of these different origins is shown in Fig. 4a. The same histogram was obtained (Fig. 4b) by using only the meteorological conditions corresponding to selected data: as expected, both these diagrams are significantly different (mainly for February and March).

Moreover, it may be observed in Fig. 5 that the CO_2 seasonal variations, calculated by the above-described method, are different between SW and NW air mass trajectories. It is worthwhile noting that, on an annual basis, the SW CO_2 is slightly higher than NW CO_2, by 0.1 ppm. This difference could be ascribed, in agreement with Beardsmore and Pearman (1987), to the fact that Antarctic seawater is supersaturated in CO_2 (360 ppm at 53° S, 60° E) whereas the sea surface is very undersaturated from 48° S to 35° S, down to 295 ppm (Goyet, pers. comm.). One consequence of these observations is that the data selection introduced a small change in the CO_2 mean values. In order to correct this artificial shift, the mean monthly values of the seasonal signal were computed separately for the 4 trajectories sectors, and subsequently combined together by assigning to each of them a weight corresponding to the actual frequency.

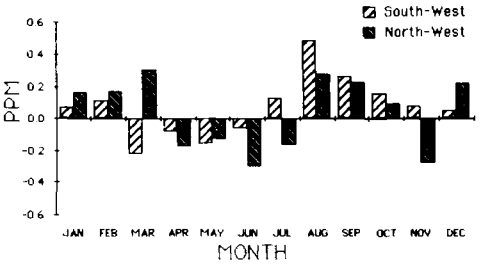

Fig. 5. CO_2 seasonal variations after data selection for air mass trajectories corresponding to sectors South-West and North-West.

3. Results and discussion

In Fig. 6, the seasonal effect obtained at Amsterdam Island is shown, month by month, after correction for air-mass trajectory effects. A clear minimum of about −0.3 ppm is observed in April–May–June, just 1 month later than in the other southern hemisphere stations. A maximum reaching up to +0.4 ppm is obtained in August, i.e., 1 month earlier than in other stations: thus only 1 month (July) separates the main peak from the end of the seasonal minimum. The peak-to-peak magnitude of 0.7 ppm is probably the smallest seasonal variation in the world.

The existence of a difference between Amsterdam Island and other stations of the southern hemisphere can be attributed to the fact that the CO_2 variations are due to 2 very different processes. On the one hand, the various sources and sinks of CO_2 vary with the season. It is obviously the case for the anthropogenic component and

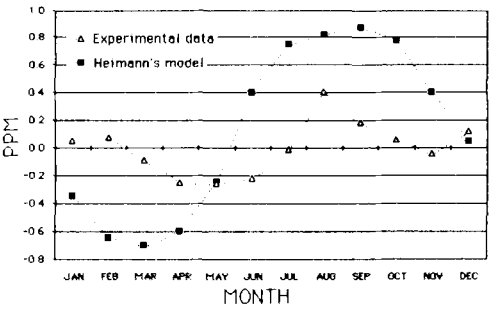

Fig. 6. CO_2 seasonal variations at Amsterdam Island: experimental data after data selection and correction of non-stochastic effects (triangles) and Heimann's computations (squares).

the continental biomass, as well as for the air–sea exchanges where we have to consider the seasonal variations of pCO_2 in superficial water and of the wind velocity which drives changes in the transfer piston velocity. On the other hand, the seasonal variation of the general atmospheric circulation leads to changes in the long-range transport of CO_2.

For this reason, modelling the CO_2 variations in a given station requires applying a general model to the particular conditions prevailing in this station. This was done by Heimann for Amsterdam Island (pers. comm.) from the model of Heimann (pers. comm.). The results are reported in Fig. 6, where a clear discrepancy can be observed between model and experimental data. In fact, the computation by Heimann showed that at Amsterdam Island, only continental biomass and air–sea exchanges driven by seasonally-varying pCO_2 plays a significant rôle, the others sources and sinks being negligible.

It was possible at Amsterdam Island to trace the rapid advections of air masses coming from South Africa, owing to monitoring ^{222}Rn whose variations have been intensively studied by Polian et al. (1986). As a matter of fact, significant peaks of ^{222}Rn, associated with such advections, are generally observed at Amsterdam Island from May to October. We have calculated separately the monthly mean values of seasonal signals obtained for ^{222}Rn concentrations larger or smaller than 2 pCi/m^3, respectively. The first ones, designated as C, correspond essentially to recent (less than 1 week) passages of the air mass over South Africa, the others being designated as X. The difference C–X is reported in Fig. 7. The same figure shows, for Amsterdam Island, the time-derivative of that part of the Heimann's CO_2 seasonal variations due to the only continental biomass, which is representative of the strength of this source. The good correlation coefficient, 0.8, between these variations shows that as a whole, Heimann's computations represent rather well the continental biomass component to CO_2 seasonal variations at Amsterdam Island. The difference pointed out in Fig. 6 therefore seems essentially due to a too-rough modelling of the air–sea exchanges and especially to the fact that, in this model, the transfer piston velocity was considered as constant over the year.

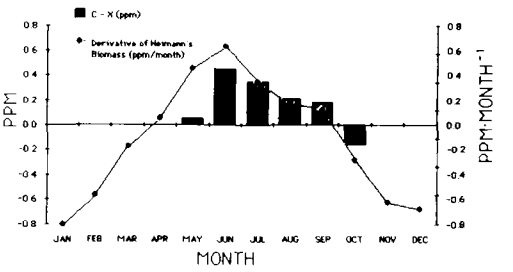

Fig. 7. The seasonal continental biomass component. CO_2 seasonal variation difference (bar) between air masses originating recently from South Africa (C) and the other air masses (X). Time derivative (black curve) of that part of Heimann's CO_2 seasonal variations due to the only continental biomass.

4. Conclusion

The CO_2 seasonal variations at Amsterdam Island, after a very strict data selection and adjustment for average meteorological conditions, show a very low peak-to-peak amplitude of 0.7 ± 0.1 ppm with a maximum in August only 3 months after a minimum around May.

It seems that the fall minimum could be attributed to a stronger strength of the oceanic sink during the colder season (April to October), according to the model of Pearman et al. (1983), where the seasonal variations of the transfer piston velocity are taken into account. However, according to our Fig. 7, from June onwards, this oceanic effect is hidden by higher CO_2 contents of continental air masses, well represented by the model of Heimann (pers. comm.).

5. Acknowledgments

The authors thank all those having contributed to data collection in the field. They are particularly grateful to Dr. J. M. Miller, for back trajectories calculations, and to Dr. M. Heimann for providing the results of his model applied to Amsterdam Island. This study was supported by the "Administration des Terres Australes et Antarctiques Francaises" and by the "Programme Interdisciplinaire de Recherches sur l'Environnement" (C.N.R.S.).

REFERENCES

Ascencio-Parvy, J. M., Gaudry, A. and Lambert, G., 1984. Year-to-year CO_2 variations at Amsterdam Island in 1980–83. *Geophys. Res. Lett. 11*, 1215–1217.

Bacastow, R. B., Keeling, C. D. and Whorf, T. P. 1985. Seasonal amplitude increase in atmospheric CO_2 concentration at Mauna Loa, Hawaii, 1959–1982. *J. Geophys. Res. 90*, 10,529–10540.

Beardsmore, D. J. and Pearman, G. I. 1987. Atmospheric carbon dioxide measurements in the Australian region: data from surface observatories. *Tellus 39B*, 42–66.

Fung, I., Prentice, K., Matthews, E., Lerner, J. and Russel, G. 1983. Three-dimensional tracer model study of atmospheric CO_2: response to seasonal exchanges with the terrestrial biosphere. *J. Geophys. Res. 88*, 1281–1294.

Gaudry, A., Ascencio, J. M. and Lambert, G. 1983. Preliminary study of CO_2 variations at Amsterdam Island (Territoire des Terres Australes et Antarctiques Francaises). *J. Geophys. Res. 88*, 1323–1329.

Gaudry, A., Monfray, P., Polian, G. and Lambert, G. 1987. The 1982–1983 El-Niño: a 6 billion ton CO_2 release. *Tellus 39B*, 209–213.

Harris, J. M. 1982. The GMCC Atmospheric Trajectory Program, NOAA Tech. Memo, ERL ARL-116.

Komhyr, W. D., Gammon, R. H., Harris, T. B., Waterman, L. S., Conway, T. J., Taylor, W. R. and Thoning, K. H. 1985. Global atmospheric CO_2 distribution and variations from 1968–1982 NOAA/GMCC CO_2 flask sample data. *J. Geophys. Res. 90*, 5567–5596.

Mook, W. G., Koopmans, M., Carter, A. F. and Keeling, C. D. 1983. Seasonal, latitudinal, and secular variations in the abondance and isotopic ratios of atmospheric carbon dioxide 1. Results from land stations. *J. Geophys. Res. 88*, 10,915–10,933.

Pack, D. H., Ferber, G. J., Heffter, J. L., Telegadas, K., Angell, J. K., Hoecker, W. H. and Machta, L. 1976. Meteorology of long-range transport. *Atmos. Environ. 12*, 425–444.

Pearman, G. I., Hyson, P. and Fraser, P. J. 1983. The global distribution of atmospheric carbon dioxide 1. Aspects of observations and modeling. *J. Geophys. Res. 88*, 3581–3590.

Peterson, J. T., Komhyr, W. D., Harris, T. B. and Waterman, L. S. 1982. Atmospheric carbon dioxide measurements at Barrow, Alaska, 1973–1979. *Tellus 34*, 166–175.

Polian, G., Lambert, G., Ardouin, B. and Jegou, A. 1986. Long range transport of continental radon in subantarctic and antarctic areas. *Tellus 38B*, 178–189.