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Preliminary Study of CO₂ Variations at Amsterdam Island (Territoire des Terres Australes et Antarctiques Francaises)

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The preliminary measurements of atmospheric CO₂ concentrations performed at Amsterdam Island between April and the end of 1980 showed two kinds of short-term variations. The first one, attributed to local effects of the photosynthesis of the island vegetation, does not seem considerably to affect the monthly mean CO₂ concentrations. The second one has been attributed to long range transport phenomena. That corresponds to large scale meteorological perturbations and generally is correlated with variations of the atmospheric radon concentrations. Therefore, the existence of regional CO₂ sources and sinks in the southern hemisphere can be felt at a very large distance. Consequently, isolated measurements of geographical gradients, could correspond to a transitory situation and should not be utilized for the determination of these sources and sinks.

INTRODUCTION

It is well known that the atmospheric CO₂ increase recorded by Keeling *et al.* [1976a, b], is accounted for by only 50% of the fossil fuel combustion [Broecker *et al.*, 1979]. The missing amount has certainly been absorbed by the other reservoirs. Therefore, the future change in CO₂ concentrations is highly dominated by the carbon exchanges between the atmosphere and those main reservoirs: continental biomass and seawater. A good knowledge of these exchanges should imply to sight the main sources and sinks of atmospheric CO₂.

One possible strategy consists in the determination of the geographical gradients of the atmospheric concentration and of their seasonal changes [C. D. Keeling, unpublished manuscript, 1981; Fraser *et al.*, 1983]. It has been shown by Komhyr and Machta [1981], that in the southern hemisphere the average differences of concentration, between polar and tropical latitudes could be of the order of 2 ppm or even less. Consequently, the accuracy required for CO₂ monitoring should be as close as possible to 0.1 ppm. Such an accuracy requires in addition to solving problems of metrology and standardization, avoiding any interference due to local effects. Now it has been shown at several stations that the CO₂ concentration variations reach sometimes more than ten ppm, under the influence of local sources or sinks [Lowe *et al.*, 1979], from human or vegetal origin, [Lowe *et al.*, 1979], as well as from the volcanic activity [Miller *et al.*, 1978]. For this reason, we have selected the Amsterdam Island, to establish, in that part of the southern hemisphere, a station for the study of the background pollution, as free as possible from local perturbations.

THE AMSTERDAM ISLAND STATION

Amsterdam Island (Territoire des Terres Australes et Antarctiques Francaises) is located in the South Indian Ocean (Figure 1: 37°47'S, 77°31'E) respectively 3.400 and 5.000 km off Madagascar and South Africa, which are the nearest continents to be considered in these latitudes to leeward of westerly winds.

There is no active volcanism and no regular marine or air traffic corridors in the vicinity of the island. The population is

limited to about 30 people, living at the scientific base Martin de Viviers (Figure 2a).

The flora has been described by H. Schenk [1904]. A limited number of species predominate, defining approximately three different areas as it can be seen in Figure 2b. The scarce specimen (less than one hundred), of *Phyllica Nitida*, a low tree, specific of Amsterdam and Tristan Da Cunha Islands, are confined in the eastern part, within a one hectare-area. The surroundings of the sampling point at Pointe Bénédicte, 2.5 km westwards from Martin de Viviers, are mainly composed of *graminea*.

Carbon dioxide has been monitored there since April 1980. Meteorological records [Annales de la Météorologie, 1977] show that the wind is blowing 60% of the time directly from the sea (Figure 2c), i.e., from the 260° to 60° sector.

Therefore, this site looks particularly well adapted to a background CO₂ monitoring station.

EXPERIMENTAL PROCEDURES

The air is collected on the top of an 8-m high aluminium tower, set up at several tens of meters of a cliff (Figure 3). The flow rate is 0.25 l min⁻¹. The air sampled crosses successively (1) a membrane pump Hartmann-Braun WISA 2, located in the



Fig. 1. The French islands in the subantarctic areas.

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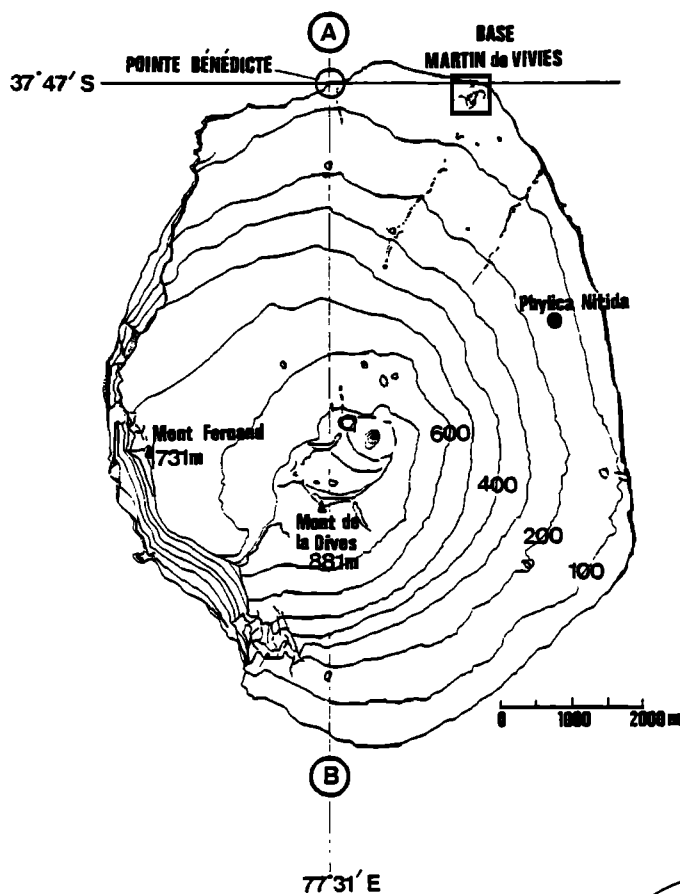


FIG 2A

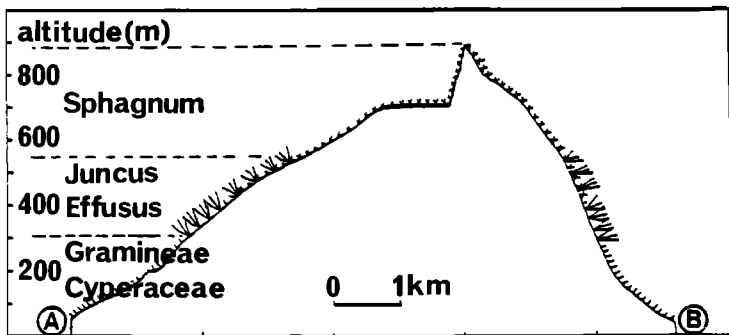


FIG 2B

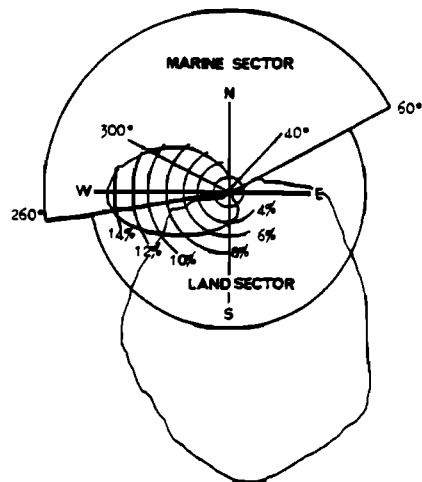


FIG 2C

Fig. 2. (a) Map of Amsterdam Island with the contour-lines. In the eastern part, a black point denotes the location of a few trees 'Phylca Nitida,' a Rhamnaceae growing in the island. (b) Altitude profile, following the north-south AB section, showing the main vegetal species with respect to the elevation. (c) Wind rose corresponding to the meteorological data recorded between 1951 and 1971.

building 1 (Figure 3b), (2) a -55°C cold trap that removes water vapor (Figure 3c), and (3) a 22-m long aluminium pipe with a 6-mm inner diameter.

Every hour, two field standard gases at 320 and 345 ppm in N_2 , respectively, are introduced during 5 min each, into the analyzer. Every other week, both are compared with another pair of standard gases whose pressure remains approximately constant.

During the first year of measurements, no standard gas certified by the Scripps Institution of Oceanography was available

at Amsterdam Island. Consequently, the whole of the following results are expressed in an arbitrary scale.

VARIABILITY AND LOCAL EFFECT

Two different shapes of records have been obtained and are shown in Figure 4. The first kind consists in a very steady curve and corresponds to either winds blowing from the marine sector and faster than 3 m s^{-1} , or strong winds faster than 10 m s^{-1} . The second kind, obtained in weak winds, for which the direction was not well defined, or for air masses having rather

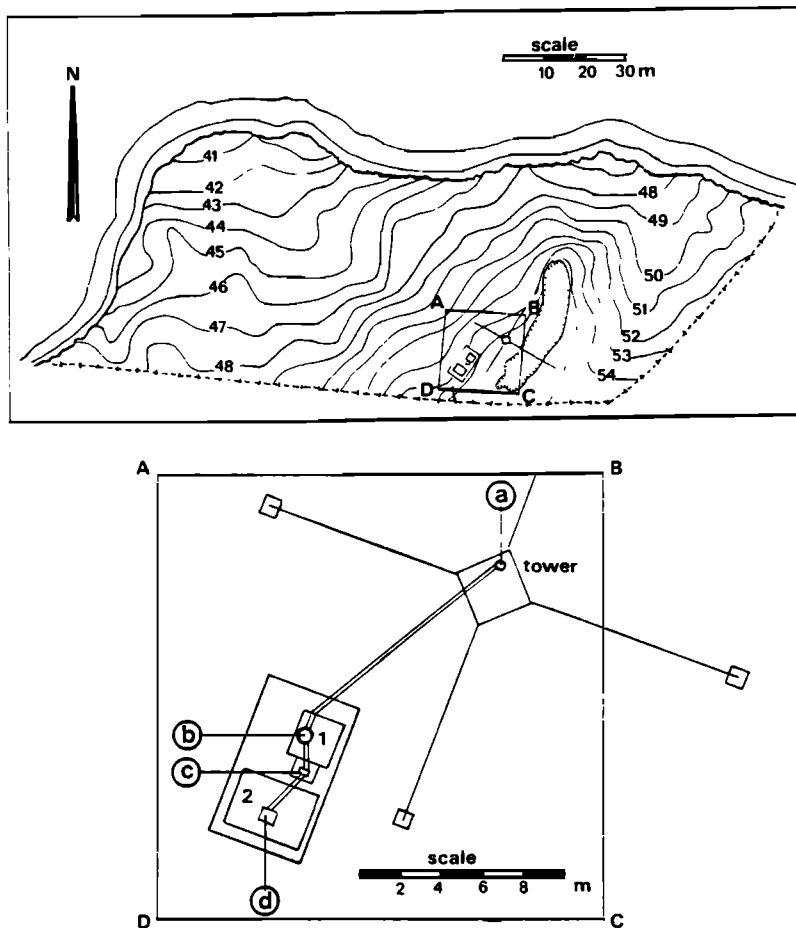


Fig. 3. At the top: The site of the sampling point at Pointe Bénédicte. The particular square ABCD has been enlarged at the bottom to show the implantation of the substructure: (a) sampling point at the top of the 8-m high tower; (b) building 1: electrical supplies and pumps; (c) ventilated box with the cold trap; (d) analyzer building (2).

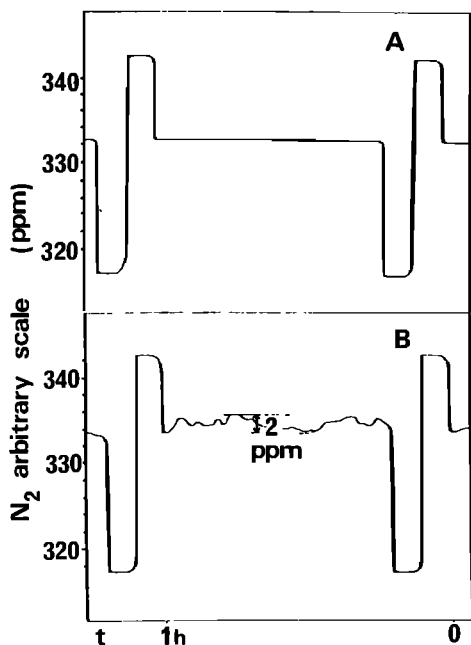


Fig. 4. One-hour records of atmospheric CO₂ concentrations obtained at Amsterdam Island. (a) In 1980, October 21, 14 hours, by a 13 m s⁻¹ wind from the 300° direction. (b) In 1980, October 22, 4 hours by 1 to 2 m s⁻¹ winds from the 100° (standard deviation $\sigma = 0.78$).

slowly crossed over the island, presents significant fluctuations.

A short-term variability can be estimated by means of the hourly standard deviation (σ) calculated from 10 points taken every 5 min. It has been observed that for a wind sector comprised between 300° and 040° (see Figure 2c), σ is frequently less than 0.2 ppm.

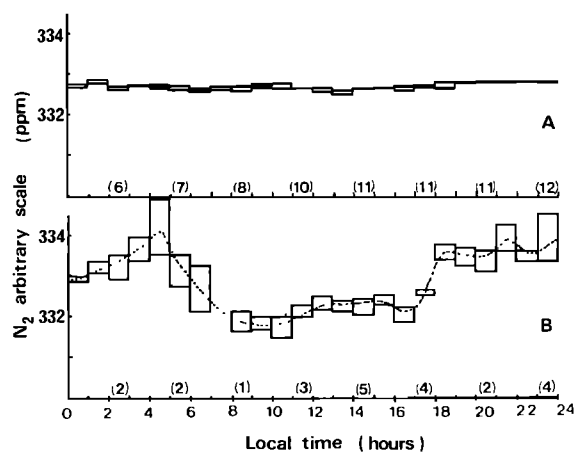


Fig. 5. One-day evolutions of atmospheric CO₂ concentration at Amsterdam Island, in 1980, (a) in September 19 by marine sector (300°–320°) and (b) in October 22 by land sector (160°–260°).

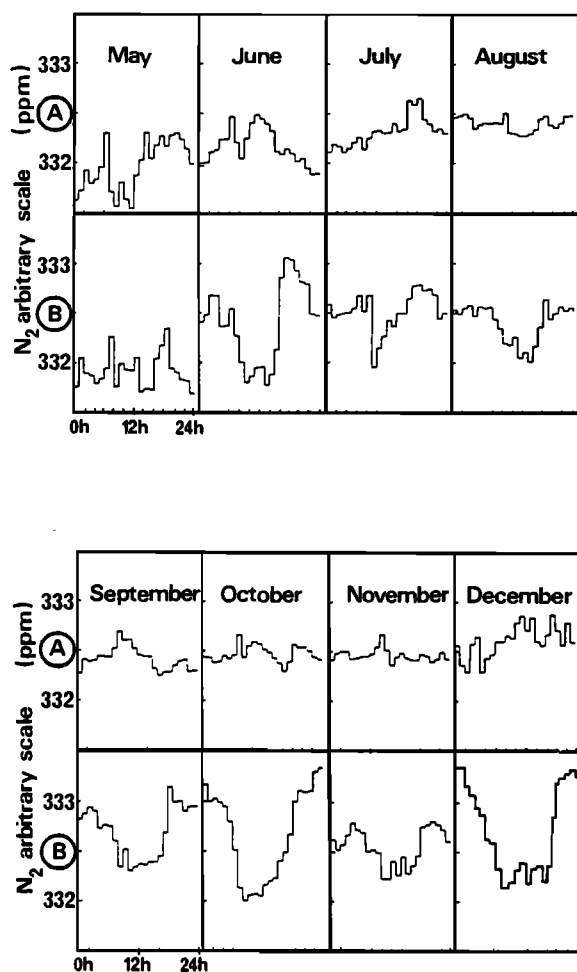


Fig. 6. Average daily atmospheric CO₂ variation from the marine sector (300°–040°) and from the land sector (60°–260°).

On the contrary, in air from a by-land sector (060° to 260°), a possible influence of the soil and of the vegetation of the island is indicated by σ reaching 1.75 ppm.

DIURNAL VARIATIONS

In agreement with the preceding remarks, it can be observed that, as far as marine air masses are concerned, no diurnal variation of CO₂ concentration occurs (see Figure 5a). In contrast, by land sector winds, a minimum of the CO₂ con-

TABLE 1. CO₂ Mean Monthly Values

Month	(1)		Difference Between sectors
	Monthly Mean CO ₂ Content by Marine Sector,* ppm	Monthly Mean CO ₂ Content by Land Sector,† ppm	
May	331.98	331.91	-0.07
June	332.19	332.42	+0.23
July	332.35	332.54	+0.19
August	332.40	332.42	+0.02
September	332.41	332.69	+0.28
October	332.47	332.67	+0.20
November	332.46	332.55	+0.09
December	332.63	332.66	+0.03
		Average:	0.12

*The marine sector corresponds to a wind blowing from the sector 300°–040°

†The land sector corresponds to a wind blowing from the sector 060°–260° (see text and figure 2).

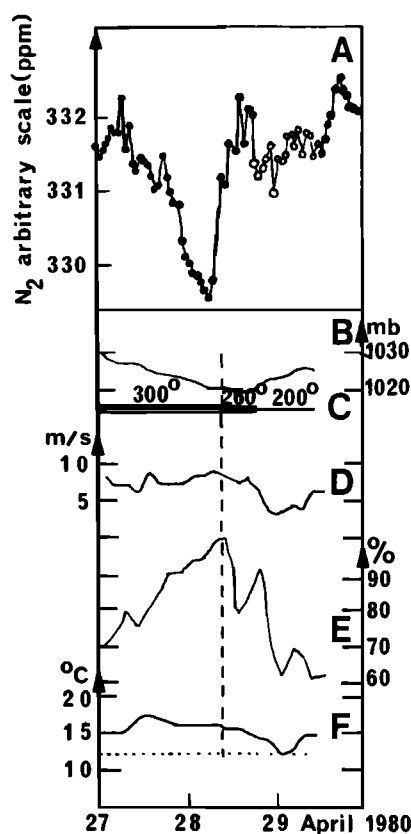


Fig. 7. Observation of a 2.5 ppm decrease of CO₂ concentration (a), corresponding to the passage of a meteorological perturbation observed at Amsterdam Island. Curve (b) represents the barometric pressure, (c) the wind direction, (d) the wind velocity, (e) the relative humidity, and (f) the air temperature.

centration can be observed at the middle of the day (see Figure 5b), which could be attributed to the photosynthesis of the island vegetation.

In order to quantify this local effect, we have calculated for every month, an average daily variation for both wind sectors.

In Figure 6, the mean CO₂ concentrations, corresponding to the marine wind sector, do not present any clear diurnal trend: the amplitude of the mean daily variations is less than 0.76 ppm. By land sector (Figure 6), a clear diurnal effect can be observed, with a magnitude ranging from 0.58 ppm to 1.34 ppm. However, this effect does not seem to be related to the seasons, but rather to the specific character of the local land biomass, as well as meteorology.

It is worthwhile pointing out that the mean monthly values obtained for both sectors, are very close, as is apparent in Table 1.

LONG-RANGE TRANSPORT OF CO₂ VARIATIONS

As shown above, it has been possible to select meteorological conditions for which any local interference can be ruled out, i.e., winds stronger than 3 m s⁻¹ blowing from a 260°–60° sector. However, even in these conditions, a significant CO₂ variability is still observed, which can be related to changes in the meteorological parameters (Figure 7).

During the short period between April 20 and September 30, 1980, not less than 29 meteorological fronts of air masses were registered at Amsterdam Island. They are listed in Table 2. In 8 of these 29, the CO₂ variations do not stand out from the noise. However, in the other 21 cases the large scale meteorological

perturbations are associated with significant CO₂ variations, also listed in Table 2, with their plus or minus sign amplitudes (in ppm).

A correct interpretation of the phenomenon could be made easier by a correlative study of the atmospheric ²²²Rn concentration. Indeed, this radioactive gas is known to be a good tracer of continental air masses and has been extensively used at the French Subantarctic stations by Lambert *et al.* [1970, 1972] and Polian [1982]. These authors have particularly shown that significant increases of ²²²Rn concentration are stably associated with meteorological fronts, during several days, and can be observed successively at Crozet, Kerguelen, and Amsterdam islands. The positions of these islands are shown in Figure 1. Hence, the existence of significant peaks of ²²²Rn, that is ²²²Rn concentrations larger than 1.5 picocuries m⁻³, is mentioned in Table 2.

Two typical examples of the progression of a radon event from west to east are given in Figures 8 and 9, where the CO₂ concentration at Amsterdam Island is also indicated. A clear correlation between CO₂ and ²²²Rn concentrations can be seen in these figures. However, this correlation seems to be sometimes positive and sometimes negative.

The results gathered in Table 2 can be summarized as follows: out of over 29 meteorological fronts, 5 are neither accompanied with a radon event, nor a CO₂ event, 7 are correlated simultaneously with a radon peak higher than 4 pci m⁻³, and with a CO₂ concentration increase, 14 are correlated with a CO₂ concentration decrease, 8 of these events being accompanied with a small, but significant radon peak, and 3 correspond

TABLE 2. Correlative Variations of CO₂ and ²²²Rn Concentrations With the Passage of Meteorological Fronts Registered at Amsterdam Island

Date	CO ₂ Event Amplitude in ppm	²²² Rn Event, picocuries/m ³
April 20, 1980	-0.8	0
April 24, 1980	-2	0
April 27-28, 1980	-2.5	0
May 12, 1980	0	1.8
June 2, 1980	+0.7	4
June 6-9, 1980	-0.8	1.6
June 13, 1980	0	0
June 15-17, 1980	+1.3	4
June 20, 1980	-1.3	0
July 1-2, 1980	-0.7	1.6
July 4-5, 1980	-1.3	0
July 8, 1980	0	0
July 10-11, 1980	0	0
July 12, 1980	0	0
July 18, 1980	0	2
July 25-27, 1980	+0.65	4.5
July 29-31, 1980	+0.7	8.5
Aug. 2-3, 1980	0	0
Aug. 4-5, 1980	+0.5	5
Aug. 12-13, 1980	+0.9	6.5
Aug. 17-18, 1980	+0.85	4
Aug. 21-23, 1980	-1.1	1.6
Aug. 25-26, 1980	-0.6	1.9
Aug. 29-31, 1980	0	2
Sept. 2-3, 1980	-1.1	2.5
Sept. 7-8, 1980	-0.7	1.5
Sept. 15-16, 1980	-1	0
Sept. 17-21, 1980	-1.6	2
Sept. 23-26, 1980	-1.1	1.6

The plus and minus signs correspond to CO₂ concentration increases and decreases, respectively, compared with the background. The radon background between 0 and 1.5 pCi/m³, is indicated by 0.

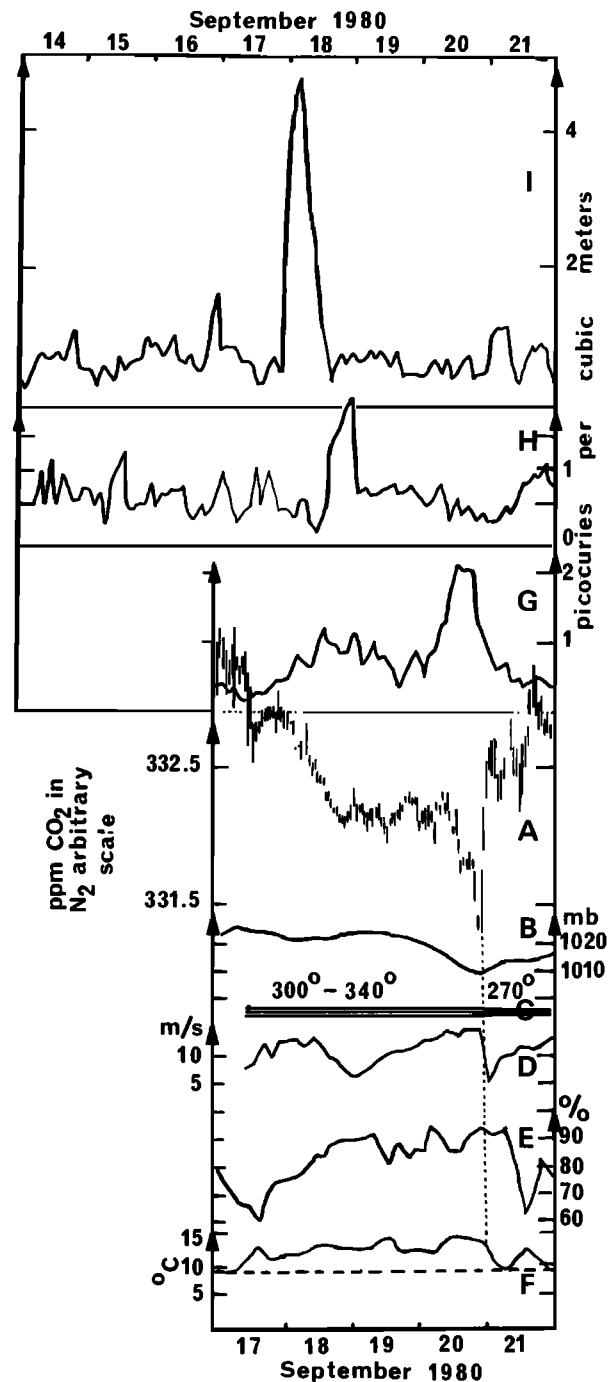


Fig. 8. Negative correlation between ²²²Rn (G) and CO₂ concentrations (\pm hourly mean standard deviation) (a) at Amsterdam Island, obtained during the passage of a front in 1980, between September 17 and 21. Curve (b) represents the barometric pressure, (c) the wind direction, (d) the wind velocity, (e) the relative humidity, and (f) the air temperature. The radon events are observed at Kerguelen (H) and Crozet (I) islands with respective lapse times of 36 and 56 hours before the corresponding passage at Amsterdam Island.

to a small peak of radon, without a significant CO₂ concentration variation.

The existence of peaks of radon concentration has been interpreted as an advection of air from South Africa. Therefore, it seems very likely that the CO₂ variations should have the same origin.

It is well known that, owing to the low vertical eddy diffusion of the air during the night, the radon concentration over a

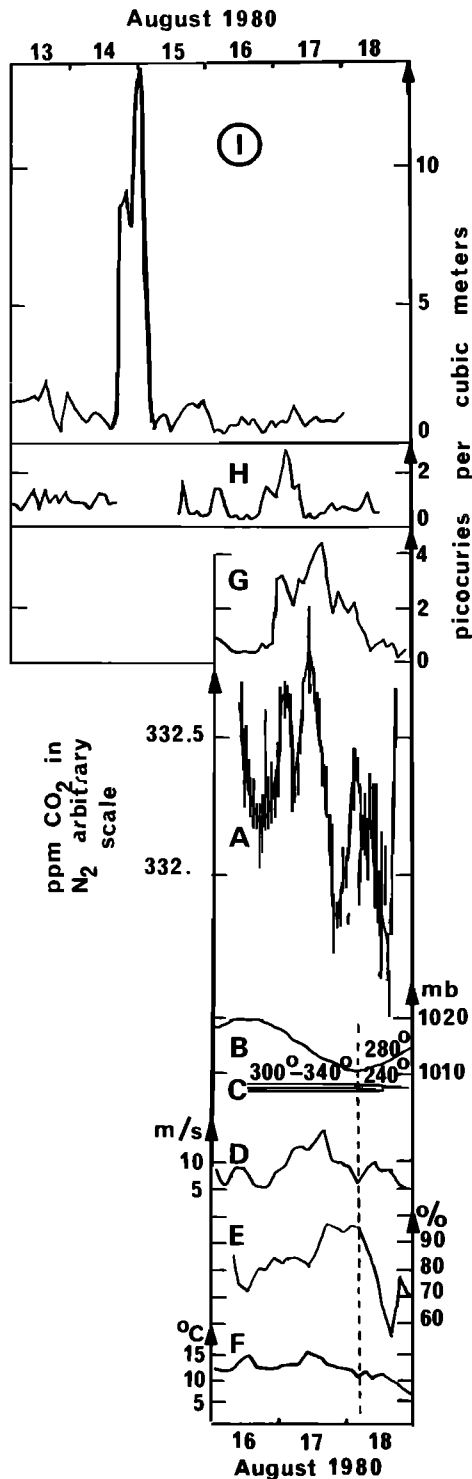


Fig. 9. Positive correlation between ²²²Rn (G) and CO₂ concentrations (± hourly mean standard deviation) (a) at Amsterdam Island, obtained during the passage of a front between August 16 and 18, 1980. Curve (b) represents the barometric pressure, (c) the wind rotations, (d) the wind velocity, (e) the relative humidity, and (f) the air temperature. The radon events are observed at Kerguelen (H), Crozet (I) islands, with respective lapse-times at 12 and 60 hours with the corresponding passage at Amsterdam Island.

continental area is then higher than during the day. The same diurnal variation is also observed in the case of CO₂ and is attributed to photosynthesis. This similitude has been shown by Dörr *et al.* [1981], who found in Europa, a good correlation

between ²²²Rn and CO₂ concentrations with a diurnal pattern.

Actually, it can be observed in Table 2, that all ²²²Rn peaks, reaching or exceeding 4 pci m⁻³ are correlated with CO₂ concentration increases. Conversely, the CO₂ concentration decreases are systematically obtained when the ²²²Rn concentrations are smaller than 2.5 pci m⁻³ or even at its background level.

To summarize, it seems that we can observe at Amsterdam Island, with similar frequencies, three different kinds of non-local variations of the atmospheric CO₂ concentration, of the order of ±1 ppm:

1. CO₂ concentration increases associated with ²²²Rn peaks superior or equal to 4 pci m⁻³, which are interpreted as advectations of night air masses from South Africa. In a few cases, the correlation between ²²²Rn and CO₂ concentrations is very sharp, as shown in Figure 10.

2. CO₂ concentration decreases associated with small ²²²Rn peaks between 1.5 and 2.5 pci m⁻³ interpreted as advectations of day air masses from South Africa.

3. CO₂ concentration decreases non-associated with any significant ²²²Rn variation that possibly could be attributed to an absorption process by the sea water.

In the three examples shown in Figures 7, 8, and 9, the evolution of the meteorological parameters shows a simultaneous increase of the temperature and the relative humidity at the start of each CO₂ event. This enables us to admit that these air masses have a tropical origin. This tropical character sharply disappears with the passage of the cold front and the end of the CO₂ event.

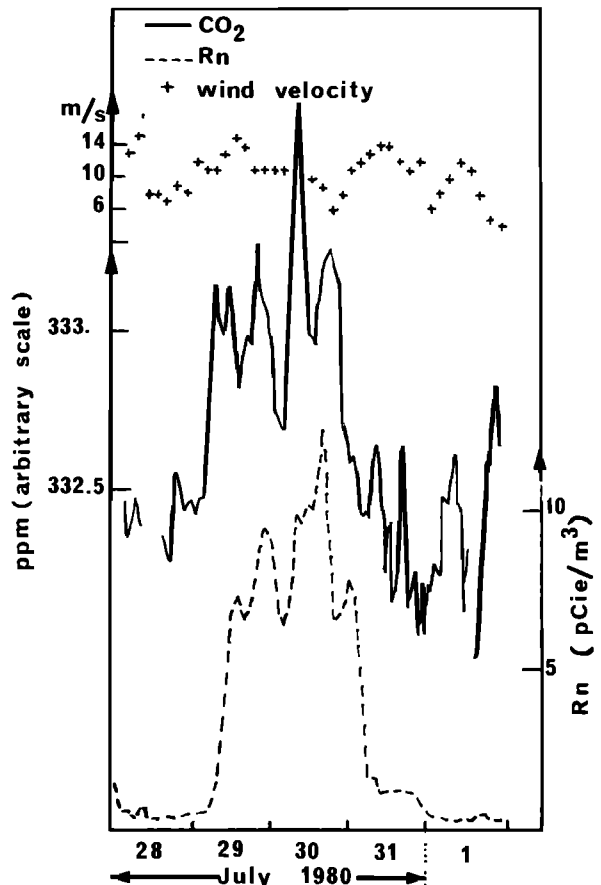


Fig. 10. Variations of CO₂ (full line), and ²²²Rn (dashed-line) concentrations obtained from July 29 to 31, 1980, by strong winds (6 to 14 m s⁻¹) from the marine sector.

CONCLUSION

After a first year of CO₂ monitoring, and despite the lack of an intercalibration, some interesting results have been obtained at Amsterdam Island, concerning the existence of a short-term variability.

Despite the exceptionally isolated situation of the sampling site, a first kind of variations can be attributed to local causes. When the winds are very light, or when moderate breezes cross the island, the photosynthetic activity of the vegetal mass generates some diurnal variations of the CO₂ concentration of the order of 1 ppm, reaching scarcely 1.6 ppm. However, a good knowledge of the meteorological conditions, and allowing for the standard deviation, enable us to discard any data disturbed by local interferences. Moreover, we have seen that the mean monthly value is very little affected by such an effect, in the case of Amsterdam Island, where the vegetation is sparse.

On the other hand, it seems that the concentrations of atmospheric trace gases, like ²²²Rn and CO₂ are rather well preserved along trajectories longer than 5000 km.

Therefore, the existence of CO₂ regional sources and sinks in the southern hemisphere can be felt at a very large distance. It involves CO₂ variations of the order of 0.5 to 2.5 ppm during 1 to 3 days in a remote station. Consequently, the measurements of geographical gradients at a given time could correspond to a transitory situation and therefore should not be utilized for the determination of these sources and sinks. Such a study could only be made in the future by considering the mean values obtained during a long time in settled stations, or possibly after a very careful study of long range transport phenomena.

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