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Continuous measurements of atmospheric CO_2 at Jubany Station, Antarctica

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ABSTRACT

The first 4 years (1994–1997) of continuous atmospheric CO_2 measurements from Jubany station located on the Antarctic peninsula are presented. Details are given on the station environment, meteorological conditions, instrumentation, and data selection strategy. The average seasonal cycle and annual growth rate are characterized and compared with other independent Antarctic CO_2 measurement records. An analysis of diurnal behaviour and local meteorology and statistical variability in the measurements suggests that Jubany is a suitable site for making systematic observations of CO_2 that are representative of large well-mixed air masses.

1. Introduction

Ongoing systematic observations in remote areas are important in detecting signs forewarning of climate change due to human activities. The rôle of CFCs in ozone destruction (WMO, 1994) and our increasing dependence on fossil fuels in the buildup of CO_2 in the atmosphere (IPCC, 1996) have received such worldwide attention that one might presume that our current global observational network has already achieved the necessary geographical coverage. While the global distribution of atmospheric CO_2 is well-documented (Conway et al., 1994) and the major sources and sinks classified (Tans et al., 1989), our understanding of the processes that drive the global carbon cycle is incomplete (Denning et al., 1996, Ciais et al., 1995, Tans et al., 1990, Keeling et al., 1989). Several carbon cycle studies (Rayner et al., 1996) have suggested that our understanding of the carbon cycle would be greatly improved if we could expand our sampling network to include areas which are, at present, under sampled, i.e., Siberia, Africa, South America, and the southern oceans.

Since the 70s, the World Meteorological Organization (WMO) Global Atmospheric Watch (GAW) program has promoted and coordinated initiatives aimed at expanding our observational network to areas of the world that have thus far been poorly sampled. Areas identified as significant regional sources and sinks of CO_2 are particularly important and require ongoing high-precision measurements with high temporal and spatial resolution. Complementary measurements of atmospheric CO_2 in the planetary boundary layer using tall towers and light aircraft and of pCO_2 in the oceans are also required to better understand the processes that control the exchange of CO_2 between the atmospheric, ocean, and terrestrial biosphere. *Carbon America* (Tans

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et al., 1996) is one plan designed to quantify the fluxes of CO_2 within North America. *EUROSIBERIAN CARBONFLUX* (*EUROSIB*) (Michel Ramonet, LSCE, France, personal communication) is similar to the Carbon America sampling strategy with the goal of improving our understanding of the magnitude and distribution of sources and sinks of CO_2 in Eastern Europe and Western Siberia. Currently underway, EUROSIB is a 3-year pilot program that will also serve to study the feasibility of an extensive measurement strategy such as that described by Tans et al. (1996).

The WMO has recently sponsored the development of remote stations at Ushuaia (Tierra del Fuego, Argentina), Arambepe (Bahia-Brazil), Bukit Koto Tabang (Sumatra-Indonesia), Tamanrasset Assekrem (Algerian Sahara), and Mt Waliguan (Chino-Tibetan Plateau). In this framework, the National Research Program in Antarctica (PNRA) of Italy and the Argentine National Department for Antarctica (DNA) have agreed to install a laboratory for continuous measurements of atmospheric carbon dioxide at the remote station of Jubany (JBN) located on the Antarctic peninsula.

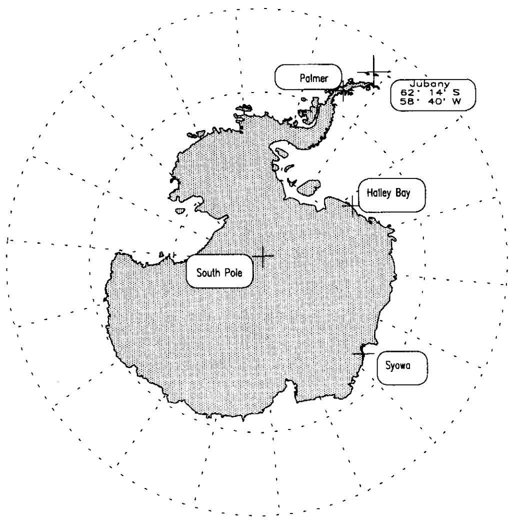

Fig. 1. Map of Antarctica showing the position of 3 GAW stations (South Pole, Syowa and Jubany) making continuous CO_2 measurements and 2 other sites (Palmer and Halley Bay) where air samples for CO_2 measurement are taken.

2. Experimental

The Jubany station (lat. 62° 14′S, long. 58° 40′W) is situated on King George Island in the South Shetland archipelago, just north of the Antarctic peninsula. The laboratory is placed 15 m above sea level, on the SE slope of Potter Bay. The bay, which is ~1 km wide and extends ~2 km inland, is surrounded by permanent glaciers except for a small section in which the station is located. Typically, the sea stretch of the bay freezes for 2–3 months each year. The base is operational year-round. During the austral summer, the station is re-supplied by an icebreaker ship. Fig. 1 shows the location of Jubany on the Antarctic peninsula. The photo in Fig. 2 shows the Jubany Station and surroundings.

The ground is lacking vegetation except for scattered patches of lichens and musk which appear during the summer when volcanic soil re-emerges from the snow cover (see Ciattaglia et al. (1996) for a more detailed description of the Jubany station and surroundings). The site is ~1000 km from Cape Horn and the forested areas of Tierra del Fuego. However, air transported from the South American continent to Jubany is sufficiently diluted and appears to have minimal influence on the atmospheric CO_2 measurements. The strong atmospheric circulation which dominates the Antarctic continent surroundings ensures that air is well-mixed. A trajectory analysis program will be implemented next and it would be much easier to identify the origin of the air masses. The Jubany station lies at the Drake Passage where the average wind speed is ~10 m s^{-1} and periods of calm are infrequent. Meteorological conditions for 1996 are summarized in Figs. 3a, b and typify the general climatology of the area surrounding Jubany. South-West and North-East are the predominant wind sectors, see also Ciattaglia et al. (1996) for further details.

Jubany is ~400 km from Palmer Station (PSA), USA (West border of Antarctic peninsula) and ~1900 km from the British Antarctic Survey base at Halley Bay (HBA), Weddell sea coast (Fig. 1). The National Oceanic and Atmospheric Administration (NOAA) Climate Monitoring and Diagnostics Laboratory (CMDL) has been making discrete observations of atmospheric CO_2 and other trace gas species at PSA, HBA, South

Fig. 2. Panoramic view of Jubany station and Potter bay (King George island — South Shetland archipelago).

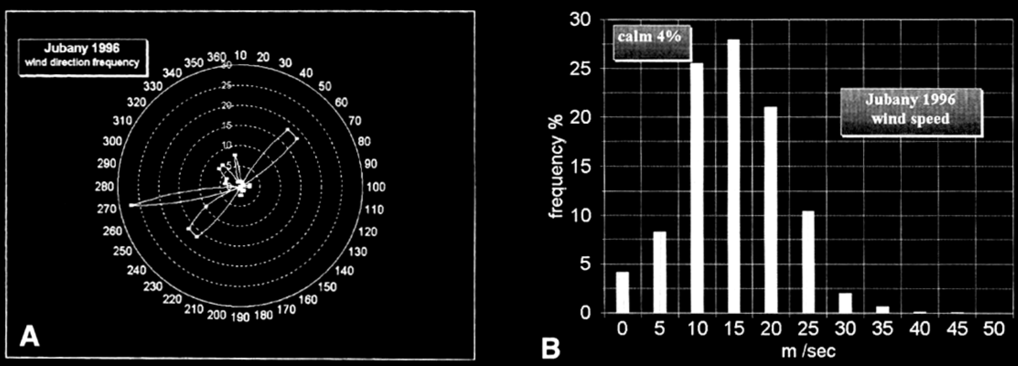

Fig. 3. (a) Wind rose for 1996: 3-h measurements taken by the local meteorological station. (b) Frequency distribution of 3-h wind speeds taken by the local meteorological station.

Pole (SPO), and Syowa (SYO) since the late 1970s. Atmospheric CO_2 is continuously monitored at Amundsen Scott Base by NOAA CMDL and at Syowa Station by the National Polar Research Institute (NPRI) of Japan. Beginning in 1994, continuous measurements of atmospheric CO_2 at Jubany provide high resolution observations on a spit of land that predominantly samples air from the southern ocean. Jubany therefore comes out as the third base making continuous CO_2 measurements in Antarctica.

The sampling strategy used at Jubany is described in detail elsewhere (Ciattaglia et al., 1996). The analysis system is based on a Siemens U5 non-dispersive infrared (NDIR) analyzer. In January 1997, a mass flow controller was installed which controls the flux (250 sccm) of each sample (air or standard gas) passing into the measurement cell. The flow of reference gas into the reference cell is manually maintained at 50 sccm using a flow meter. A glass U-shaped tube placed in a freezing trap maintained at −70°C removes water vapour from the ambient air and measuring gases before they enter the analyzer. The air intake line is mounted on a 10-m mast located 40 m from the Laboratory building.

Two sets of 4 CO_2 in dry-air station standards are currently in use at Jubany. The 8 standard gas cylinders were initially calibrated in 1994 with reference to the Italian national standard scale (maintained by ENEA in Rome). The two sets were returned separately to Rome where they were recalibrated in November 1997 and February 1998 before being refilled and returned to the station. Relative concentration drifts in the cylinders during the 3-year period were small (maximum: $+0.3$ ppm for an individual tank, $< +0.2$ ppm the whole drift of the scale). In the future, recalibration of station standards will occur every 2 years. The national standard scale maintained by the ENEA is based on a set of 8 primary reference cylinders (range 335–385 ppmv) that were calibrated in 1993–1994 by the Central CO_2 Laboratory (maintained, at the time, by the Scripps Institution of Oceanography, USA). A new refilling and calibration of ENEA primaries is scheduled for 1999 at NOAA CMDL; therefore, only after this operation would it be possible to ascertain any drift of individual tanks or of the scale. All CO_2 concentrations at the present time are expressed according to the WMO X93 scale.

The analyzer scale is automatically recalibrated every 3 h using 2 working standards (zero and span) that differ by no more than 20–25 ppm with respect to each other. The measuring cell is flushed with cylinders' air for 5 min before beginning a 1-min recalibration measurement. Working standards are calibrated weekly against the station standards. The accuracy achieved in the calibration phase and in the atmospheric CO_2 measurement is 0.1 ppm and the precision is of the order of 0.05 ppm.

3. Data handling

Data are acquired by means of an analog-to-digital 12-bit card connected to the analog port of the analyzer. From the high-frequency scan of the signal, 1-min values are calculated. 10-min averages are computed and average values having standard deviation (s.d.) $\leqslant 0.5$ ppm are retained. Hourly averages are computed from the 10-min average data. Again, only those hours with s.d. $\leqslant 0.5$ ppm are considered. The hourly average data set is constrained further using wind speed and direction; all hourly averages obtained when winds are from the sector 270–300° (corresponding to the base location) with wind speed $\leqslant 5$ m s^{-1} are eliminated. Finally, daily averages are computed. We assume that daily averages having s.d. > 1 ppm have been compromised during sampling or analysis and are excluded from the selected data set. The selected data set contains 80% of the original data and is available from the WMO World Data Centre for Greenhouse Gases (WDCGG) in Tokyo. For the purpose of this study, a last selection criterion considers only daily averages where the difference between 2 consecutive days is < 1 ppm. This constraint which excludes 1–2 days per month is applied in order to select air masses having the same origin on the assumption that a day-per-day stability means a homogeneus air mass. This criterion will be discarded when back trajectories are available for the site. Fig. 4 shows selected daily mean values for the period 1994–1997. The graph includes a dashed line representing the interpolation of the data record and a continuous line representing the long term best fit. Calculated annual mean values at Jubany (JBN), Palmer (PSA), Halley Bay (HBA), and South Pole (SPO) are shown in the Table 1.

The measured growth rate in 1996 is ~ 2.10 ppm (with respect to 1995), considerably higher than the increases measured by CMDL at SPO (1.58 ± 0.03 ppm), PSA (1.53 ± 0.05 ppm), and HBA (1.3 ± 0.05 ppm), and with respect to preliminary values from the New Zealand baseline station at Baring Head (courtesy of Martin Manning, NIWA, New Zealand). This result has been carefully examined. A number of hypotheses have been taken into consideration concerning station standard drift and potential problems in sample collection and analysis (analyzer, air pump, freezing trap, etc). We cannot completely exclude the possibility of a systematic offset in the Jubany measurements; however, it might be that the 1996 observations document a year of anomalous regional outgassing in the southern ocean. Jubany

Table 1. *Annual mean CO_2 at Jubany, Palmer, Halley Bay and South Pole stations*

	1985	1996	1997
JBN	358.2	360.3	361.8
PSA	358.1	359.6	361
HBA	358.1	359.4	360.1
SPO	357.9	359.5	361.1

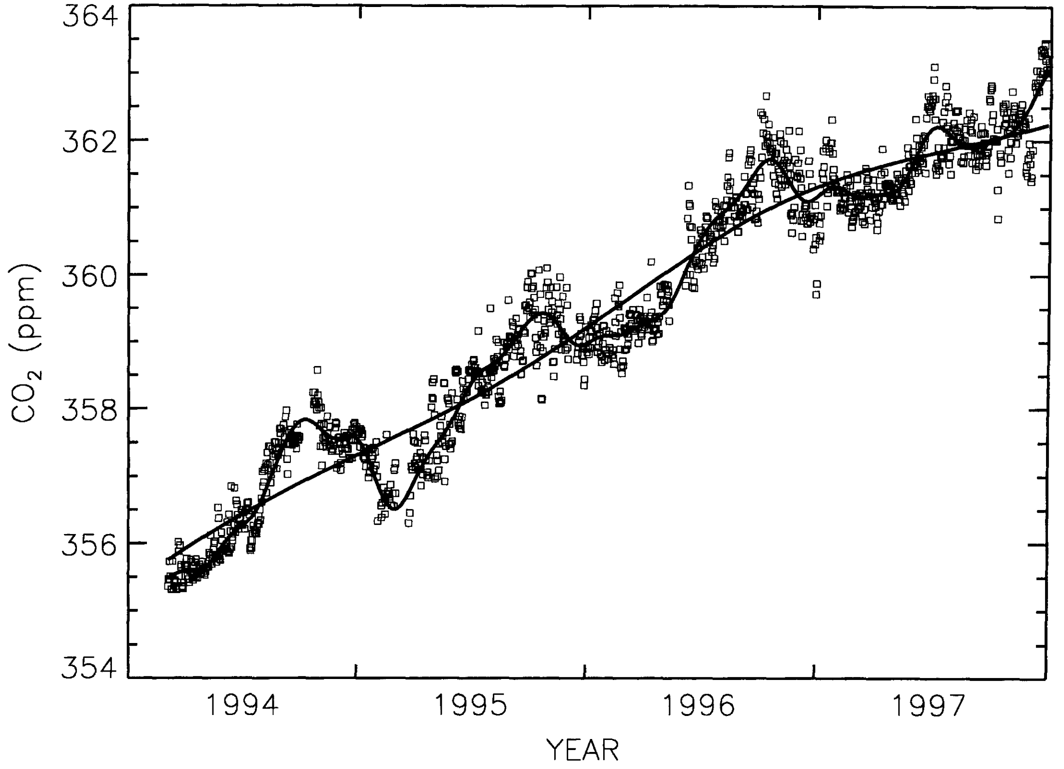

Fig. 4. 4 years of CO_2 daily averages: square dots (selected according to the criterion detailed in the text), smooth curve fit and long-term trend are also shown.

is strategically located on the Antarctic peninsula and observations there may be providing a glimpse of the natural variability in southern ocean CO_2 flux. Work continues to ensure the measurements are of the highest quality and that the large increase in 1996 is real. Until this issue is resolved, the data should be interpreted with caution.

4. Evidence for site remoteness

Fig. 5 shows the seasonal pattern in the observations; maximum values (August to November) occur during the austral spring, and minimum values (January to March) during the summer. Selected daily mean values with the long-term trend removed are shown in the Fig. 5.

Superimposed solid lines refer respectively to the seasonal cycle for each year and to the average seasonal cycle of Jubany calculated for the period 1994–1997. Interannual variability in the seasonal cycle is quite evident. The average seasonal cycle observed at Jubany was also compared with the seasonal cycles from CMDL flask measurements at PSA, HBA, and SPO. Only CMDL data for the 4-year period 1994–1997 were considered. The curve fitting method used in this analysis is described in detail by Thoning et al., (1989). Briefly, the average seasonal cycle is estimated by fitting a function of the form

$$f_{STA}(t) = a_0 + a_1 t + a_2 t^2 + \sum_{k=1,2} [b_{2k-1} \sin(2\pi kt) + b_{2k} \cos(2\pi kt)] \quad (1)$$

to the measurements, where t is the time in years since 1 January 1994. The average seasonal cycle is approximated by the harmonic components of eq. (1). The amplitude of the average seasonal cycle at JBN (1.0 ± 0.2 ppm) is comparable (Fig. 6a) to the average amplitude at PSA (1.3 ± 0.1 ppm), HBA (1.2 ± 0.4 ppm), and SPO (1.0 ± 0.1 ppm). The average seasonal cycle at

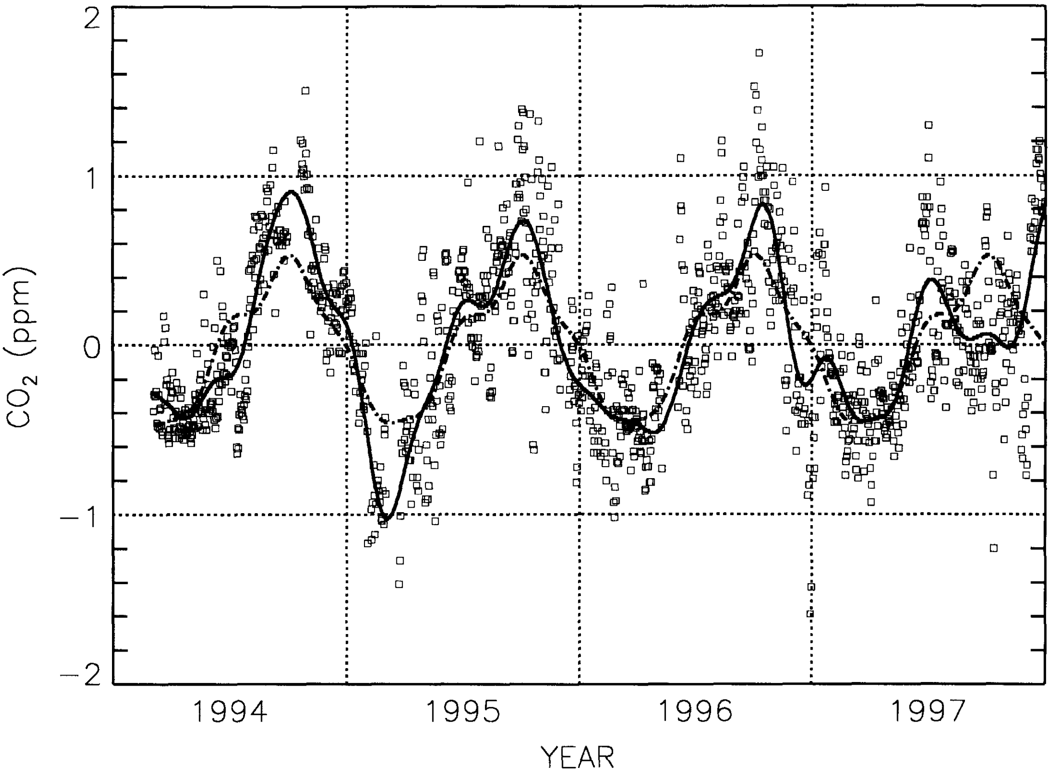

Fig. 5. Detrended daily CO_2 averages for 1994–1997 (square dots), seasonal cycle for each year (solid line), and average seasonal cycle (dash-dot line).

these sites appears to be nearly in phase with small differences likely due to regional influences from biospheric activity, ocean exchange, and atmospheric transport.

To better understand the importance of the Jubany observations relative to existing observations, we compare the long-term trend at Jubany with the trends at the 3 CMDL sites. The long-term trend is constructed using eq. (1). To account for interannual variability in the long-term trend, the residuals can be digitally filtered through a low-pass filter with a full width at half maximum of approximately 1 year. The result from the 1-year filter is then combined with the polynomial terms in eq. (1) to produce the deseasonalized trend. Fig. 6b shows the trend curves derived from measurements at JBN, PSA, HBA, and SPO. The trends are similar prior to 1996. In 1996, the trend at Jubany departs from the trends at the CMDL sites with a maximum difference of ~ 1 ppm. By late 1997, the trend at Jubany is again consistent with the trends observed at the CMDL sites. To explain this behaviour, one would require a source of CO_2 that is detected at Jubany but not at the other locations. While this explanation is possible, we prefer to postpone any conclusion to the end of the recalibration procedure and with the aid of the back trajectories tool.

An indication of site remoteness can be drawn from the following analysis. Selected hourly average values for 1994 have been fitted with a single exponent smoothing model (Gardner, 1985). A large % of the residuals from the smooth curve fit (smoothed values minus data) lies between ± 0.5 ppm. In particular, they are 75% during November–December and 85% during May (Fig. 7); the gap 1–20 October 1994 was due to a failure in the data acquisition system. The higher residuals are during the local summer when the weather improves and the number of visitors to

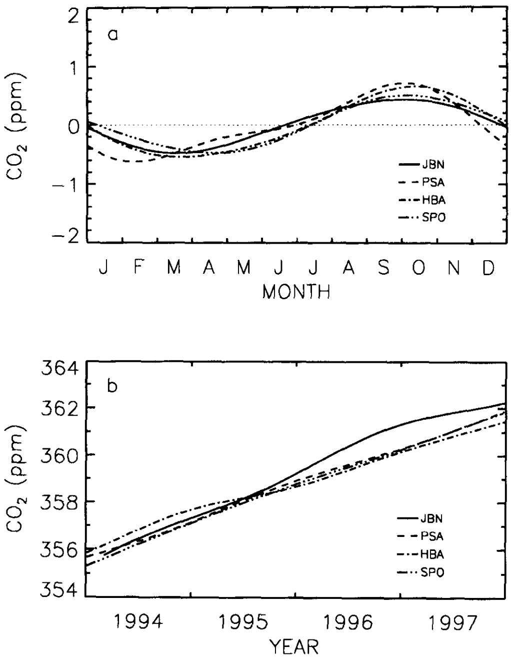

Fig. 6. (a) CO_2 average seasonal cycle at Jubany (JBN), Palmer (PSA), Halley Bay (HBA) and South Pole (SPO). (b) 1994–1997 CO_2 trend curves for Jubany, Palmer, Halley Bay and South Pole.

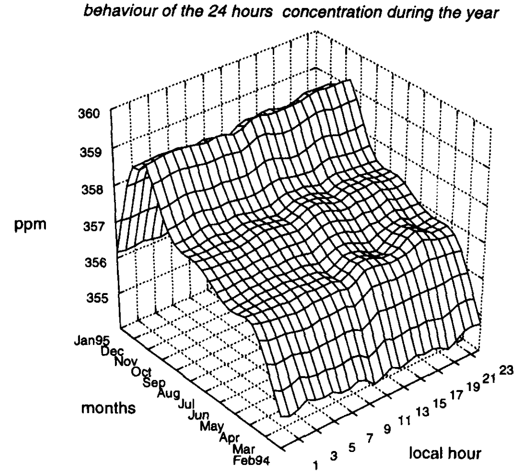

Fig. 8. 3-dimensional graph showing the Jubany monthly averaged CO_2 diurnal behaviour 1–24 (local hours) in the year 1994.

the base increases. Another explanation could reside in the increased air-sea exchange along the coast when the sea ice is melted. It is our opinion that this result demonstrates that hourly values undergo only small temporal fluctuations and consequently, concentrations obtained at Jubany are characteristic of background conditions most of the time.

The possible presence of a diurnal cycle at Jubany has also been investigated. Fig. 8 shows a 3-dimensional distribution of monthly averages of each hour in the day for 1994.

The surface in Fig. 8 suggests that there is no significant variability in the CO_2 mixing ratio related to the time of the day throughout the year.

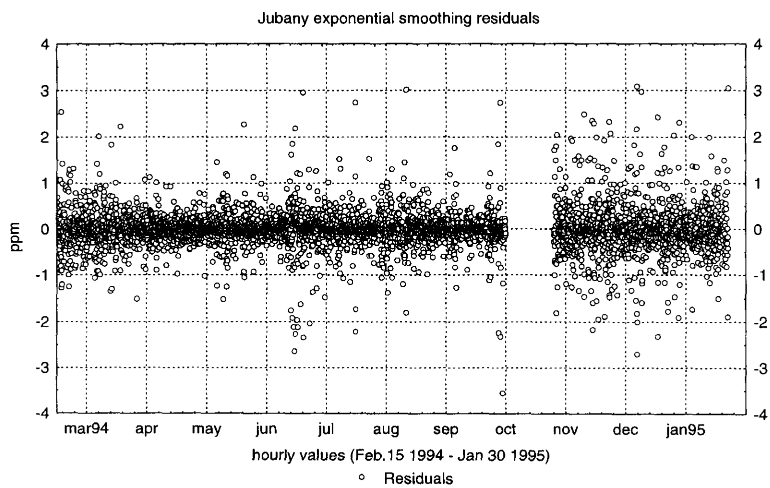

Fig. 7. Single exponential smoothing CO_2 residuals calculated on the 1st-year hourly values for Jubany.

A similar surface for a northern hemisphere station would be characterized by a deep drawdown (caused by the convective activity) for the hours 0900–1800 during the months when photosynthesis is most active (Cundari et al., 1995) and a respiration enhancement at night when stability increases. This result is further evidence that there is minimal influence from local vegetation (missing on the island) and transport from the forested land of Tierra del Fuego on the Jubany measurements.

Finally, we look for a potential relationship between wind direction and CO_2 concentration. Surface-wind measurements are made by the local meteorological station where the operator takes measurements every 3 h by using a direct reading anemometer and a wind vane. Winds at the station are predominantly from the SW and, to a lesser extent, NE (Fig. 3).

Fig. 9 shows the relationship between wind direction/speed and CO_2 using the technique described below. The surface represents contemporary 3-h CO_2 1997 concentrations detrended (Z-axis) as a function of wind directions (X-axis) and wind speed (Y-axis). The surface, derived from a cubic spline function, suggests only a fair relationship between concentration and winds with an amplitude not exceeding 0.3–0.4 ppm. This result suggests that data selected according the criteria described earlier are not affected by air mass origin in the same way as the data of middle latitudes or continental sites.

5. Conclusions

The first 4 years (1994–1997) of atmospheric CO_2 measurements from Jubany station on the Antarctic peninsula have been presented. Analysis of the Jubany record suggests that CO_2 measurements are minimally influenced by the South American continent. Strong winds characteristic of the region ensure that air reaching Jubany is well-mixed and representative of large air masses. Local contamination removal, using a selection strategy that employs measurements of wind speed and direction and short-term variability in the CO_2 record should be better defined in the future when a back-trajectories program will be used in order to identify the air mass origin.

The location appears ideal for making measurements on the Antarctic peninsula and in the Drake

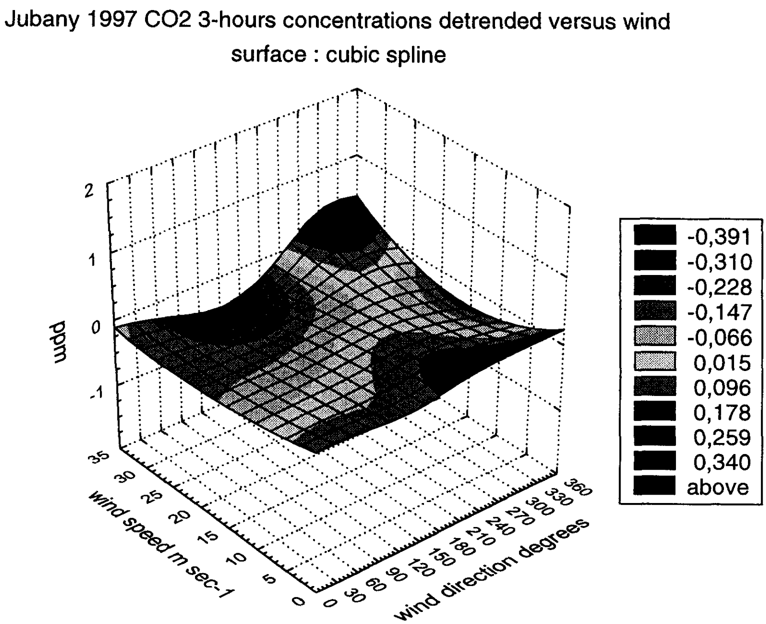

Fig. 9. A cubic spline surface showing hourly detrended CO_2 concentrations versus wind direction and speed.

Passage. Jubany measurements generally compare well with flask measurements from CMDL's Antarctic sites. If the differences between Jubany and other Antarctic sites starting in 1996 are verified, it may suggest that Jubany may document interannual variability in regional southern ocean CO_2 fluxes. The selected CO_2 hourly average data set has been submitted to the WMO WDCGG in Tokyo and has been included in recent efforts to construct a cooperative globally-consistent data set of CO_2 for use in carbon cycle modeling studies (GLOBALVIEW-CO_2, 1997).

6. Acknowledgements

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