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Carbon dioxide observations at Izaña baseline station, Tenerife (Canary Islands): 1984–1988

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ABSTRACT

Atmospheric carbon dioxide concentrations have been monitored at Izaña Observatory (Tenerife, Canary Islands) during 1984–1988. Because of its position on top of a mountain plateau at 2,367 m above sea level, the sampled air at this baseline station is usually representative of the free troposphere in the southern part of the North Atlantic. A criterion to select those half-hourly values representative of baseline conditions is established and from these selected data, daily means are calculated. Oscillations produced by different synoptic situations still remain in the selected record and its power spectrum shows a hint of significant frequencies in the typical synoptic range. A low-pass filter with a cutoff frequency of 2 months was used to obtain a record free from synoptic influences representing "background" air and yielding a mean annual cycle with a peak-to-peak amplitude of approximately 7 ppmv.

1. Introduction

The remote baseline station of Izaña is located at 28°18′N, 16°29′W (Fig. 1) on the island of Tenerife (Canary Islands), 1000 km from the nearest point of the European continent and about 400 km from Africa. The station has been running since June 1984, as a result of an international agreement between the governments of Spain and the Federal Republic of Germany. At present, it is operated by the Spanish Weather Service (Instituto Nacional de Meteorología, INM). Continuous measurements of carbon dioxide (CO_2) have been carried out right from the beginning.

The observation program at Izaña and data obtained from the first 15 months of operation have been presented by Schmitt et al. (1988), showing the influence of the long-range transport from source regions on the variability of the measurements of several trace gases. The present paper explains the provisional data set up to December 1988 and those features having an effect on the record. Emphasis will be put on different time and space scales: within half-hourly variations connected to local influences, day to day fluctuations presumably related to the large scale transport of air masses and the seasonal variation in response to the global biospheric activity.

The local effects due to the position of the observatory will be used to determine a strict criterion to select data representative of the free troposphere. A subsequent spectral analysis of this selected data set will allow us to separate the different time-scale contributions. After having applied a low pass filter, the main seasonal features appear in the representative "background" filtered data set, whereas the short-term fluctuations of the CO_2 concentration with respect to the smoothed curve reveal the synoptic influences. A similar analysis has been done previously by Thoning et al. (1989). They also used a digital filtering technique to smooth data and to separate the seasonal cycle from the long-term increase in the CO_2 record of Mauna Loa (Hawaii). Frequent reference to this station operated by the Geophysical Monitoring for the Climatic Change program of the National Oceanic and Atmospheric Administration (U.S.A.) will be made in different parts of this paper. Also the continental station of the Italian Meteorological Service in Mt. Cimone (Italy) will be mentioned. From the comparison to these high altitude stations in the Northern

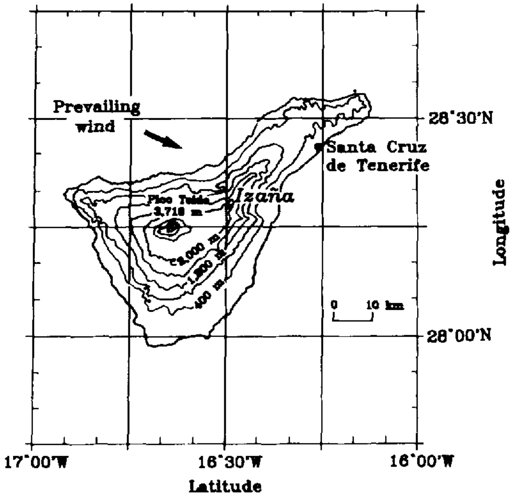

Fig. 1. Location of Izaña station on Tenerife showing the topography of the island. The arrow indicates the prevailing wind direction at the level of the station.

Hemisphere we will test how the results obtained here fit the observed global distribution of the atmospheric CO_2.

2. Weather characteristics in the sampling site

Because of their geographical position, the Canary Islands are in the way of well differentiated air masses. Their successive arrivals at the sampling site determine the main features in the observed CO_2 concentrations. Following Font (1956) and Huetz de Lemps (1969), three main types of synoptic situations define the climatology of Canary Islands:

- Trade wind circulation, whose origin is the high pressure system centered over the Azores islands, is the most common situation.
- Saharan outbreaks, transporting dryer and warmer air from the nearby African continent, have a maximum of occurrence in summer.
- Oceanic disturbances associated with low pressure systems, generally occurring in winter. The most frequent disturbances, that have an effect on the Canary Islands are: polar outbreaks, cutoff lows and southwestern storms.

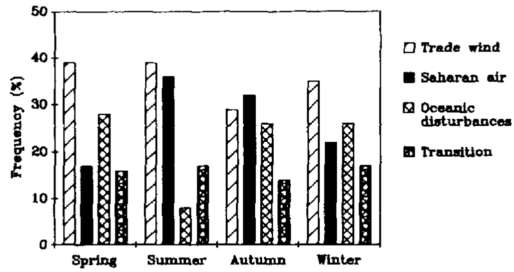

Fig. 2. Seasonal frequency distribution of typical synoptic situations at Izaña from June 1984 to December 1988.

On the basis of this, and with the aid of weather charts, data from the radio-soundings carried-out in Santa Cruz (Tenerife), and meteorological observations at the station, the whole period of measurement has been analyzed on a daily basis and classified according to the kind of prevalent synoptic situation for each season. A fourth group with transition or alternative conditions had to be included. As expected, trade wind circulation appears as the predominant weather situation (more than 30%), while Saharan invasions and Oceanic disturbances do normally occur in summer and winter, respectively (Fig. 2), but the frequency varies from one year to another.

3. Experimental

The CO_2 measurements were performed by a Siemens Ultramat-3 NDIR analyzer. Sample air was being pumped to it from a main air intake whose inlet is 13 m above ground on top of the observatory building. Approximately every 2.5 h, three working standard gases were cycled through the analyzer for 6 min each, using a programmable solenoid valve system. To reduce water vapour interference to the NDIR CO_2 analyzer, all gases were dried by passage through a glass trap cooled at $-35°C$ by an electric refrigerator. Every 10 s, the analog output signal of the analyzer was transferred to a HP computer by a data acquisition unit. Sampled air data were processed and stored on magnetic tape as half-hourly averages and standard deviations ($\delta^{m}_{1/2}$). During the first 3 min after a gas change, the output signal was ignored by the computer to allow the analyzer to equilibrate, so a 3-min mean of 18 single values was calculated for the standards and stored on tape together with the standard deviation (δ_3^c).

The CO_2 concentrations used in this paper are referred to an internal scale based on three primary CO_2-in-nitrogen tanks, and a set of CO_2-in-synthetic air tanks. At present, an intercomparison against the WMO-1987 CO_2 calibration scale is being performed at the Schauinsland station (FRG) under the sponsorship of the Umweltbundesamt (Berlin/FRG). The first results suggest that a linear correction of the data set is necessary. The intercomparison process will not be finished before the end of 1990.

4. Results and discussion

4.1. Local influences

The observatory is located at 2367 m above sea level on top of a mountain plateau on the Dorsal Ridge which crosses the island, overlooking the northern and eastern valleys. To the southwest, the ridge rises to higher altitudes culminating at a distance of 10 km in the Teide volcano at 3716 m above sea level, so the station is exposed to the influence of the dominant northwesterlies from the Atlantic (Fig. 1). The last eruption of the Teide occurred at the beginning of this century. Apart from farming at low altitudes, a pine wood covering from 1000 to 2000 m above sea level surrounds the island. Its nearest point to the observatory is at 3 km to the north, while the vegetation in the vicinity is restricted to sparse low shrubs.

The station is normally above a temperature inversion layer, generally well established over the island, so that sampled air is free from local anthropogenic source influences. However, diurnal heating and the orography of the surroundings lead to an upslope windflow reaching the station during daytime influencing the concentrations of atmospheric compounds. During the night, no downslope wind arrives at the observatory and the air generally represents the free tropospheric composition. Diurnal cycles are present in all observed components. Water vapour pressure increases and CO_2 concentrations decrease during the daytime due to the upslope transport of air from the lower biogenically affected and moister levels. The highest influence on CO_2 occurs in June, lasting from 8 to 20 GMT with a decrease of approximately 2 ppmv, whereas in winter the CO_2 decrease is only 1 ppmv (Fig. 3). Similar local effects have also been found in the CO_2 measured at the Mauna Loa station (see, for example, Pales and Keeling, 1965; Keeling et al., 1976). This observatory, located on the slope of the Mauna Loa volcano, is also affected by a thermally induced local wind circulation described by Mendonca (1969). However, the well-established downslope wind flow arriving at Mauna Loa station during the night occasionally exhibits a highly variable CO_2 concentration due to outgassing of the Mauna Loa volcano (Miller and Chin, 1979), whereas no contaminated air by the volcanic activity of the Teide volcano has been detected at Izaña station.

4.2. Data selection

To obtain a data set representative of baseline conditions, it is necessary to reject the locally affected measurements. As the short-term CO_2 variability at Izaña station is mainly due to the diurnal cycle we could use only night time CO_2 values (from 8 p.m. to 8 a.m.), but this method will remove valid measurements since local influences on the daytime data neither are observed all of the time, nor last the same number of hours. On the other hand, at attempt at defining a "clean air sector" as it has been done for other baseline stations (Monfray, 1987; Robinson et al., 1988)

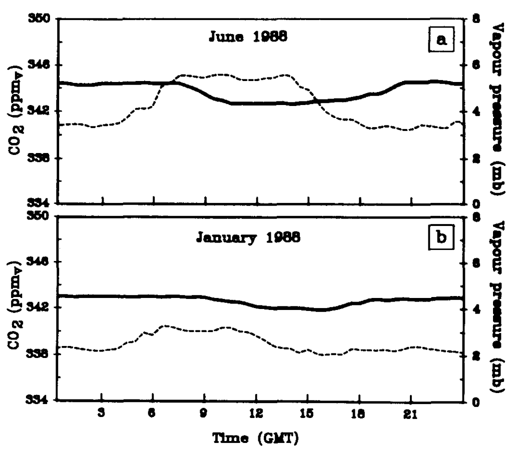

Fig. 3. Mean diurnal variation of the water vapour pressure (dashed line) and CO_2 observations (solid line) at the Izaña observatory in (a) June 1988. (b) January 1988.

did not succeed. For the frequency distribution of half hourly CO_2 standard deviations ($\delta^m_{1/2}$) with respect to wind direction reveals that low CO_2 variability ($\delta^m_{1/2} < 0.1$ ppmv) occurs in all wind directions, most often during the prevailing north-westerlies and sometimes during east wind conditions that appear when the air flow comes from the Sahara desert.

Another way to select baseline data is based on the assumption that an homogeneous air mass free of local contamination has small short-term CO_2 concentration changes. The smallest CO_2 variability that we can measure is in the range of the instrument noise. Taking the variability of measurements made with calibration gases, δ^c_3, as a measure of this instrument noise results in an upper limit for the change in stable concentrations of 0.05 ppmv. Examination of the frequency distribution of 10 s CO_2 measurements for each half-hour period, $\delta^m_{1/2}$, for the entire day and by using only night data (Fig. 4) shows that for most of the data $\delta^m_{1/2} < 0.1$ ppmv, so that $\delta^m_{1/2}$ for night ambient air is comparable to the instrument noise. On this basis, $\delta^m_{1/2} \leqslant 0.075$ might be a satisfactory criterion to select those data used to calculate daily means that represent baseline conditions at Izaña station.

The percentage of the time which satisfies this criterion has been calculated for every month from June 1984 to December 1988, and reaches about 40% on the average. June exhibits the greatest variability and about 70% of the half-hourly data were removed by the criterion selection. It could be expected since in this month the length of the diurnal dip in CO_2 concentration is largest. In contrast, during September and October, CO_2 variability is at a minimum and about 55% of the data are rejected from the background record.

The magnitude of local effects exhibits a dependence on the different air masses reaching the station. The difference between daily mean CO_2 concentration calculated from all half-hourly data, and by using only selected data, has been computed and related to the synoptic situation for every day. This difference is low (between 0 and 0.25 ppmv) in a significantly higher percentage of cases under Saharan conditions. This could possibly be due to the air mass origin itself as well as to the stable stratification established in the hot air mass during its travel over the ocean resulting in a weakening of the local breeze system. It suggests that this situation is the most favourable for avoiding local influences. The small variability in the CO_2 record under Saharan transport has also been detected in Mt. Cimone baseline station (Ciattaglia et al., 1987).

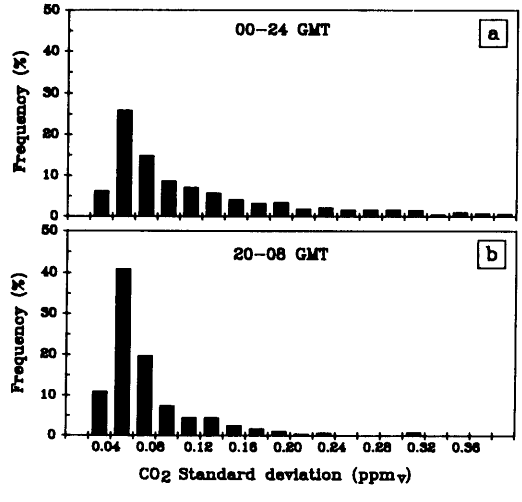

Fig. 4. Frequency distribution of the standard deviation of CO_2 concentration measurements at 10 s intervals for half hour periods ($\delta^m_{1/2}$) in July 1988 for (a) the entire day (from 00 to 24 GMT). (b) during night-time (from 20 to 8 GMT).

4.3. Analysis of time-scale contributions

Inspection of daily averages calculated from data selected using the $\delta^m_{1/2}$ criterion (Fig. 5) shows that day-to-day oscillations frequently occur with

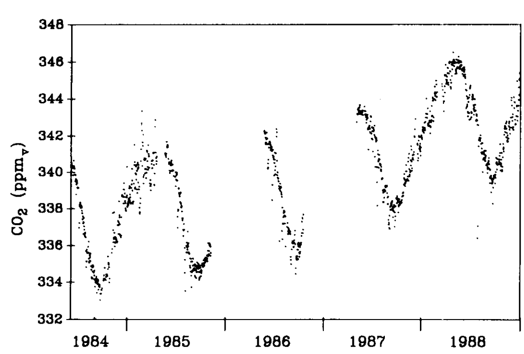

Fig. 5. Selected daily values of CO_2 at Izaña. The selection is for values where the standard deviation of 10-second observations for half-hourly periods were less than 0.075.

magnitudes of up to several ppmv. Once the data have been selected for baseline conditions, application of additional filtering is needed to smooth these variations which are due to long-range transport.

In a manner similar to the Thoning et al. (1989) analysis of the 1974–1985 Mauna Loa data set, the power spectrum of the Izaña CO_2 record has been calculated and a filter has been designed and applied by using programs and methods described by Shumway (1988). Due to the existence of very big gaps in the whole record, we have only used a data set made up of daily selected values from May 1987 to December 1988. Small gaps still present in this period have been filled by linear interpolation. The power spectrum has been computed by means of the Fast Fourier Transform algorithm. As smoothed spectral estimators, the average of the periodogram over an interval centered at each frequency has been used. In order to evaluate the significance of the peaks, we have previously removed from the series the influence of the clearest features e.g. the annual cycle, its first harmonic, and the secular trend, by subtracting from the data the least-squares fit to the function:

$$CO_2(t) = a + bt + \sum_{i=1}^{2} C_i \sin\frac{2\pi i t}{T} + D_i \cos\frac{2\pi i t}{T} \quad \text{for} \quad T = 365 \text{ days.}$$

The resulting series shows a high "persistence". The lag-one autocorrelation coefficient r_1 differs from zero by a statistically significant amount ($r_1 = 0.56$), and the lag-two and lag-three autocorrelation coefficients r_2, r_3 approximately satisfy the condition:

$$r_2 \simeq r_1^2, \qquad r_3 \simeq r_1^3 \qquad \ldots$$

Thus, according to WMO (1966), a Markov red noise is present in the series. A theoretical Markov spectrum was then derived together with its 95% and 5% confidence limits as a null hypothesis to test the existence of any non-randomness. In Fig. 6, this "null continuum" appears plotted over the power spectrum previously computed. Several small departures from the Markov spectrum occur at frequencies from 3 to 7 days. Also a frequency of approximately 1 cycle per 1.5 month appears as a significant peak in the periodogram. Unfortunately, the record length is still rather short to detect frequency peaks with much confidence.

In order to remove the day-to-day fluctuations from the data set, a low-pass filter with a cutoff frequency at 2 months was then designed and applied. The filtered record (solid line in Fig. 7) is free from synoptic influences and represents "background" atmospheric composition at the latitude of Izaña. The annual cycle shows that the seasonal maximum occurs at the beginning of May and the minima in mid September. A peak-to-peak amplitude of approximately 7 ppmv may be observed.

The residuals calculated by subtraction of the daily selected data and the filtered data are normally distributed with mean equal to zero and standard deviation equal to 0.49 ppmv. An attempt has been made to relate the departures in

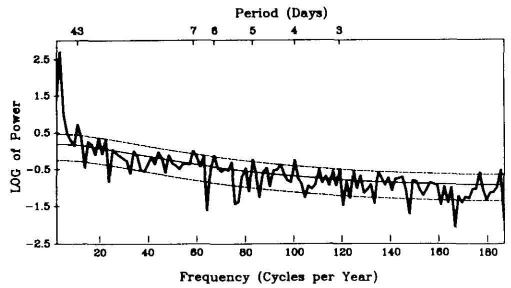

Fig. 6. Power spectrum of the Izaña selected daily average data from May 1987 to December 1988. The smooth solid curve represents the theoretical Markov spectrum and the dashed lines are the 5% and 95% confidence levels.

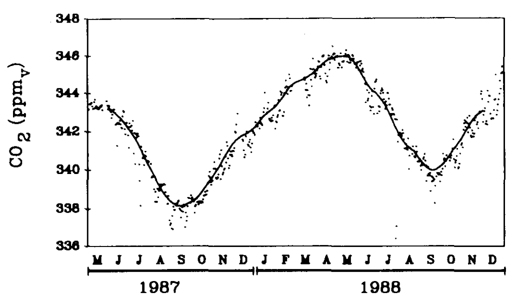

Fig. 7. Selected daily averages at Izaña. The smooth solid line is obtained by filtering the data with a cutoff frequency at 2 months.

the original selected data set from the filtered record to the above mentioned airmass classification. Conclusive results were not found, although, individual short-term fluctuations have been attributed to a transport from higher latitudes under Oceanic disturbances conditions (Schmitt et al., 1988), with the sign of the departure depending on the season of the year. Backward trajectory analyses support these explanations.

The 1.5 month peak in the periodogram could be related to the so called "40-day" wave, a baroclinic eastward propagating disturbance with low zonal wave number, whose period ranges from 30 to 60 days. It was first detected by Madden and Julian (1971, 1972) in the spectral analysis of tropical rawinsonde data and its origin seems to be the large-scale convection associated with the seasonal migration of the intertropical convergence zone. This oscillation is most prominent in the zonal wind field in the tropics (Madden, 1986) and in outgoing long-wave radiation (Weikmann, 1983) in the western Pacific and Indian oceans. However, fluctuations with similar period have been also detected in many variables both in the atmosphere and the ocean and in midlatitudes as well as the tropics (Madden, 1986; Knutson and Weickmann, 1987).

A visual inspection of the record evidences the increase in the CO_2 atmospheric global level due to anthropogenic release by fossil fuel combustion, but due to the short length and the gaps in the series, an additional low pass filter yielding the long term trend cannot be used.

4.4. Comparison with Mauna Loa and Mt. Cimone stations

Geographical coordinates and the characteristics of the CO_2 average seasonal cycle observed at Mauna Loa (Thoning et al., 1989) and Mt. Cimone (Ciattaglia et al., 1987) besides those of Izaña station are listed in Tables 1 and 2, respectively, in order to compare Izaña to other observatories at high altitude in the Northern Hemisphere. Note that the technique used to obtain the annual cycle is different in the case of Mt. Cimone. Ciattaglia et al. fit monthly values with an analytic function consisting of a linear term plus 2 Fourier harmonic terms. Also, the data are referred to different scales, but this only affects the value of amplitude.

Table 1. *Geographical characteristics of three baseline stations*

Station	Latitude	Longitude	Altitude (m a.s.l.)
Mauna Loa	19°32′N	155°35′W	3,397
Izaña	28°18′N	16°29′W	2,367
Mt. Cimone	44°11′N	10°42′E	2,165

The CO_2 seasonal cycle at Mauna Loa presents very similar features to those found in the filtered record of Izaña. The Mauna Loa cycle is slightly delayed (a half month) with respect to the Izaña cycle, but both of them present the same asymmetry, seven and a half months are needed to reach the maximum from the minimum, whereas the annual decrease is completed in four and a half months. The resemblance is not surprising if we bear in mind the similarity of both remote sites, at very close latitudes (Mauna Loa slightly south of Izaña), at high altitude on two islands: Hawaii and Tenerife in the Pacific and Atlantic oceans respectively. A comparison of amplitudes is not possible at both stations until the data are available in the same scale.

On the other hand, as a result of the comparison to Mt. Cimone station, we observe: (i) a phase lag at Izaña in respect to the Mt. Cimone seasonal cycle; (ii) a considerably smaller amplitude of the Izaña cycle; (iii) the annual cycle is more symmetrical at Izaña. These differences could

Table 2. *CO_2 seasonal cycle characteristics at three baseline stations*

Station	Date of maximum	Date of minimum	Mean amplitude (peak to peak)
Mauna Loa	mid May	late Sep.–early Oct.	6.8 (WMO-1985)
Izaña	early May	mid September	6.9 (internal scale)
Mt. Cimone	late March	August	13 (WMO-1980)

be explained by considering the location of Mt. Cimone at higher latitudes than the Izaña station; that it is in Europe, so that it is influenced more directly by the seasonal variation of the regional natural and anthropogenic sources and sinks; and the CO_2 meridional gradient observed.

From isotopic (^{13}C) analyses, it appears that the ocean-atmosphere CO_2 gas exchange does not contribute in a significant manner to the seasonal variations at Izaña; they are mainly biogenic in origin (Schmitt et al. 1988). On the other hand, no biogenic release and uptake of CO_2 produced by the vegetative annual cycle should be expected in the nearby and broadest desert of the Sahara. Thus, it seems that is the latitudinal atmospheric exchange, by means of a long range transport from northern continents, which induces the seasonal variations observed at Izaña.

The results obtained from the comparison to Mauna Loa and Mt. Cimone agree with the Northern Hemisphere CO_2 patterns described by Tanaka et al. (1987) and Conway et al. (1988), who also attribute the phase shift and smaller amplitude observed at lower latitudes to transport from the north.

5. Conclusions

The high percentage of "baseline conditions" occuring at Izaña shows the advantages of the site to sample "clean air" at mid latitudes over the North Atlantic, especially during Saharan outbreaks. Its position is also unique to study the composition of air coming from the African continent nearby.

Short term fluctuations in the record are probably due to the influence of long range transport. Departures from the main "background" annual cycle must be re-analyzed to identify the origin of the air mass in each case more accurately than has been done. This may be carried out with the aid of a climatology of backward trajectories as well as with simultaneous measurements of other trace gases.

The apparent 1.5-month variation should be studied and corroborated by using a longer of data set, when it becomes available in the near future. Also, another low-pass filter to determine the trend could be applied.

Finally, the annual cycle features observed at Izaña station are in concordance with the CO_2 global distributions described previous to this work.

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