CO_2 CONCENTRATION IN THE MEDITERRANEAN: MEASUREMENTS AT THE ISLAND OF LAMPEDUSA IN THE PERIOD 1992-2001

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ABSTRACT

Atmospheric concentrations of carbon dioxide and other greenhouse gases are routinely measured since 1992 at the station for climate observations of the National Agency for New Technology, Energy, and Environment (ENEA) of Italy at Lampedusa. Lampedusa is a small island in the Mediterranean, approximately 100 km east of Tunisia, and 250 km south of Sicily. The 9-year data set has been analysed to quantify trends, and characterize short period (weekly), annual, and inter-annual variability. The data show an average trend of +1.5 ppmv/y; the average annual cycle has an amplitude of about 10 ppmv. In the period of investigation the annual growth rate varies between 0.5 and 4.0 ppmv/y, and the amplitude of the annual cycle between 7 and 11 ppmv/y. The CO_2 growth rate appears to be related to large scale dynamic phenomena, like El Niño/Southern Oscillation (ENSO), and the North Atlantic Oscillation (NAO). In particular, an evident signature of the 1997-98 El Niño event is found on the CO_2 record. A high correlation between the global average temperature and the 12-month average carbon dioxide growth rate also exists.

1. INTRODUCTION

Ice core studies have shown that the atmospheric carbon dioxide concentration has varied roughly between 180 and 290 ppmv throughout the last four glacial cycles [e.g. *Petit et al.*, 1999], has remained at approximately 280ppmv during the last interglacial period, and has dramatically increased, by more than 25%, since the industrial revolution, reaching a present value of about 365 ppmv, unprecedented in the last 400,000 years. This increase, and its possible influence on the Earth's climate, has prompted the need of high quality accurate measurements of the carbon dioxide in the atmosphere. In this paper a nine year CO_2 concentration data set obtained in the Mediterranean sea is described, and the behaviour of the carbon dioxide concentration with respect to large scale phenomena is discussed.

2. MEASUREMENTS

Since May 8, 1992, air samples have been collected on a weekly basis at the island of Lampedusa (33.5°N, 12.6°E), in the Mediterranean sea. The island, whose position is shown in Figure 1, is relatively isolated in the marine environment, about 100 km East of Tunisia, and 200 km North of Libya. Lampedusa has a surface area of about 20 km^2, is rocky, and a poor vegetation is present. On the island there is a village with 4000 inhabitants. Limited influence from the local vegetation and emissions is expected. Air samples have been collected, in the period 1992-1997, from the top of the 20 m tall lighthouse at Capo Grecale, on a promontory on the North-Eastern edge of Lampedusa (sampling altitude of ~65 m). In 1997 a Laboratory for Climatic Observations has been established in a building close to Capo Grecale; since then the air has been sampled at an altitude of 2 m above the ground, approximately 45 m a.s.l. In the sampling procedure the atmospheric air is collected through a viton pipe by means a membrane pump; the air flows through a chemical trap to remove moisture, and is contained in a glass flask kept at a pressure of 3 bar. Prior to the air sampling, flasks are emptied with a vacuum pump to reduce the presence of residing impurities, and ambient air is flushed several times before collection. The carbon dioxide concentration is determined by means of an analyzer composed of a set of electro-valves to select different air sources; a water vapour trap, constituted by a nafion dryer and a deep freezer, that cools the air to approximately -70 °C to remove water vapor from the air sample; a Siemens Ultramat 5E non-dispersive infra red (NDIR) analyzer that measures the CO_2 relative concentration by determining the IR absorption of the gas sample through a cell 180 mm long. All the measuring gases and sampled air fluxes are regulated by a mass flow controller which maintains a stable and laminar flux through the measuring cell.

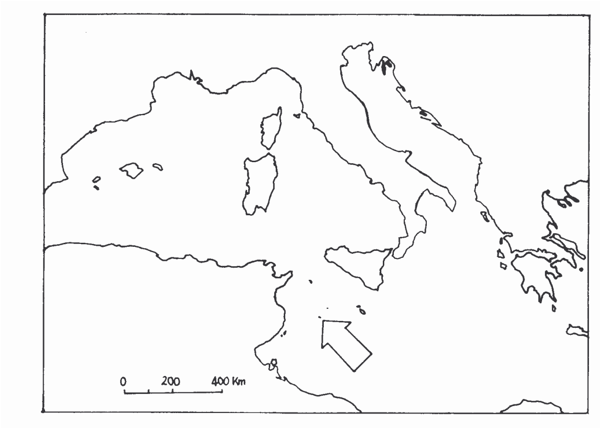

Fig. 1. Map of the central Mediterranean sea. The arrow indicates the position of the Lampedusa island.

The relative concentration is referred to an absolute scale through the following procedure: the gases from two cylinders, containing known amounts of CO_2, are used as working standards during the routine operations; their concentration is measured every three hours by the same system, providing two extrema for the linear response interval of the analyzer. Eight reference sources at known CO_2 concentration provided by the Climate Monitoring and Diagnostic Laboratory (CMDL) at the National Oceanic and Atmospheric Administration (NOAA), are used to calibrate the working standards once a week. The reference scale is the one adopted by the World Meteorological Organization. Standard provided by Central Calibration Laboratory of the Scripps Institute of Oceanography, La Jolla, California, were used before year 2000. A cross check of the two sets of reference standards has shown that a very good agreement exists, and no correction to the measurements carried out prior to year 2000 must be applied. The CO_2 concentration of the eight reference cylinders has been determined by comparison with primary standards, whose concentration was measured with an absolute method [*Zhao et al.*, 1997].

The system, that allows the determination of the CO_2 concentration with an accuracy of less than 0.1 ppmv, has been operational since 1992 at the Casaccia Laboratory of ENEA for the analysis of the weekly flask samples. In 1998 it has been installed at Lampedusa, where an aspiration pump allows the collection of atmospheric air from the top of a 10 m meteorological tower, and the continuous monitoring of carbon dioxide concentration. In this paper the weekly flask measurements will be described.

3. ANALYSIS

The time series of carbon dioxide measured at Lampedusa in the period 1992-2000 is shown in Figure 2. Some general characteristics of the series may be outlined: a progressive increase is evident, with significant yearly variations. The large annual cycle, with a maximum at the end of the winter, has an amplitude of approximately 10 ppmv.

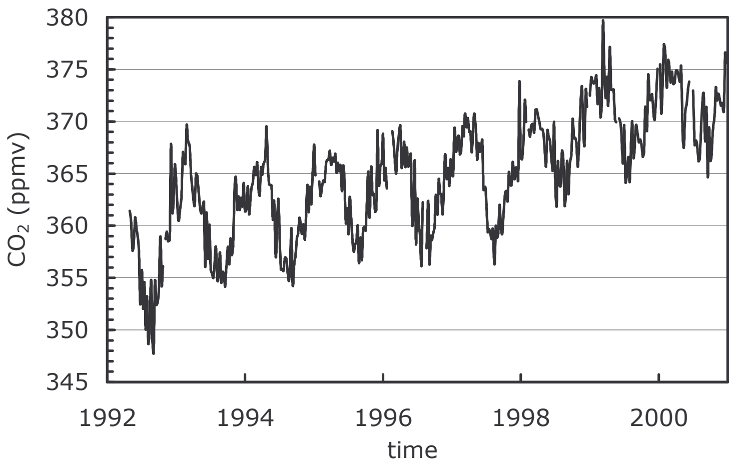

Fig. 2. Evolution of the weekly carbon dioxide concentration at Lampedusa.

Relatively large variations up to 4-5 ppmv occur on a weekly basis, and are probably associated with different origins of the sampled airmasses.

To identify the main periodicities that contribute to the cyclic behaviour of the CO_2 concentration a Fourier analysis has been carried out on the 452 available data. This analysis has confirmed the dominant role of the annual cycle; some role is played by the semi-annual cycle, while periods shorter than 6 months contributing negligibly. Thus, the CO_2 behaviour has been reconstructed by a least-square fit with the equation

$$y=c_1+c_2\, e^{\alpha m} + A \sin[2\pi/T_1(m+\phi_1)]+ B \sin[2\pi/T_2(m+\phi_2)] \qquad (1)$$

where y is the weekly carbon dioxide concentration, m is the week number (week 1 starts on May 8, 1992), α, c_1 and c_2 are constants, T_1 and T_2 are the semi-annual and annual periods respectively, ϕ_1 and ϕ_2 are the semi-annual and annual phases (in weeks), and A and B are the semi-annual and annual amplitudes. Due to the limited length of the record, periods longer than 1 year have not been included in the fit. The parameters obtained from the fit, calculated over the whole 1992-2000 time period, and assuming for c_1 (the CO_2 concentration at time $-\infty$) a value of 280 ppmv, are reported in Table 1.

The exponential growth term may be substituted by a linear term, whose slope is given by αc_2 , and expression (1) has been substituted by the following equation:

$$y=a+b\, m + A \sin[2\pi/T_1(m+\phi_1)]+ B \sin[2\pi/T_2(m+\phi_2)], \qquad (2)$$

where a is a constant (corresponding to the CO_2 concentration at the beginning of the record) and b is a linear growth rate, equal to 1.53 ppmv/y. The annual cycle dominates the periodic behaviour, with an amplitude of about 9 ppmv (two times B). The semi-annual period has maxima in mid-May and mid-November.

Table 1. Parameters of the fit.

Parameter	Value
A	-0.89 ppmv
B	-4.5 ppmv
α	$1.98\cdot10^{-2}$/y
ϕ_1	0.83 y
ϕ_2	- 0.094 y

As shown in Figure 2, a large interannual variability is present. The interannual variability is typical of carbon dioxide records, and is generally attributed to changes of emissions and/or changes of the amount of carbon held in biomass and soils, possibly affected by large scale phenomena [see e.g. *Conway et al.*, 1994, *Keeling et al.*, 1995, and others]. To study the interannual behaviour of the CO_2, expression (2) has been fitted to the observations in 12 month periods, each period starting at the beginning of each month. In this way, a time series of the parameters resulting from the fits are obtained. These parameters have been smoothed by calculating 12 month averages, to remove the variability induced by the variations of the fitting periods with respect to the dominating annual cycle. Figure 3 shows the evolution of the annual growth rate, b. In the period 1993 – mid-1997 the growth rate remains below 2 ppmv/y. Years 1992 and 1993 are known as characterized by a low carbon dioxide growth rate [e.g. *Lambert et al.*, 1995]; this slow CO_2 increase has been related to the effects of the Pinatubo eruption (Philippines, 1991). A much faster increase of the CO_2 concentration takes place in the second half of 1997 and early 1998. A peak growth rate of about 4.5 ppmv/y is reached in mid 1998. The CO_2 growth slows afterwards, returning to ~1.5 ppmv/y in late 1999.

The changes of the growth rate are associated to significant variations of the annual and semi-annual cycle amplitudes (not shown). The annual cycle amplitude has maxima of about 11 ppmv in years 1993 and in mid 1997; values close to or smaller than 8 ppmv occur in 1995, and in 1998-2000. The semi-annual cycle amplitude is always smaller than 3 ppmv, being its maximum in early 1994. A large reduction of the annual and semi-annual amplitudes occurs in correspondence with the fast increase of the growth rate in 1998, indicating that changes of the CO_2 fluxes with the vegetation may play a significant role in the determination of the behaviour of b.

Changes of the growth rate have been related to large scale phenomena, like El Niño/Southern Oscillation (ENSO) [e.g. *Bacastow*, 1976, *Conway et al.*, 1994, *Keeling et al.*, 1995, and others]. In Figure 3 we have plotted the 12-month averages of the Southern Oscillation index (SOI) and of the North Atlantic Oscillation index (NAOI). Large values of the correlation (-0.48) between the SOI and the CO2 growth rate lagged by 9 months. *Thoning et al.* [1989] have found at Mauna Loa (19.5°N) a similar correlation, with a 5 month lag. These results appear consistent with the behaviour reported by Conway et al. [1994], who found an increase of the time lag with latitude.

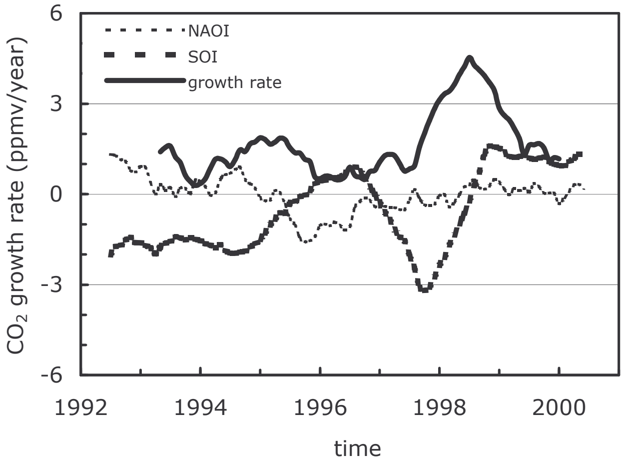

Fig. 3. Evolution of the 12-month averages of the CO_2 growth rate, North Atlantic Oscillation Index and Southern Oscillation Index (the two indices are adimensional).

The correlated behaviour at Lampedusa is dominated by the effect of the 1997/98 El Niño, which is the largest event in the record. A linear relationship between the CO_2 growth rate and SOI in the period 1997-2000 has been used to derive an empirical carbon dioxide growth rate dependent only on the SOI. The difference between the observed growth rate and the empirical one estimated from SOI has been related with the North Atlantic Oscillation index (NAOI). A linear correlation coefficient of –0.45 between the NAOI and the CO_2 growth rate residuals lagged by 19 months is found. By combining the two linear dependencies on SOI and NAOI it is possible to derive an empirical growth rate that takes into account the two indices. The empirical growth rate is within 0.5 ppmv/y of the observed growth rate throughout the period 1994-early 1999. Largest differences, up to 1.5 ppmv/y, are found in the second half of 2000. A large positive linear correlation (0.9) between the global temperature and carbon dioxide growth rate lagged by 3 months is also found. All these results emphasize the role played by large scale processes on the regulation of the carbon dioxide in the atmosphere, and on the carbon cycle.

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