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U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

Two Case Studies Correlating the Baseline CO_2 Record at Mauna Loa With Meteorological and Oceanic Parameters

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TWO CASE STUDIES CORRELATING THE BASELINE CO_2 RECORD AT MAUNA LOA WITH METEOROLOGICAL AND OCEANIC PARAMETERS

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Using the extended monthly mean values of CO_2 concentration at Mauna Loa Observatory and sujecting the data to low and high frequency filters, we have compared the changes in concentration with geophysical parameters thought to have a possible impact on the observations. For the high frequency perturbations, no significant correlation was found between the CO_2 concentration change per month and the sea surface temperature change per month in the area between Hawaii and North America at 20°N. A physical mechansim is proposed to account for the observed relationship, and we show that this variation is distinct from that in the global production rate of CO_2.

1. INTRODUCTION

It is a very difficult task to determine to what extent measurements of atmospheric variables represent regional averages and hence how valid they are as baseline measurements for global changes. A multitude of factors that may or may not have an influence on a particular measurement must be systematically sorted and tested. Because the CO_2 measurement program at Mauna Loa Observatory (MLO), Hawaii (19.5°N; 155.5°W; elevation 3401 meters), has been in existence longer than any other, this record was selected for investigation.

Any meteorological variable is affected both by local and large-scale phenomena. Professor Keeling's group at Scripps (Ekdahl and Keeling, 1973) and the Mauna Loa staff have worked together to assure that the history of CO_2 values at the observatory from 1958 to the present have no local contaminating effects, i.e., the upslope flow to the observatory. The basic question that remains about the CO_2 record is whether we can identify a link between other variables (natural or man-made) and the CO_2 values. Our approach in attempting to answer this question has been to consider the mean monthly values of CO_2 at Mauna Loa and to correlate them against two of the multitude of possible factors: (1) the atmospheric flow patterns, and (2) the sea surface temperature.

2. CO_2 DATA

Figure 1 depicts the monthly mean CO_2 data as reported by Pales and Keeling (1965), Keeling et al. (1974). Recently it was found that a constant must be added to these values (Keeling, personal communication). This change does not affect the present results. These data show variability on three separate time scales, thus each must be considered separately: (1) long-term growth pattern resulting in an increase of about 11

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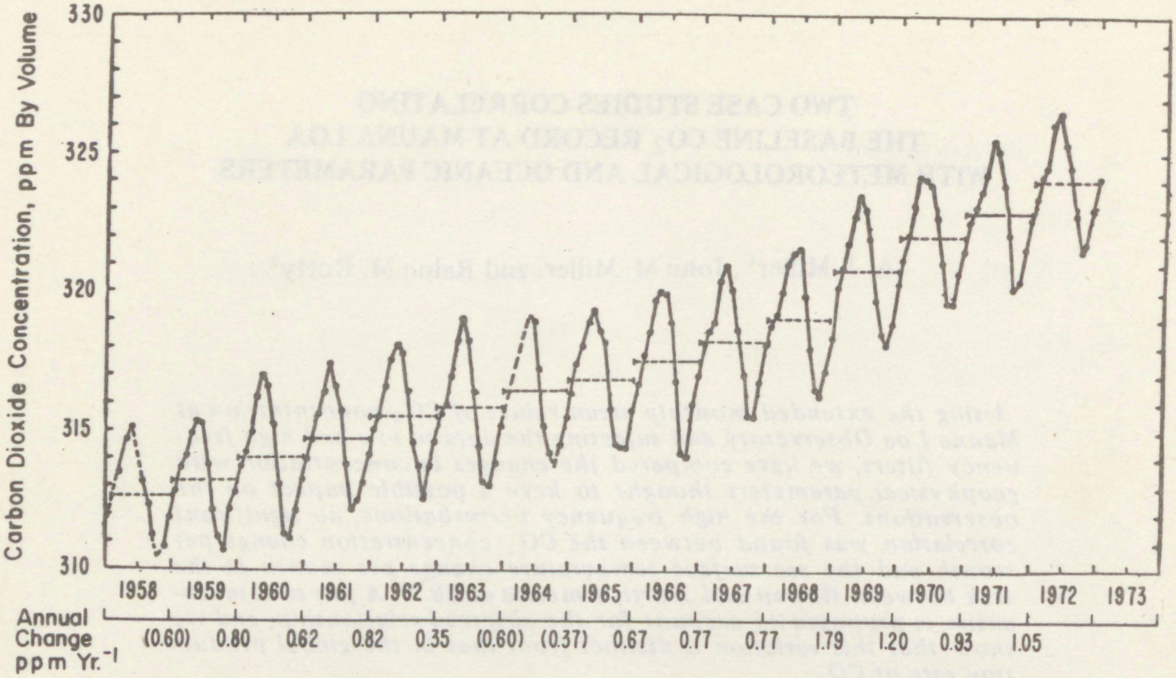

Figure 1. Monthly mean CO_2 concentration at Mauna Loa Observatory [after Keeling et al., (1974)].

ppm over 13 years; (2) very pronounced annual cycle; (3) month-to-month variation.

In an attempt to differentiate between these three scales for our analysis, we used the following filtering techniques.

A. The smoother long-term growth pattern was determined by subjecting the monthly CO_2 values to a 23-point binomial filter whose weights are 1/144(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1). The response function of the filter is shown in figure 2, and it was chosen on the basis of certain properties desirable for this study. For example, it has zero response at both 12 months and 1 and 2 months, which allowed us a virtually complete separation of the long-term growth from the annual and the short-term variation. In addition, the use of this particular filter proved quite expeditious when the time differences were considered, as will be discussed below.

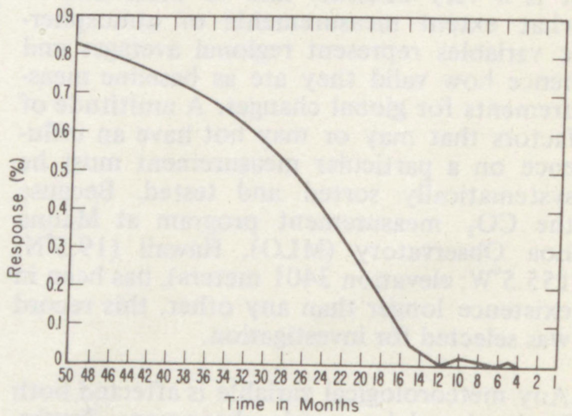

Figure 2. Response function of 23-point binominal filter employed in this study.

B. The smoothed long-term growth pattern from figure 3 was subtracted from the original monthly values. This resulted in a normalized curve composed

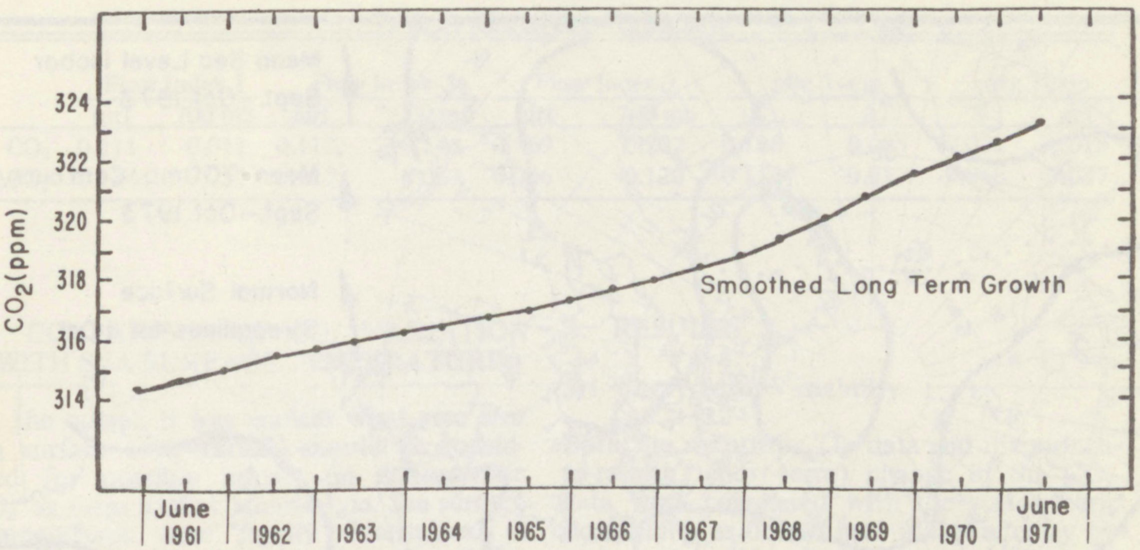

Figure 3. Smoothed long-term growth of CO_2 concentration (ppm) at Mauna Loa.

of the annual cycle and the short-term variations.

C. The annual cycle was determined by averaging all values from (B) for each month of each year.

D. The annual cycle subtracted from (B) left the month-to-month variation.

3. COMPARISON OF CO_2 VARIATION WITH ATMOSPHERIC FLOW

To compare the atmospheric flow patterns with the quantitative CO_2 data, we determined an index of the flow for each month from mean surface and 700 mb maps (figure 4). These maps were constructed by the Long Range Prediction Group of the National Meteorological Center of NOAA. Each author independently assigned a numerical value of +1, 0, or -1 to each monthly flow pattern depending on the extent he felt the air might be coming from areas such as the North American continent and having high, average, or low CO_2 constant.

One can postulate that short-term variations in the CO_2 measurements are a consequence of changes in the lower atmosphere. Since Mauna Loa Observatory's elevation is close to the 700 mb surface, we felt that the surface and the 700 mb mean monthly maps would be the best indicators of lower atmospheric changes.

The data from the indexing of the maps did not appear to contain any long-term trend, but they show a marked annual cycle and month-to-month variability. The annual cycle was removed by the same procedures used in removing the annual cycle from CO_2 data, i.e., steps (C) and (D) above.

We felt that the month-to-month *change* in CO_2 values might be affected more by atmospheric patterns than the CO_2 values themselves. Therefore, the CO_2 values (month-to-month) were subjected to the same treatment for eliminating the annual cycle and long-term trend as were the monthly values and the resulting short-term variations were correlated with the atmospheric flow pattern data.

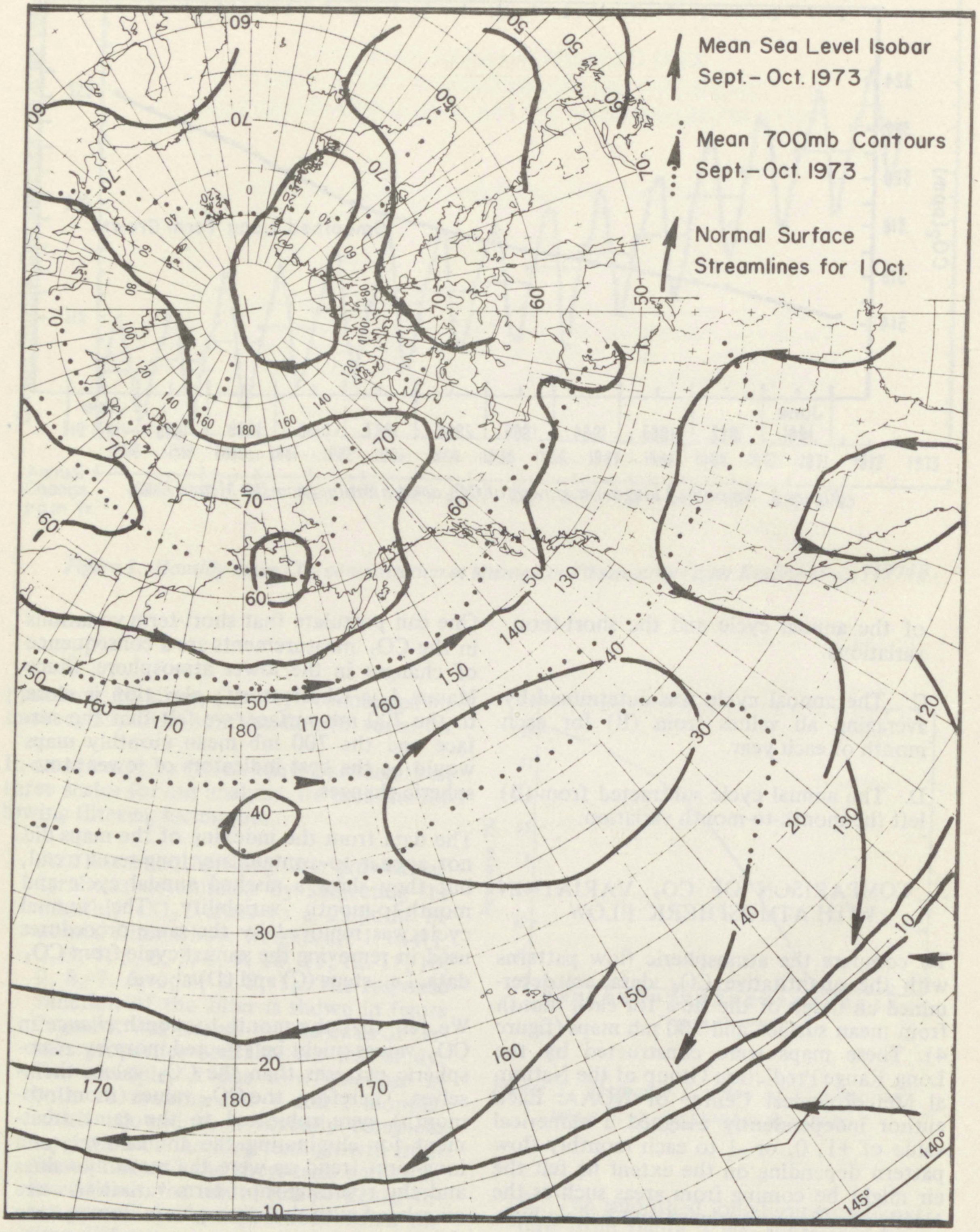

Figure 4. Typical monthly mean surface and 700 mb map used to determine atmospheric flow patterns near Mauna Loa.

Table 1. *Correlation Coefficients*

	Flow Index 1		Flow Index 2		Flow Index 3		Min Temp		Avg Temp	
	surf	700 mb	surf	700 mb	surf	700 mb	T	ΔT	T	ΔT
CO_2	0.111	-0.011	0.112	0.148	0.169	0.202	0.188	0.085	0.031	0.015
ΔCO_2	0.134	0.057	-0.017	0.063	0.046	-0.120	-0.114	0.037	-0.046	0.037

4. COMPARISON OF CO_2 VARIATION WITH SEA SURFACE TEMPERATURE

At the outset, it was unclear what area (for sea surface temperature) should be considered for possible impact on atmospheric CO_2 as measured at Mauna Loa. Sea surface temperatures were finally determined at seven different locations (or by seven different ways) and the temperature correlated with the CO_2 data. These data were taken from the fishing information compiled by the National Marine Fisheries Service, NOAA.

The seven different techniques were used to determine the temperatures:

1. lowest value that occurred among the averages for that month between North America and Hawaii along the 20°N parallel,

2. average value for that month between North America and Hawaii along the 20°N parallel,

3. average temperature for that month at 40°N, 140°W,

4. average temperature for that month at 40°N, 180°W,

5. average temperature for that month at 20°N, 180°W,

6. average temperature for that month of the Pacific Ocean east of 180°W and between 20°N and 60°N,

7. average temperature for the month of the entire Pacific Ocean north of 20°N.

5. RESULTS

5.1 Short-Term Variability

Both the monthly CO_2 data and the month-to-month (short-term) change in the CO_2 data were correlated with the atmospheric flow index as determined independently by each author. No significant correlation (at the 95 percent level a 0.21 correlation is required) was found, as indicated in Table I. Minimum value of average temperature along the 20°N parallel also showed no correlation with CO_2 values, and the *changes* from one month to the next in these minimum temperature values also showed no correlation. The same was true for the values of the *average* temperatures along the 20°N parallel. Table 1 shows the correlations for sea surface temperature at 20°N with the CO_2 as well as the atmospheric flow index as described above.

5.2 Long-Term Variability

Although the short-term variability did not yield any correlations of significance, the variation of CO_2 on a long-term (year-to-year) basis appeared to show year-to-year trends similar to those of the sea surface temperature but with the opposite sign (fig. 5).

The correlation between the change in CO_2 and the change in sea surface temperature along the 20°N parallel was found to be -0.648 and -0.607, respectively, depending on whether the temperature used was the minimum monthly or the average along the parallel. Table 2 shows that other locations

Table 2. *Correlation Coefficients: CO_2 vs. Temperature*

Technique used to determine temperature (See Sec. 4)	1	2	3	4	5	6	7
Correlation Coefficient	-0.648	-0.607	-0.157	-0.138	0.091	-0.231	0.208

for sea surface temperatures did not give the same level of significant results. When the data filtering procedure is taken into consideration, the number of independent observations is reduced, and at the 95 percent significance level a correlation of 0.468 is required.

For comparison, figure 5 also shows the average global CO_2 production rate as a function of time. We see that the monthly CO_2 change cannot be simply explained by the varying production; e.g., from 1968 to 1971 the CO_2 change is decreased, but the CO_2 production is increased.

The one case that had a significant correlation deserves more explanation. As the colder water penetrates south along the California coast it brings more CO_2 that had been absorbed farther north. This water then turns west and is warmed along its way toward Hawaii [Huang, 1972]. Some of the CO_2 is released and increases the amount measured at MLO. We note, however, that this correlation accounts for only about 30 percent of the variation in MLO CO_2 values. This phenomenon does not describe all the variations of CO_2 at MLO, but it does indicate that sea surface temperature is one parameter that has an influence. One can conclude that regional effects such as sea surface temperature may be a variation imposed on the dominating global trends.

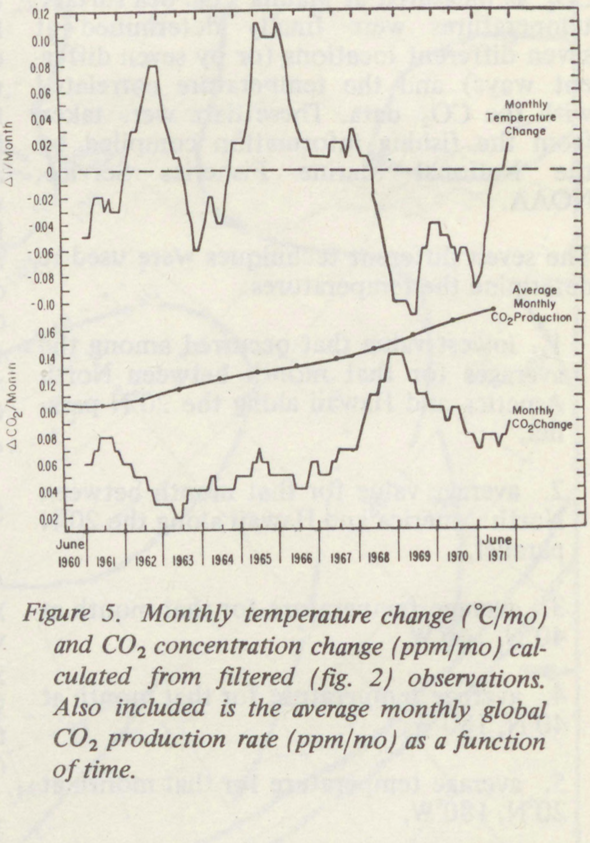

Figure 5. Monthly temperature change (°C/mo) and CO_2 concentration change (ppm/mo) calculated from filtered (fig. 2) observations. Also included is the average monthly global CO_2 production rate (ppm/mo) as a function of time.

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