# Technical report: Early Scripps Pier, La Jolla, CA in-situ atmospheric $CO_2$ mixing ratio measurements, 1957 – 1962

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# 1 Introduction

This report accompanies a dataset of in-situ measurements of atmospheric $CO_2$ mixing ratios made at La Jolla, California between March 1957 and May 1962 by Charles D. Keeling. The data were originally processed at half-hourly resolution and later into daily, weekly, and monthly products. This report provides a broad overview of the project and the methods used to recover a half-hourly resolution record along with daily, weekly, and monthly records.

Keeling arrived at the Scripps Institution of Oceanography in La Jolla, California late in the summer of 1956 and began air measurements at La Jolla in early 1957 using two of four infrared analyzers from the Applied Physics Corporation (APC) that Keeling obtained to support $CO_2$ measurements for the International Geophysical Year (Keeling, 1977; Keeling 1998). The La Jolla measurements were mainly made for the purpose of testing methods that were later used at Mauna Loa, Hawaii and Antarctica (Keeling, 1977). As the first quasi-continuous time series of atmospheric $CO_2$ made to modern standards of precision and accuracy, these measurements are of historical interest and may provide useful insights into the spectrum of $CO_2$ variability in Southern California in that era.

A high degree of consistency was demonstrated between these data and the Mauna Loa $CO_2$ data in the Mauna Loa 20$^{th}$ Anniversary Report (Keeling, 1978). Monthly averages of data between April 1957 and May 1962, with gaps, were tabulated in that report, but a high-resolution version of the early La Jolla dataset existed previously only in paper archives at Scripps, to our knowledge. With these paper records, we were able to generate a digital record with half-hourly resolution for the period of September 9, 1958 to May 10, 1962 that includes gaps when no measurements were recorded. We have further digitized a daily minimum version starting earlier on March 21, 1957. The half-hourly data shows a regular diurnal cycle and other variability related to local $CO_2$ sources and sinks. The weekly and monthly products are based on data which was selected in order to minimize these influences. The method involved selecting daily minimum $CO_2$ concentrations from the half-hourly data, and from these, selecting a

weekly minimum with some consideration given to the length and stability of the periods of low $CO_2$ readings. These weekly minima were then averaged to produce monthly data. This monthly summary, which was tabulated in Keeling (1978) and duplicated in Figure 1 below, represented the only previously published data product that we are aware of from these early measurements.

## 2 Site Position and Description

The records suggest that starting from March 21, 1957 until the setup was discontinued in 1962, the sampling was done from a laboratory window at (Old) Ritter Hall and at the end of the Scripps Pier (Keeling, 1977). The analyzer in (Old) Ritter Hall was on the second floor, with an attic above, and connected to a tube extended out the North window for air intake. Ritter Hall is approximately 110 m to the current modern pier entrance. The analyzer on the pier was presumably located in the small lab that existed then near the end of the pier. The USGS benchmark on the end of the modern pier has coordinates 32°52.0'N, 117°15.4'W and the original pier was only ~20 meters to the south of the modern pier. The elevation of the intake was presumably around 10 MASL.

The anlyzers used and their locations were not always marked on the paper records, so internal reference gas reports, named Research Report No. 1 to 5, were used to nail down the times and locations of the measurments. Scans were made of these reference gas reports and the first report describes the locations of the analyzers from March 1957 through July 1958 and also explains how the measurements of gas ppm were calculated. The first report was labeled "Research Report No. 1, Copy No. 1, October 15, 1958" and scanned into the file refgas_research_report_no_1_1958.pdf. Two analyzers, numbered 46 and 55, were used during this sampling period. Internal reference gas reports covering the time period of 1957 to 1962 summarize the locations of the two analyzers, dates of use, analyzer sensitivity, and index values of reference tank gases measured by the analyzers. In reference gas report #1, a history of use and location is tabulated for analyzers 46 and 55 from March 21, 1957 to July 24, 1958 and is summarized in Table 1 below. From the analyzer dates of use and location, it can be determined that the half-hourly resolution paper records found starting on September 9, 1958 are from the SIO

Pier using analyzer 55. Daily minima records before September 9, 1958 are from both analyzers 46 and 55 which were alternately located at Ritter Hall and the SIO pier as noted in Table 1.

Data sheets with half-hourly resolution were found from September 9, 1958 to May 10, 1962 for each day measured and are here-after referred to as daily half-hourly data sheets. Although the analyzer used was not noted on the data sheets, the recorder span value used with the analyzer was recorded as 340 and this value matches that recorded for analyzer 55 in the reference gas reports during the half-hourly record. The span of analyzer 46 was set differently at 310 and 500 in the reference gas reports. The recorder span value used with an analyzer is explained in section 6.1. No daily half-hourly data sheets were found before September 9, 1958 even though analyzer 55 started recording at the SIO Pier on July 24, 1958.

A tabulation of daily minima was found for March 21, 1957 to May 10, 1962. The daily minima from September 9, 1958 to May 10, 1962 can be confirmed from the daily half-hourly data sheets. Hand plotted half-hourly $CO_2$ indices from March 22, 1957 to December 31, 1959 indicate that half-hourly measurments were performed before September 9, 1958 and the daily minima marked on these plots match those on the tabulated sheets. Because analyzers were only at the SIO pier from September 20, 1957 to October 13, 1957 and July 24, 1958 onward, daily minima from March 21, 1957 to September 19, 1957 and from April 4, 1957 to July 23, 1958 are analyzer values from Ritter Hall. No measurments were taken between October 14, 1957 to April 3, 1957 as the analyzer was used on a cruise. The reference gas reports and the lack of hand plotted $CO_2$ indices from October 13, 1957 to April 4, 1958 confirm this.

Further infomation about the location of the analyzers can be found as notes on charts of hand plotted half-hourly $CO_2$ indices (see Figure 2). A move date for the analyzer of September 20, 1957 is supported by handwritten notes in C.D. Keeling's hand on charts which were used as part of the La Jolla data workup. One of these states "Moved from Ritter Hall to Pier morning of Sept 20". There is about an 8-hour gap in the chart record corresponding to this move, consistent with the move being accomplished in one day.

This notation evidently dates from 1973 as indicated by additional notes written with the same pen, one of which states "entered Nov 10, 1973". A similar note also states "NW corner of Ritter Hall" to indicate the location of measurements from March 21 to September 16, 1957. A further comment which bears on the earlier location and the time of the move is made by C.D. Keeling in the 1978 report: “except for a few days when air was sampled from a laboratory window, all measurements were made near the end of a 1,000-foot ocean pier”. The laboratory window comment may be consistent with the NW corner remark since (Old) Ritter Hall indeed has windows on its northwest corner. The "except for a few days" comment is puzzling, however, because the 1973 pen marks seem to indicate that the analyzer was located in Ritter Hall for many months, i.e. March to September, 1957. Further notes of analyzers moved were not found on the hand plottted half-hourly $CO_2$ indices but in reference gas report #1, it states that the analyzer on the pier was used from October 16, 1958 to December 23, 1958 on a cruise. An analyzer appears on the pier again on July 24, 1958.

# 3 Analyzer Details

Continuous measurements were made using an Applied Physics Corporation non-dispersive infrared gas analyzer with a water vapor freeze trap. The analyzer was the same model used for the measurements at Mauna Loa (Keeling et al., 1982). Two infrared gas analyzers, numbered 46 and 55, were in use during the yearly La Jolla measurements from 1957 to 1962. Each analyzer was connected to an electronic chart recorder which responded to changes in signal from the analyzer. The sensitivity of the analyzer as measured on the chart recorder is referred to as a recorder scale factor. It's a ratio of voltage difference measured by the chart recorder and the ppm index difference measured by the analyzer. Recorder scale factors, which change with time, for each analyzer and reference tank index values in ppm are recorded in a series of internal reference gas reports. The relevant reference gas reports are #1 - #5 covering 1957 to 1962.

# 4 Measurement Details – Sample Switching and Raw Data

From information contained on strip chart records of these measurements, which were located at Scripps as part of this project, the following measurement details seem clear: The analyzer was run continuously, recording output voltages on chart paper. A timer switch cycled between two different ambient air intakes and a working reference tank of $CO_2$-in-nitrogen. The ambient air intakes ran through an electric cold trap (freezer unit ~-50 deg F) to remove water. Two air intake lines were used to help diagnose possible contamination from the lines. The order that these intakes were run changed from time to time, but usually, they totaled 20 minutes of air sampling between the two intakes and 10 minutes of working tank sampling during each 30 minute cycle. Each measurement cycle is called a jog. In the example chart trace in Figure 3, there is a short 'spike' when the valve switches and then it takes a while for the new gas to sweep out of the analyzer and for the measurement to stabilize at the new level. Two common measurement sequences are outlined here.

Example measurement sequence #1:

1. Cycle 1: Working tank – 10 min
2. Cycle 1: Air intake (L1) – 10 min
3. Cycle 1: Air intake (L2) – 5 min
4. Cycle 1: Air intake (L1) – 5 min
5. Cycle 2: Working tank – 10 min

Example measurement sequence #2:

1. Cycle 1: Working tank – 10 min
2. Cycle 1: Air intake (L1) – 10 min
3. Cycle 1: Air intake (L2) – 10 min

4. Cycle 2: Working tank – 10 min

The data were worked up directly by ruling on the chart record. The voltage difference between the ambient air and the working tank were measured in grid cells on the chart by using a ruler to pencil in lines extending the mean ambient and tank values by eye. The working tank corrected for instrument drift. This procedure generated what was referred to as 'lineout' voltages, and there were two values measured for each 30 minute cycle. In the example measurement sequence #1, the voltage differences measured the distance between periods 1 and 2, corresponding to L1, and between periods 4 and 5, corresponding to a second measurement for L1. In this case, L2 was monitored during the 'lineout' procedure just to screen for potential problems with the L1 intake. In the example measurement sequence #2, 'lineout' voltage values measured the distance between periods 1 and 2, corresponding to L1, and between periods 3 and 4, corresponding to L2. Averaging these two values together gives a mean half-hour value (L average).

# 5 Conversion of APC Voltage to Calibrated $CO_2$ Concentrations

In order to calculate $CO_2$ concentration from the voltage measurements recorded on the data sheets, we applied the following conversions:

**1. APC voltage to $CO_2$ index**

The $CO_2$ index, index *I*, is linearly related to the APC infrared analyzer response and is expressed in units close to $CO_2$ mole fraction in ppm. As stated above, an analyzer is connected to a chart recorder which responds to changes in signal from the analyzer. The sensitivity of the analyzer as measured on the chart recorder is referred to as a recorder scale factor. It's a ratio of voltage difference measured by the chart recorder and the ppm index, assessed using reference gases calibrated on the I scale. A recorder scale factor represents the analyzer's sensitivity. Two different versions of recorder scale factors are used in the data gathering and related linearly. One, a "linear recorder scale", is often found as a notation on the daily half-hourly data sheets. The other, a "recorder scale factor", is found in the reference gas reports. They are related as:

$$Recorder\ Scale\ Factor = 18 * (linear\ recorder\ scale)$$

The multiplier of 18 is explained below in section 6.2.

All data are initially recorded on the *I* scale using the following equation.

$$I = (\text{voltage difference})/(linear\ recorder\ scale) + working\ tank\ index$$

where the values *linear recorder scale* and *working tank index* depend on the time period the analyzer was used and the working tank used at the time. Table 3 summarizes the working tanks ($CO_2$-in-nitrogen tanks) used and their assigned index values along with the linear recorder scale values recorded on the daily half-hourly data sheets. Working tank numbers recorded on data sheets are occassionally abbreviated to the last two numbers, e.g. tank 3751 is abbreviated to tank 51. The full tank number is recorded in the reference gas reports.

**2. *I* scale to *J* scale**

A linear transformation converts the *I* scale to the *J* scale, established in 1959, on the basis of early manometric calibrations to bring the *I* scale closer to true mole fraction scale. The linear *I* and *J* scales are related by the following equation (Keeling et al., 2002):

$$J = 1.2186 * (I - 311.51) + 311.51$$

**3. *J* scale to *X08A* scale**

The *X08A* scale is the calibrated scale based on the mercury constant volume manometer, accounting also for the pressure-dependent carrier gas effect (Keeling et al., 1976). This effect is related to differences in the infrared $CO_2$ peak broadening in air compared to nitrogen. The 08A label designates the version number of the scale (08 designating the year the scale was developed). For these early data, the average difference between the 08A scale and the version of the scale used in the 1978 Mauna Loa report was -0.14 ppm. In these early years, the 08A scale is identical to the more recently extablished X12 scale.

# 6 Analyzer Sensitivity and Working Tank Index Values

At various time intervals during the use of the analyzer, reference gas tests were performed on the analyzer to calculate a recorder scale factor which measures the sensitivity of the analyzer. Calibrations of working tank indices were also performed. The results of the tests are recorded on reference gas data sheets and finalized in the reference gas reports. The recorder scale factor and the working tank index measured were also marked on the daily half-hourly data sheets and finalized in the reference gas research reports. The chart traces for the reference gas tests are presumed to be cut from the pier gas chart trace and stored in a location we have not yet located.

These reference gas tests calculated index values of reference gas tanks and determined the sensitivity of the analyzer represented by a recorder scale factor. To calculate the index value of a gas measured with the analyzer, the analyzer was calibrated with reference gasses of known index values. This calibration method is described in reference gas report #1. Due to changes in the sensitivity of the analyzer, the recorder scale factor is recalculated over time. The recorder scale factor relates a voltage difference output of the chart recorder with an index difference of two gasses measured on the analyzer. The sensitivity of the analyzer is assumed to change linearly over time. The reference tank used in parallel with ambient air is called a working tank.

## 6.1 Chart recorder settings used with an analyzer

The span control of the recorder governs the response of the recorder to changes in signal from the analyzer and can be adjusted to control the size of the trace. The zero setting of the recorder changes the position of the trace on the chart. These values are recorded in the header of the daily half-hourly data sheets.

## 6.2 Recorder scale factor

The recorder scale factor of an analyzer is defined in reference gas report #1, 1958. Two primary reference gas standards with a known index difference of 18.0 ppm were measured on an analyzer to set up a base relationship between index values and chart

output. The chart grid-scale (chart scale) difference of the analyzer output was adjusted using the span control of the recorder so that the pen of the recorder would move approximately 1 chart scale division for a change of 1 ppm in the index. If the analyzer is kept at the same span value and the chart scale division difference is measured at a later time, there will be a different value due to changes in the sensitivity of the analyzer. This drift is assumed to be linear with time between calibration intervals and could drift up or down from the original setting which was one chart scale division change per 1 ppm change. With the same span setting over an extended period of time, changes in scale factor reflect directly changes in the sensitivity of the analyzer. To relate this chart scale difference with the original chart scale difference, a linear recorder scale is defined. Over time, different reference gasses with known index values are used to replace depleted standards. To reflect the original ppm difference of the standard gases used, a factor of 18 is applied to the linear recorder scale. This is called a recorder scale factor, RSF.

$$\frac{(chart\ scale\ difference)}{(ppm\ difference)} = (linear\ recorder\ scale) * \frac{(original\ chart\ scale\ difference)}{(original\ ppm\ difference)}$$

where

$$original\ chart\ scale\ difference = 18$$

$$original\ ppm\ difference = 18\ ppm$$

so

$$linear\ recorder\ scale = \frac{(chart\ scale\ difference)}{(ppm\ difference)}$$

And define

$$Recorder\ Scale\ Factor = 18 * (linear\ recorder\ scale)$$

## 6.3 Working tank indices and tank numbering

The I index value of a gas was calculated via the following formula using the analyzer recorder scale factor, RSF, and a working tank gas with a known index value:

$$I_{gas} = (18/RSF) * (\text{Chart Scale}_{gas} - \text{Chart Scale}_{working\ tank}) + I_{working\ tank}$$

and since the chart scale difference is the voltage recorded on the daily half-hourly data sheets, the formula can be rewritten as follows:

$$I = (\text{voltage difference})/(\textit{linear recorder scale}) + \textit{working tank index}$$

### 6.4 Comparison of reference gas reports to daily half-hourly data sheets

There are slight differences between the working tank index values and recorder scale factors recorded on the daily half-hourly data sheets and those in the reference gas reports. The working tank index differences may be due to the daily half-hourly data sheets only using analyzer 55 to compute an index value and the reference gas report averaging the results from both analyzerers 46 and 55 to compute a final index value. The recorder scale factors marked on the daily data sheets seem to have been a selected average or a selected single recorder scale factor of the values recorded in the reference gas report for analyzer 55. In this report, we use the values marked on the daily half-hourly data sheets instead of the values in the reference gas reports.

In a paper folder entitled "SIO PIER DATA, 1958-60, Daily Average Summary", we found a tabulated list of the working tanks used over specified time periods, working tank index values, and analyzer recorder scale factors over the period from September 10, 1958 to June 16, 1960. This matches with notations found on the daily half-hourly data sheets and are used for Table 3. For the period of March 20, 1962 to May 10, 1962, the values off the daily half-hourly data sheets are used for Table 3.

## 7 Data Resources Available For This Project

For this project we were able to locate data sheets, plots, and summaries as inventoried in Table 2, including daily half-hourly data sheets which are the primary record that we relied on here (see example in Figure 4). We also located a lab notebook and original chart records. Information about the analyzers and reference gas tanks used was found in internal reference gas reports, reference gas data sheets, and daily half-hourly data sheets.

From these materials, we infer that the original data reduction path was as follows:

1. Lineout chart traces while assigning times to the jogs.

2. Record two voltage difference values per 30 minute cycle on a data sheet for each day and average to half hour values.

3. Record a daily minimum value on a data sheet for each month.

4. Hand plot half-hourly $CO_2$ index values and mark daily minimum values on chart paper.

5. Further process daily minima to yield weekly minima and monthly averages of weekly minima.

Only these first two steps are needed for recovery of the half-hourly record. The recovery of the daily minimum, weekly, and monthly data is described later in the report.

## 7.1 Daily half-hourly data sheets

The record of daily half-hourly data sheets starts on September 9, 1958. We were unable to locate any daily half-hourly data sheets before September 9, 1958 but did find hand plotted half-hourly $CO_2$ indices and chart traces. Presumably, these data sheets were misplaced among the many boxes in storage and we were not able to locate them. These daily half-hourly data sheets contain two voltage differences for each half-hour cycle, either one each for ambient intake line L1 and L2, or sometimes two for the same line at the beginning and end of the half-hour cycle. These two values were averaged to create a half-hour average voltage difference, L average. The sheets also include header information: station, date, sheet number, span, zero, freezer temperature, air flow (liters/minute), working reference tank ID, and tank pressure. Notes were made when reference tanks were changed, reference gas tests were done, traps were thawed, pen or chart paper problems, etc. Notes were also made on the sheets which identify an analyzer chart recorder scale and a working tank index which is used to convert measurement voltages to $CO_2$ concentrations. At the bottom of each data sheet from 1958 to 1960 is a

pencil notation of a formula to convert voltage into ppm, (working tank index) + sigma/(linear recorder scale) where sigma is a measurement voltage difference. In 1962, the notation changed to record the ratio of the working tank index over the recorder scale factor.

A puzzling aspect of these half-hourly data sheets is that they often have an extra entry (or two), more than 48 per day, written in the margins at the top or bottom of the page or on the back of the sheet. We verified that these extra data points come directly from the chart trace readings. We infer that the timer used to switch intakes tended to run fast. Some days it seems to be running as fast as 28 minutes per cycle instead of 30 minutes exactly. These extra cycles were recorded for completeness. The result is that the timestamps on the half-hour averages, as recorded on the data sheets, are only approximate, an issue we address in the methods section below.

The daily half-hourly data sheets were located in seven folders of the first drawer of a file cabinet in Alane Bollenbacher's office labeled as "SCRIPPS PIER DATA (1958-62)". The labels on the folder tabs are as follows: SIO PIER DATA SHEETS, Sept. – Dec. 1958, SIO PIER DATA SHEETS, Jan. – April 1959, SIO PIER DATA SHEETS, May – Aug. 1959, SIO PIER DATA SHEETS, Sept. – Dec. 1959, SIO PIER DATA SHEETS, Jan. – March 1960, SIO PIER DATA SHEETS, April – June 1960, and SIO PIER Data Sheets, March – May 1962.

## 7.2 Plots and summaries

In the first drawer of a file cabinet in Alane Bollenbacher's office labeled as "SCRIPPS PIER DATA (1958-62)" we located handwritten daily minimum, daily average, and mean summaries for each month, along with several hand-drawn data plots of the half-hourly data and daily minima. These materials represent Tim Whorf’s analysis of the time series (personal communication with Alane Bollenbacher). They support the March 1957 start date of the measurements and provide a data workup pathway, starting at daily minimum values, for the monthly averages in the Keeling (1978) publication.

This file drawer also contained two paper folders relating to the early daily, weekly, and monthly La Jolla data. One of these folders was entitled, "SIO PIER DATA, 1958-60, Daily Average Summary" and was used in conjunction with daily half-hourly data sheets to create Table 3 relating working tank usage times, working tank index values, and linear recorder scales. This table is used for the half-hourly data to convert chart scale voltages into index values. The other folder was entitled “SIO PIER DATA, 1957-1962, Daily $CO_2$ Minimums and Averages” and provides sufficient detail to clarify how monthly values were computed from continuous measurements. Each month is summarized with a single page that lists the daily minimum values for each day of the month that measurements were made and the time of day that the minimum occurred. These monthly summaries extend from March 1957 to May 1962 with some data gaps. From September 9, 1958 onward, they are supported by the daily half-hourly data sheets.

Before September 9, 1958, the basis for these daily minimum values is less clear because we were unable to locate daily half-hourly data sheets for this earlier period. But we were able to locate hand plotted half-hourly data with a daily minimum noted in red. The method seems clear from the later data, but the data path was not fully recovered here. In any case, tabulations of daily minima are available for the full period in the folder entitled “SIO PIER DATA, 1957-1962, Daily $CO_2$ Minimums and Averages” and scanned into the file scan_of_sio_pier_data_daily_co2_minimums_and_averages_1957-1962.pdf. In supplemental materials, we have transcribed the daily minima from this scan into digital format (Early_LaJolla_CO2_daily_minima_1957-1962.csv). The minima after September 9, 1958 can easily be read from the digital half-hourly data which we are separately making available (Early_LaJolla_CO2_raw_half hourly_1958-1962.csv).

### 7.3 Lab notebook

The primary ‘lab book’ we found for these measurements started on January 1, 1959 and ran through May 9, 1962. This leather bound notebook was located in Alane Bollenbacher’s office on top of a file cabinet. The lab book has a label "Leather Book" on the spine. An inner page is labeled "Scripps Pier, Latitude 32°52'N, Longitude 117°15'W". The first log page is labeled "Log Book for APC Analyzer Used at Scripps

to observe atmospheric carbon dioxide". It documents technicians visiting the analyzer once or twice a day (generally at 8am and possibly again in the late afternoon). The notes include such information as the reference tank used, tank pressure, analyzer span and zero setting, freezer temperature (-50 deg F), names of people maintaining the station, times when the water cold trap was thawed and replaced, problems with flow rates of sampling lines, etc. They also include some recording of weather observations: clouds visibility and wind direction and speed. During these visits, the time was also recorded on the chart paper and checked that the system was working properly. This resource may be useful for determining the cause of data gaps.

## 7.4 Chart records

The chart records were located in cardboard boxes numbered 135 and 140-146 stored at the UCSD self-storage facility on Trade Street in San Diego, California. Box 135 contains SIO Pier chart traces from January to June of 1960, March 1962, and May 1962. Boxes 140 and 141 contain SIO Pier and Ritter Hall chart traces from 1956 to 1957. Boxes 142 and 143 contain SIO Pier Chart Traces from April to December 1958. And boxes 144, 145, and 146 contain SIO Pier Chart Traces from 1959 and April 1962.

## 7.5 Reference gas reports and reference gas data sheets

The internal reference gas reports #1 - #5 covering 1957 to 1962 were located in the UCSD Special Collections & Archives as Accession No.: 2003-38 box #137. The names of the relevant reports in the box are "Research Report No. 1, Copy No. 1, October 15, 1958", "Research Report No. 2, Copy No. 1, June 1, 1961", "Research Report No. 3, Copy No. 1, June 1, 1961", "Research Report No. 4, Copy No. 1, October 20, 1961", "Research Report No. 5, Copy No. 1, March 15, 1963." Scans were made of these reference gas reports and named refgas_research_report_no_1_1958.pdf, refgas_research_report_no_2_1961.pdf, refgas_research_report_no_3_1961.pdf, refgas_research_report_no_4_1961.pdf, and refgas_research_report_no_5_1963.pdf.

The reference gas data sheets were found in UCSD Special Collections & Archives as Accession No.: 2003-38 boxes #34 and #35. The names of the relevant paper folders in

the boxes are "Laboratory Data, User Reference Gas, Data Sheets, 1a-100, [July 24, 1958 - October 9, 1959]", "Laboratory Data, User Reference Gas, Data Sheets, 101-200, [October 19, 1959 - August 10, 1960]", "Laboratory Data, User Reference Gas, Data Sheets, 201-301, [August 15, 1960 - August 22, 1961]", and "Laboratory Data, User Reference Gas, Data Sheets, 302-399, [August 28, 1961-April 10, 1962]."

# 8 Methods Used in Reconstructing Half-hourly Data

## 8.1 Data entry

For the period of September 9, 1958 through May 10, 1962, we created a digital record of the raw data from the daily half-hourly data sheets. Katy Piper, Cynthia Uribe, and Lisa Welp typed the half-hour averages of each jog from the data sheets into excel data files for each day. A standard daily excel template for each data sheet was used that allowed one extra jog entry (i.e. 49 total), and given the time 0:15. If no extra jog was present, this was given a value of -999. In days with more than one extra jog, extra rows were added to the table as needed, with the second given a time of 0:20 and the third a time of 0:25. These files were created on a monthly basis, concatenating data from the daily sheets, listing the timestamp, L average, and additional comment columns as needed. These monthly files are stored in the supplemental folder monthly_halfhour_data.

For a 48 half-hour day, the data sheets began at jog time 0:30 and ended at 24:00. For data sheets with extra jogs that didn't fit in the sheet's 48 half-hour entries, these extra entries, which come in L1, L2 pairs, were averaged together just like half-hourly entries and assigned arbitrary timestamps that preserved the sequencing. Extra values at the beginning of a day, before 0:30, are included between times 0:00 and 0:30 of that day. Extra values at the end of a day, after 24:00, are included between times 0:00 and 0:30 of the following day.

The monthly files of the half-hourly data sheets were concatenated into a file entitled "Early_LaJolla_CO2_raw_halfhourly_1958-1962.csv" and contain all half-hourly jogs with an L average value. Here the extra jogs are not assigned times, but rather simply

listed in chronological order. In this file, the raw voltages, L average, were converted to index values and $CO_2$ mole fractions (X08A scale) using conversions described below.

The dates and times of working tank changes, working tank index, and analyzer recorder scale were entered into a separate working tank data file (Table 3). These were used to convert the raw voltages into index values.

## 8.2 Time zone and stamp issues

As far as we were able to ascertain, the times recorded on the strip charts and hence on the data sheets are nominally all in Pacific Standard Time. Although this interpretation was not directly confirmed by any annotations, it is consistent with the general practice of the program at that time. Also, a spot check of one date (April 24, 1960) on which there was a transition to daylights savings time (DST) showed no gap, as would have been expected if the times were transitioning to and from DST. A further test of this hypothesis might be possible by comparing the quasi-regular daily cycles in $CO_2$, to see if they showed a 1 hour shift at the transitions to and from DST. We did not carry out such a test, however.

A challenge in interpreting this data set is that the timer controlling the intake and tank switching was evidently generally running faster than an exact 30 minute cycle interval, as discussed above. By inspecting several of the original chart traces, we conclude the times notated on the half-hourly data sheets are only approximate. Nearly every morning, someone visited the analyzer and wrote the date and time directly on the chart trace paper and recorded the weather and various system checks on a stamp in the lab notebook. Frequently, a check was also made in the afternoon. When the traces were read or 'lined out', the morning timestamps were used to approximate the nearest half-hour with the nearest measurement cycle, and results from earlier and later measurement cycles on that day were used to fill in the table consecutively, a process which sometimes led to extra jogs per day at either the beginning or end of the day.

From the available records alone, we can't say with confidence that the times were intended to represent time-ending, beginning or centered averages. However, based on

an analysis of the month of May 1959, measuring the distance on the chart from the handwritten timestamp to the ambient peak center, it looks like the intention was for half-hour averages to be centered on the half-hour (Figure 5). For example, data entered at 8:00 represents an average of data nominally starting at 7:50 and ending at 8:10.

### 8.3 Correcting timing inaccuracies

Our goal was to generate a record with half-hour resolution with the timing as accurate as possible, given the available resources, including the extra measurement jogs recorded at the top and bottom of the half-hourly data sheets. Lisa Welp first double-checked to confirm that all the extra jogs were transcribed into the monthly excel files. Since the extra jogs imply a faster cycle length than 30 minutes, the timestamps of the jogs needed to be adjusted. A 48 half-hour day was assumed to start at 8am and not midnight. The 8:00am jog assignments were assumed to be accurate because someone would check the instrument nearly every morning around 8am (plus or minus a couple of hours) and write a time on the chart paper. These morning 'checks' seem to be used as the starting point to count half-hour jogs forward and backward. The 8:00am point is thus presumably accurate to within 25 minutes based on an analysis of May 1959 (Figure 5).

The total number of jogs between the 8am entry of one day and the 8am entry of the following day was 48-51 if there were no instrument interruptions. With instrument interruptions, some jog entries did not have a recorded value, but the number of jogs was still assumed to be 48-51. This means that if an extra jog entry occured at 0:15 and there were values missing at other half hours, the period was still assumed to be a 49 jog period. This means that the 'true' cyle length was 28-30 minutes depending on the number of jogs in this defined 24 hour period. This yielded adjusted timestamps that were not on the exact centered half-hours (:00 or :30). The jog times were then linearly interpolated back onto a half-hour time scale, a 48 jog period, centered on the half hours. Jog values missing on the raw half hours were not interpolated.

Due to the large data gap from June 16, 1960 to March 21, 1962, the timestamps were interpolated separately over two date ranges from September 9, 1958 to June 16, 1960 and from March 21, 1962 to May 9, 1962 and then concatenated together. For data

before and after 8am of each of these date ranges, the timestamps were not interpolated to an adjusted 8am to 8am range because there was no information before 0:30 for the first day and no information after 24:00 for the last day. Any extra jogs found before and after 8am of each date range were not used to adjust timestamps and the half-hour timestamps and values were used as entered. This time-adjusted dataset is presented in the file: Early_LaJolla_CO2_halfhourly_1958-1962.csv. We expect this method will yield data on a time scale that is accurate to within around 30 minutes.

# 9 Methods Used in Reconstructing Weekly Minima Data

The original monthly summaries of daily minima contained quality flags indicating the degree of stability, i.e. roughly how long the low values persisted. Weekly minimum values were selected from consecutive 7-day increments (starting Sunday and ending Saturday) of daily minima: selecting the lowest day within this interval, or the lowest two days, if two consecutive days had identical minima, or the lowest three days, if three consecutive days had identical minima. Summaries of the weekly minimum values were included on the monthly summary pages and may contain 1 to 5 values. Weekly minima were occasionally omitted from the monthly averages with notations such as "Jan 13 min. during period of continental contamination". This shows that additional screening was done to minimize local influences. This procedure was evidently somewhat subjective and probably took account of absolute $CO_2$ values, wind conditions, and stability of daily minima. These weekly minima values transcribed from the data sheets (monthly summaries of daily minima) are in the file Early_LaJolla_CO2_raw_weekly_minima_1957-1962.csv.

## 9.1 Weekly product details

In the original monthly summaries, the weekly minima were given a date corresponding to the Saturday at the end of the week. In the weekly minimum file reported here, Early_LaJolla_CO2_weekly_minima_1957-1962.csv, we instead use the actual date on which the daily minimum (that was selected for the weekly minima) occurred. As the original dates were evidently based on local time, we assign a time of (local) noon for the

daily minimum. In some cases, two or more dates with identical minima were averaged in the original monthly summaries. In these cases we assign a date/time corresponding to the average of the daily local noon times, leading to occasional values assigned a time of (local) midnight. In our weekly minimum data product, we include only the weekly minima that were used in the monthly averages for the 1978 Mauna Loa report. This yields a product that is consistent with the screening for background conditions used also for the monthly product. From reading the 1978 report, it appears that June 1958 didn't get a monthly value because there was only one weekly value in that month (for June 22nd). Here we nevertheless include this week in the weekly minimum product. This weekly product may be useful as providing the highest resolution version of a $CO_2$ concentrations selected for background conditions from the early La Jolla data.

# 10 Methods Used in Reconstructing Monthly Minima Data

These weekly minimum values within each month are then averaged, sometimes including nearby values from adjacent months or excluding values that appear deviant, to yield a value not too influenced by a few outliers. No gap filling was done to the data, so monthly averages may not represent mid-month conditions. The number of weekly minimum values that went into the monthly average is also noted. From the close correspondence, it is clear that the data sheets in this folder directly supported the 1978 Mauna Loa Report (Keeling, 1978), see Figure 1 below.

## 10.1 Monthly product details

To support the estimate of monthly values, we have transcribed a table scanned into the file scan_of_sio_pier_workup_for_1978_report_by_cd_keeling.pdf from the folder entitled “SIO PIER DATA, 1957-1962, Daily $CO_2$ Minimums and Averages” that summarizes monthly values and was used to back up the monthly $CO_2$ data presented in the 20th anniversary Mauna Loa report (Keeling, 1978). This table contains index (I) values as well as X values, which we note are identical to those that appear in the Keeling (1978) report (see Figure 1 below). This transcribed table is presented in supplemental materials (Early_LaJolla_transcribed_CO2_monthly_1957-1962.csv). We use the index

I values in this table to support calculating values on the X08A scale in the primary product (Early_LaJolla_CO2_monthly_1957-1962.csv). The monthly average date is the average of included weekly minimum dates.

We have detected one probable error in this table for April 1962 where there appeared to be a transcription error associated with the I value, identified by comparing the monthly summary tables in the same file folder. The new I value of 316.8 was identical to the I value from May 1960, and the X value was from May 1960 was thus also assigned for April 1962. The J value for April 1962 presumably also needed correction, and here was simply deleted. There are some special columns labeled $J_L$ and J' in this table which are relevant only for the first two months of data, March and April 1957. A plot of X versus I across all the data in this table suggest that the I to X conversion for these months is identical to those of the other months despite these extra columns. This table also includes ice-floe data which was in the original table and transcribed here without changes. It also includes one data point from the Downwind Oceanographic cruise for October 1957 which however, was evidently not used in the Mauna Loa report summary.

# 11 Description of Data Products

## 11.1 Primary Products

1. **Early_LaJolla_CO2_halfhourly_1958-1962.csv**

   Header information:

   This file contains measurements of $CO_2$ concentration (ppm) on the X08A scale at La Jolla, California from September 9, 1958 through October 10, 1962. The raw times were linearly interpolated onto a half-hour time scale with 48 measurement points in a day centered on the half hours since the raw data occasionally had more than 48 measurement points, jogs, in a day.

2. **Early_LaJolla_CO2_weekly_minima_1957-1962.csv**

   Header information:

This file contains weekly minimum index and $CO_2$ mole fraction (X08A scale) from monthly data sheets recorded at the SIO pier in La Jolla, California from 1957-1962. The daily minima were arranged into calendar weeks, and weekly minima were identified. Any obviously contaminated minima were omitted. For some weeks, the minima value was the same over multiple days. If over three days, the sample date chosen was the middle of these days. If over two days, the sample date was the $12^{th}$ hour of the first day.

3. **Early_LaJolla_CO2_monthly_1957-1962.csv**

Header information:

This file contains monthly averages of the weekly minimum index and $CO_2$ mole fraction (X08A scale) from monthly data sheets recorded at the SIO pier in La Jolla, California from 1957-1962. The average monthly date is the average of included weekly minima dates. No gap filling was done to the data, so monthly averages may not represent mid-month conditions. A few obviously contaminated minima were omitted in assembling the monthly means. This data file compares to Table 2 in the 1978 20th anniversary report, but differs by including a value from March 1957 that was missing in the anniversary report and differs by the data being updated to the X08A scale.

## 11.2 Supplemental Material

1. **Early_LaJolla_CO2_raw_halfhourly_1958-1962.csv**

Header information:

This file contains raw data from the measurements of ambient $CO_2$ concentrations made at La Jolla, California from September 9, 1958 through October 10, 1962. Times are as marked on the daily half-hourly data sheets. Times are only approximate because the switching timer tended to run fast, leading occasionally to extra jogs at the beginning and/or end of each day. Extra values at the beginning of a day, before 0:30, are included between times 0:00 and 0:30 of that

day. Extra values at the end of a day, after 24:00, are included between times 0:00 and 0:30 of the following day. These are entered in chronological order without timestamps.

**2. Excel files used for data entry in the folder monthly_halfhour_data**

Header information:

Raw half-hourly data for each month are in a folder named monthly_halfhour_data which contains csv files with a naming convention ljo_yyyy_mm.csv where yyyy is the 4 digit year and mm is the two digit month. These files contain the individual jogs entered by hand from the daily half-hourly data sheets. In each file, there are at least three initial columns entitled Date, Time, and L average and any extra columns are for comments. The date is of the format month/day/year and the time is of the format hour:minute. Times are as marked on the daily half-hourly data sheets. Times are only approximate because the switching timer tended to run fast leading occasionally to extra jogs at the beginning and/or end of each day. The extra data points were added in at placeholder times of 0:15, 0:20 and 0:25. There were from 0-3 extra points each day. If the L average value was not recorded on the data sheet, it is left blank in the csv file. For the placeholder time at 0:15, an empty value is represented as -999. Placeholder times at 0:20 and 0:25 are added as necessary with their L average values. Details of the data entry are described above.

**3. Early_LaJolla_CO2_daily_minima_1957-1958.csv**

Header information:

This file contains daily minimum $CO_2$ values from monthly data sheets recorded at the SIO pier in La Jolla, California from 1957-1962. The values are transcribed from the data sheets (monthly summaries of daily minima) that were hand marked by C.D. Keeling to indicate which days were the weekly minimum and also to indicate how long the minimum persisted. (These were indicated on sheets using one or two x marks). In this file, daily minima are listed at the year, month, day,

and time that it occurred. Flags mark whether the daily minima is included as part of the weekly minima, whether the value is omitted due to being contaminated, and whether the minima persisted over a period longer than one hour or longer than 4 hours. The index value for each minima was also recorded.

4. **Early_LaJolla_CO2_raw_weekly_minima_1957-1962.csv**

Header information:

This file contains weekly minimum $CO_2$ index values from monthly data sheets recorded at the SIO pier in La Jolla, California from 1957-1962. See pdf scan: scan_of_sio_pier_data_daily_co2_minimums_and_averages_1957-1962.pdf. The values are transcribed from the data sheets (monthly summaries of daily minima) that were hand marked by C.D. Keeling to indicate weekly minima. Weeks start on Sunday and end on Saturday. For some months, a weekly minima from the previous or next month was chosen to be included in the monthly average of weekly minima for that month. If a minima occurred over multiple days and were marked on the data sheet, they are listed. A few obviously contaminated minima were omitted as marked on the data sheets. In the tabulation, weekly values are organized by month, where the month includes all weekly minimum that were used in the corresponding monthly average. In some cases weekly minimum from adjacent months were used.

5. **Early_LaJolla_transcribed_CO2_monthly_1957-1962.csv**

Header information:

This file is a transcription of a hand-written table of monthly averages of weekly minimum index and $CO_2$ mole fraction on the X74 scale for La Jolla Pier, 1957-1962 and Ice floe data from 1957. This table is contained in a file folder entitled: SIO Pier data, 1957-1962, Daily CO2 minimums and averages and scanned into the file sio_pier_workup_for_1978_report_by_cd_keeling.pdf. The table is entitled as follows: Worksheet for Dec 20, 1977, 'Southwestern U.S. Data' SIO Pier Data table published in 1978 Mauna Loa anniversary report. There is an

assumed error in index value I for April 1962, 316.6, found in the worksheet table and corrected with the value 316.8 found from the April 1962 monthly data sheet.

6. **scan_of_sio_pier_data_daily_average_summary_1958-1960.pdf**

   Header information:

   This digital file is a scan of a paper folder entitled "SIO PIER DATA, 1958-60, Daily Average Summary" located in the first drawer labeled as "SCRIPPS PIER DATA (1958-62)" of a file cabinet in Alane Bollenbacher's office. The folder contains daily tabulations from September 10, 1958 to June 16, 1960 of working tank information and analyzer scale factors along with summary information of daily average pier air index values. The working tank days and tank numbers match those noted on the daily half-hourly data sheets. The tank index and analyzer scale factor tabulated also match those noted on the daily half-hourly data sheets at the bottom in pencil, except for some cases of presumed human error in notating the data sheets. For example, the working tank changes from #51 to #A-14 on September 20, 1958, which is noted on the daily data sheet, but the tank index and analyzer recorder scale notes at the bottom of the sheet are for tank #51 and not #A-14. Presumably because on September 23, 1958, the tank is changed back from #A-14 to #51 and the hand written notes missed this. So for 1958-1960, the tank indices and analyzer recorder scales are used from these summary sheets to create Table 3. For 1962, there are no summary sheets and so the values notated on the daily data sheets are used.

7. **scan_of_sio_pier_data_daily_co2_minimums_and_averages_1957-1962.pdf**

   Header information:

   This digital file is a scan of a portion of contents of a paper folder entitled "SIO PIER DATA, 1957-1962, Daily CO2 Minimums and Averages" located in the first drawer labeled as "SCRIPPS PIER DATA (1958-62)" of a file cabinet in Alane Bollenbacher's office.

**8. scan_of_sio_pier_workup_for_1978_report_by_cd_keeling.pdf**

Header information:

This digital file is a scan of a portion of contents of a paper folder entitled "SIO PIER DATA, 1957-1962, Daily CO2 Minimums and Averages" located in the first drawer labeled as "SCRIPPS PIER DATA (1958-62)" of a file cabinet in Alane Bollenbacher's office. This scan includes all sheets which we ascertain dated from the 1970s and were used to support the workup for the 1978 report.

# 12 Funding Acknowledgements

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# 14 Tables

**Table 1: Location and dates of use of analyzers from reference gas report #1**

**Location: Ritter Hall**

| Start Date | End Date | Analyzer |
|---|---|---|
| 3/21/1957 | 5/27/1957 | 46 |
| 5/29/1957 | 6/28/1957 | 46 |
| 8/29/1957 | 9/20/1957 | 46 |
| 4/4/1958 | 4/22/1958 | 46 |
| 4/25/1958 | 5/25/1958 | 46 |
| 6/12/1958 | 7/23/1958 | 46 |

**Location: Ritter Hall - intermittant use with vacuum line**

| Start Date | End Date | Analyzer |
|---|---|---|
| 12/6/1957 | 7/24/1958 | 55 |
| 7/24/1958 | | 46 |

**Location: SIO Pier**

| Start Date | End Date | Analyzer |
|---|---|---|
| 9/20/1957 | 10/13/1957 | 46 |
| 7/24/1958 | | 55 |

**Location: Ritter Hall - ref tank analyses**

| Start Date | End Date | Analyzer |
|---|---|---|
| 8/1/1957 | 8/14/1957 | 55 |
| 12/4/1957 | 12/5/1957 | 55 |

**Table 2. Inventory of located data sheets, plots, and summaries.**

| Year | Mon | 1/2 hr data sheets | 1/2 hr plots by hand | Daily min & summary@ | Daily min hand plot* | Daily weather obs. | Daily ave summary** | Daily mean summary+ | Ref gas indices plot |
|---|---|---|---|---|---|---|---|---|---|
| 1957 | Jan | | | | | | | | |
| | Feb | | X | X | | X | | | |
| | Mar | | X | X | | X | | | |
| | Apr | | X | X | | X | | | |
| | May | | X | X | | X | | | |
| | Jun | | X | X | | X | | | |
| | Jul | | X | X | | X | | | |
| | Aug | | X | X | | X | | | |
| | Sep | | X | X | | X | | | |
| | Oct | | | | | X | | | |
| | Nov | | | | | X | | | |
| | Dec | | | | | X | | | |
| 1958 | Jan | | | | | X | | | |
| | Feb | | | | | X | | | |
| | Mar | | X | X | X | X | | | |
| | Apr | | X | X | X | X | | | |
| | May | | X | X | X | X | | | |
| | Jun | | X | X | X | X | | | |
| | Jul | | X | X | X | X | | | |
| | Aug | X | X | X | X | X | X | X | X |
| | Sep | X | X | X | X | X | X | X | X |
| | Oct | X | X | X | X | X | X | X | X |
| | Nov | X | X | X | X | X | X | X | |
| | Dec | X | X | X | X | | X | X | |
| 1959 | Jan | X | X | X | X | | X | X | |
| | Feb | X | X | X | X | | X | X | |
| | Mar | X | X | X | X | | X | X | |
| | Apr | X | X | X | X | | X | X | |
| | May | X | X | X | X | | X | X | |
| | Jun | X | X | X | X | X | X | X | |
| | Jul | X | X | X | X | X | X | X | |
| | Aug | X | X | X | X | X | X | X | |
| | Sep | X | X | X | X | X | X | X | |
| | Oct | X | X | X | X | X | X | X | |
| | Nov | X | X | X | X | X | X | X | |
| | Dec | X | X | X | X | X | X | X | |
| 1960 | Jan | X | X | X | X | X | X | X | |
| | Feb | X | X | X | X | X | X | X | |
| | Mar | X | X | X | X | X | X | X | |
| | Apr | X | X | X | X | X | X | X | |
| | May | X | X | X | X | X | X | X | |
| | Jun | | | | | | | | |
| | Jul | | | | | | | | |
| | Aug | | | | | | | | |
| | Sep | | | | | | | | |
| | Oct | | | | | | | | |
| | Nov | | | | | | | | |
| | Dec | | | | | | | | |
| 1962 | Jan | | | | | | | | |
| | Feb | X | X | | | | | | |
| | Mar | X | X | | | | | | |
| | Apr | X | X | | | | | | |
| | May | | | | | | | | |
| | Jun | | | | | | | | |
| | Jul | | | | | | | | |
| | Aug | | | | | | | | |
| | Sep | | | | | | | | |
| | Oct | | | | | | | | |
| | Nov | | | | | | | | |
| | Dec | | | | | | | | |

*Reference tank numbers indicated. Some annotations regarding weather conditions.

**Scale div difference, # of comparisons, RSF, index diff, ref tank #, ref tank index, air index

+Day, $CO_2$ index value, # of comparisons. Monthly summary in front with 'MANO' values included.

@Notes from 1977 including $CO_2$ mole fraction calculation (I, J, X)

**Table 3. Working tank dates and scale factors**

| Tank # | Start Date/Time | End Date/Time | Scale | Index |
|---|---|---|---|---|
| 58 | 9/9/1958 0:30 | 9/9/1958 17:30 | 1.03778 | 313.84 |
| 51 | 9/9/1958 17:30 | 9/20/1958 15:00 | 1.01222 | 321.89 |
| A-14 | 9/20/1958 15:00 | 9/23/1958 14:30 | 1.01667 | 277.96 |
| 51 | 9/23/1958 14:30 | 10/3/1958 18:00 | 1.01222 | 321.89 |
| A-14 | 10/3/1958 18:00 | 10/5/1958 11:00 | 1.01667 | 277.96 |
| 2418 | 10/5/1958 11:00 | 11/7/1958 17:00 | 1.01667 | 290.72 |
| A-17 | 11/7/1958 17:00 | 11/21/1958 9:30 | 1.01667 | 282.62 |
| 51 | 11/21/1958 9:30 | 11/21/1958 15:00 | 1.01667 | 321.89 |
| 83 | 11/21/1958 15:00 | 1/2/1959 15:30 | 0.98000 | 308.83 |
| 51 | 1/2/1959 15:30 | 2/14/1959 9:30 | 0.97389 | 309.26 |
| 54 | 2/14/1959 9:30 | 3/23/1959 13:30 | 0.96389 | 320.77 |
| 58 | 3/23/1959 13:30 | 5/1/1959 17:00 | 0.97944 | 322.04 |
| 26 | 5/1/1959 17:00 | 6/2/1959 6:30 | 0.97944 | 325.38 |
| 25 | 6/2/1959 6:30 | 7/1/1959 13:30 | 0.93500 | 325.33 |
| 72 | 7/1/1959 13:30 | 8/2/1959 16:30 | 0.93500 | 326.98 |
| 74 | 8/2/1959 16:30 | 9/9/1959 15:30 | 0.93500 | 326.76 |
| 75 | 9/9/1959 15:30 | 10/12/1959 9:30 | 0.94833 | 294.62 |
| 72 | 10/12/1959 9:30 | 11/5/1959 17:00 | 0.97889 | 320.51 |
| 23 | 11/5/1959 17:00 | 12/8/1959 17:00 | 0.97556 | 292.48 |
| 84 | 12/8/1959 17:00 | 1/7/1960 16:00 | 0.93222 | 320.19 |
| 85 | 1/7/1960 16:00 | 2/3/1960 15:30 | 0.93944 | 318.46 |
| 64 | 2/3/1960 15:30 | 3/1/1960 15:00 | 0.94667 | 319.11 |
| 84 | 3/1/1960 15:00 | 3/21/1960 10:00 | 0.94889 | 328.91 |
| 57 | 3/21/1960 10:00 | 4/15/1960 16:30 | 0.94556 | 330.68 |
| A-20 | 4/15/1960 16:30 | 5/2/1960 15:30 | 0.94722 | 310.57 |
| 2399 | 5/2/1960 15:30 | 6/13/1960 16:30 | 0.94778 | 317.86 |
| 6074 | 6/13/1960 16:30 | 3/20/1962 13:00 | 0.95000 | 332.73 |
| 2418 | 3/20/1962 13:00 | 3/27/1962 9:30 | 0.98550 | 308.17 |
| 7362 | 3/27/1962 9:30 | 4/25/1962 11:00 | 0.98550 | 301.84 |
| 1540 | 4/25/1962 11:00 | 5/10/1962 8:00 | 0.98550 | 305.51 |

# 15 Figures

| Average date | No. of weekly minima included | Average observed $CO_2$ concentration (ppm) |
|---|---|---|
| 1957–Mar. 24 | | |
| Apr. 17 | 4 | 315.91 |
| May 16 | 4 | 315.92 |
| June 16 | 4 | 315.43 |
| Sept. 12 | 5 | 310.16 |
| Oct. 4 | 2 | 311.15 |
| 1958–Apr. 21 | 3* | 316.72 |
| May 16 | 3 | 317.71 |
| June 22 | 1 | 319.08* |
| July 17 | 5 | 313.52 |
| Aug. 18 | 4 | 310.83 |
| Sept. 13 | 4 | 311.08 |
| Oct. 19 | 3* | 313.17 |
| Nov. 20 | 5 | 315.64 |
| Dec. 20 | 4 | 316.76 |
| 1959–Jan. 19 | 3* | 317.38 |
| Feb. 14 | 4 | 316.89 |
| Mar. 18 | 5 | 317.89 |
| Apr. 18 | 4 | 317.52 |
| May 17 | 4 | 317.52 |
| June 14 | 4 | 317.65 |
| July 14 | 5 | 313.95 |
| Aug. 16 | 4 | 310.52 |
| Sept. 12 | 4 | 311.14 |
| Oct. 13 | 5 | 314.58 |
| Nov. 8 | 2* | 316.19 |
| Dec. 16 | 5 | 315.95 |
| 1960–Jan. 16 | 3* | 317.19 |
| Feb. 14 | 4 | 317.94 |
| Mar. 17 | 5 | 317.95 |
| Apr. 16 | 4 | 319.82 |
| May 12 | 3 | 320.57 |
| June 12 | 2 | 318.58 |
| 1962–Mar. 25 | 2 | 320.43 |
| Apr. 13 | 4 | 320.06 |
| May 6 | 2 | 321.07 |

*One weekly minimum omitted from average.

**Table 2. Mean of weekly minimum concentration of atmospheric carbon dioxide (relative to dry air) by infrared gas analysis, for Scripps pier, La Jolla, California, at 33°N, 117°W, elevation 8 m**

*Figure 5. Monthly averages of the weekly minimum atmospheric $CO_2$ concentration at La Jolla, California. Concentrations were determined with a nondispersive infrared gas analyzer.*

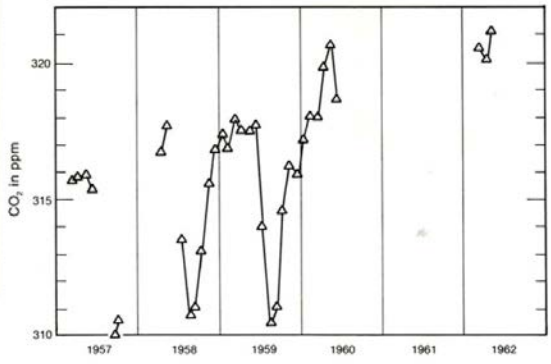


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**Figure 1.** Keeling 1978 Mauna Loa special report (Keeling, 1978) presentation of early La Jolla, CA monthly $CO_2$ values.

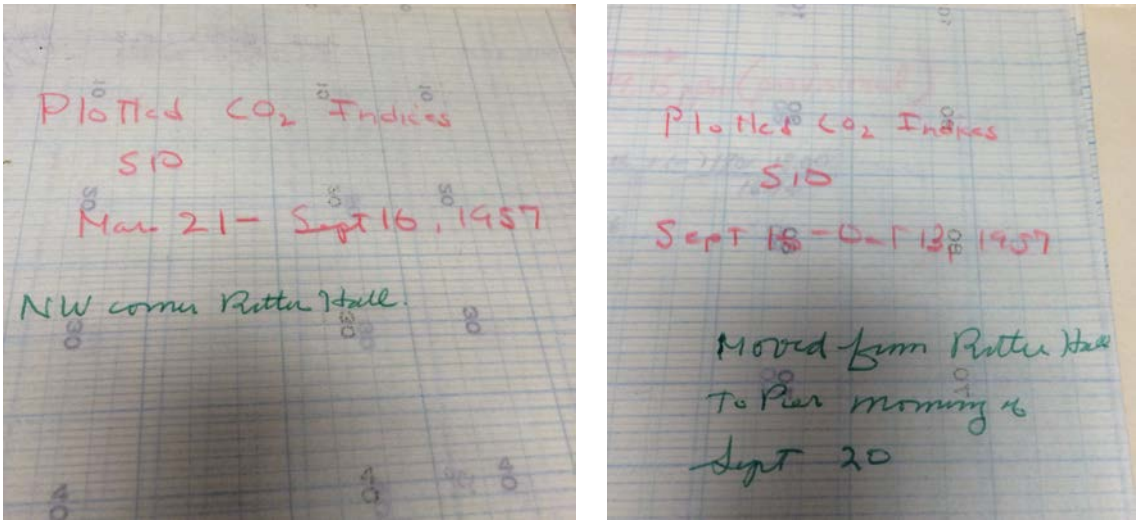



**Figure 2.** Photograph of hand plotted $CO_2$ indices which document the APC analyzer being used from March 21, 1957 to September 16, 1957 at the North West corner of Ritter Hall. And moved from Ritter Hall to the Pier on September 20, 1957.

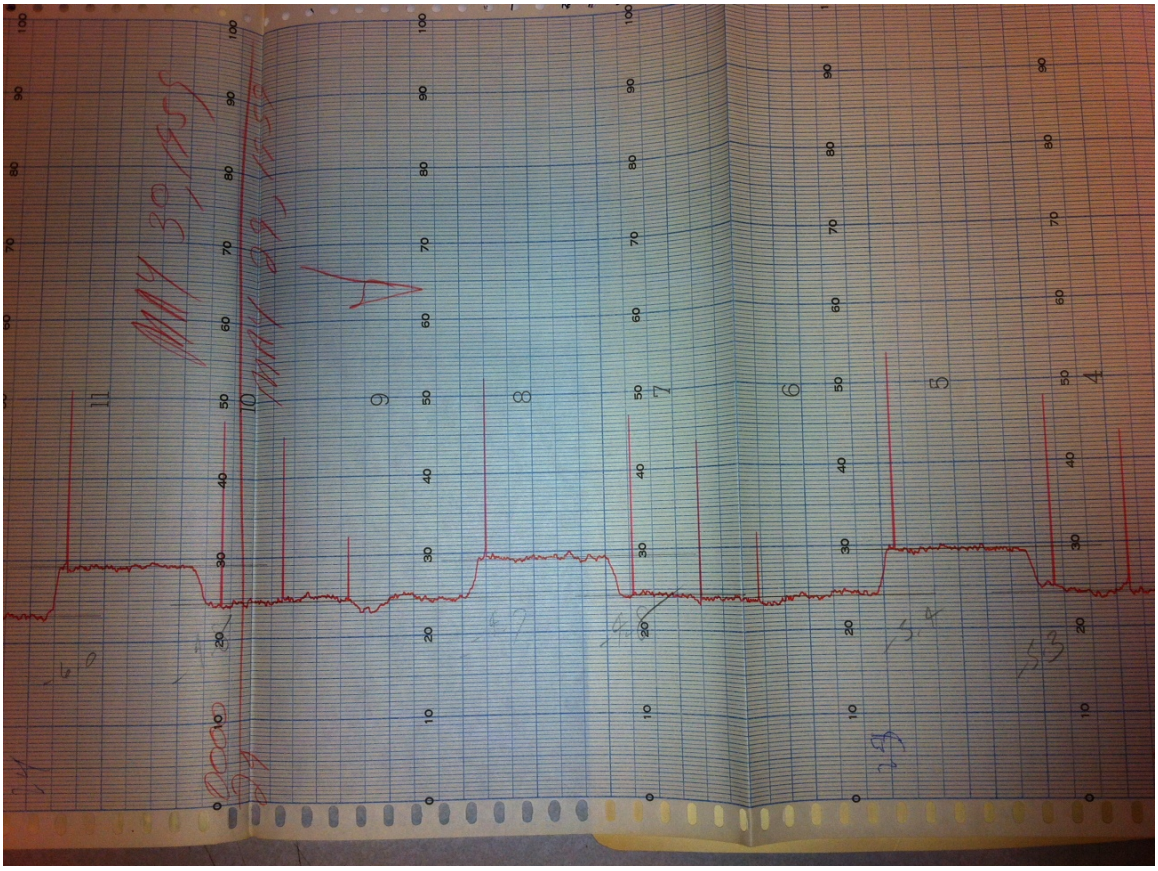
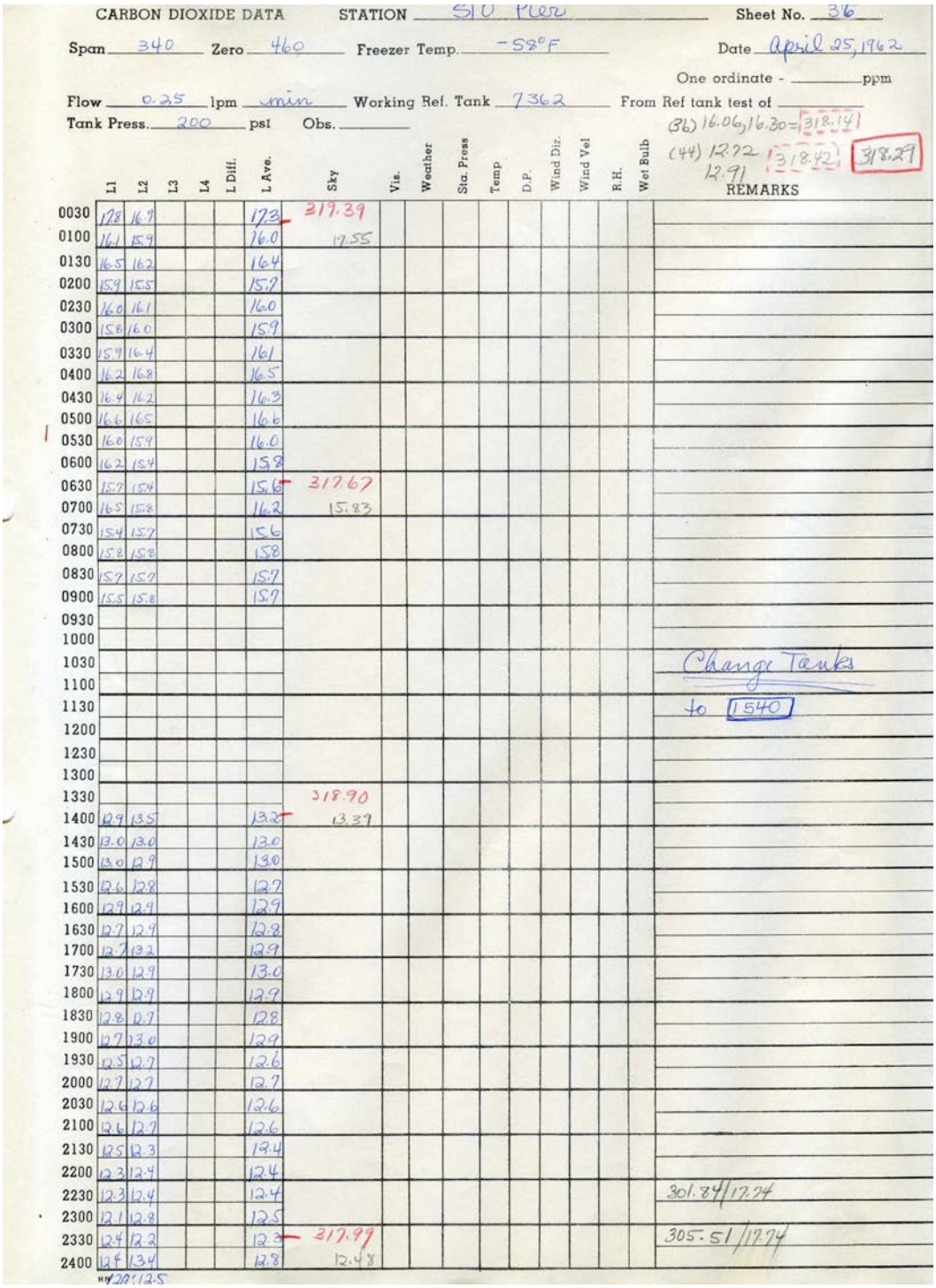


**Figure 3.** Example of a chart trace showing APC voltages. Spikes are inlet-switching events. Pencil marks are from 'lineout' readings with voltage differences listed. Time proceeds right to left.



CARBON DIOXIDE DATA STATION 510 Pier Sheet No. 36

Span 340 Zero 460 Freezer Temp. -58°F Date April 25, 1962

One ordinate - _____ ppm

Flow 0.25 lpm min Working Ref. Tank 7362 From Ref tank test of _____

Tank Press. 200 psi Obs. _____

(36) 16.06, 16.30 = 318.14

(44) 12.72 318.42, 12.91 318.29

| | L1 | L2 | L3 | L4 | L Diff. | L Ave. | Sky | Vis. | Weather | Sta. Press | Temp | D.P. | Wind Dir. | Wind Vel | R.H. | Wet Bulb | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0030 | 12.8 | 16.9 | | | | 17.3 | 319.39 | | | | | | | | | | |
| 0100 | 16.1 | 15.9 | | | | 16.0 | 17.55 | | | | | | | | | | |
| 0130 | 16.5 | 16.2 | | | | 16.4 | | | | | | | | | | | |
| 0200 | 15.9 | 15.5 | | | | 15.7 | | | | | | | | | | | |
| 0230 | 16.0 | 16.1 | | | | 16.0 | | | | | | | | | | | |
| 0300 | 15.8 | 16.0 | | | | 15.9 | | | | | | | | | | | |
| 0330 | 15.9 | 16.4 | | | | 16.1 | | | | | | | | | | | |
| 0400 | 16.2 | 16.8 | | | | 16.5 | | | | | | | | | | | |
| 0430 | 16.4 | 16.2 | | | | 16.3 | | | | | | | | | | | |
| 0500 | 16.6 | 16.5 | | | | 16.6 | | | | | | | | | | | |
| 0530 | 16.0 | 15.9 | | | | 16.0 | | | | | | | | | | | |
| 0600 | 16.2 | 15.4 | | | | 15.8 | | | | | | | | | | | |
| 0630 | 15.7 | 15.4 | | | | 15.6 | 317.67 | | | | | | | | | | |
| 0700 | 16.5 | 15.8 | | | | 16.2 | 15.83 | | | | | | | | | | |
| 0730 | 15.4 | 15.7 | | | | 15.6 | | | | | | | | | | | |
| 0800 | 15.8 | 15.8 | | | | 15.8 | | | | | | | | | | | |
| 0830 | 15.7 | 15.7 | | | | 15.7 | | | | | | | | | | | |
| 0900 | 15.5 | 15.8 | | | | 15.7 | | | | | | | | | | | |
| 0930 | | | | | | | | | | | | | | | | | |
| 1000 | | | | | | | | | | | | | | | | | |
| 1030 | | | | | | | | | | | | | | | | | Change Tanks |
| 1100 | | | | | | | | | | | | | | | | | |
| 1130 | | | | | | | | | | | | | | | | | to 1540 |
| 1200 | | | | | | | | | | | | | | | | | |
| 1230 | | | | | | | | | | | | | | | | | |
| 1300 | | | | | | | | | | | | | | | | | |
| 1330 | | | | | | | 318.90 | | | | | | | | | | |
| 1400 | 12.9 | 13.5 | | | | 13.2 | 13.39 | | | | | | | | | | |
| 1430 | 13.0 | 13.0 | | | | 13.0 | | | | | | | | | | | |
| 1500 | 13.0 | 12.9 | | | | 13.0 | | | | | | | | | | | |
| 1530 | 12.6 | 12.8 | | | | 12.7 | | | | | | | | | | | |
| 1600 | 12.9 | 12.9 | | | | 12.9 | | | | | | | | | | | |
| 1630 | 12.7 | 12.9 | | | | 12.8 | | | | | | | | | | | |
| 1700 | 12.7 | 13.2 | | | | 12.9 | | | | | | | | | | | |
| 1730 | 13.0 | 12.9 | | | | 13.0 | | | | | | | | | | | |
| 1800 | 12.9 | 12.9 | | | | 12.9 | | | | | | | | | | | |
| 1830 | 12.8 | 12.7 | | | | 12.8 | | | | | | | | | | | |
| 1900 | 12.7 | 13.0 | | | | 12.9 | | | | | | | | | | | |
| 1930 | 12.5 | 12.7 | | | | 12.6 | | | | | | | | | | | |
| 2000 | 12.7 | 12.7 | | | | 12.7 | | | | | | | | | | | |
| 2030 | 12.6 | 12.6 | | | | 12.6 | | | | | | | | | | | |
| 2100 | 12.6 | 12.7 | | | | 12.6 | | | | | | | | | | | |
| 2130 | 12.5 | 12.3 | | | | 12.4 | | | | | | | | | | | |
| 2200 | 12.3 | 12.4 | | | | 12.4 | | | | | | | | | | | |
| 2230 | 12.3 | 12.4 | | | | 12.4 | | | | | | | | | | | 301.84/17.24 |
| 2300 | 12.1 | 12.8 | | | | 12.5 | | | | | | | | | | | |
| 2330 | 12.4 | 12.2 | | | | 12.3 | 317.99 | | | | | | | | | | 305.51/17.24 |
| 2400 | 12.4 | 13.4 | | | | 12.8 | 12.48 | | | | | | | | | | |

HW 20:12.5

**Figure 4.** Example data sheet. Each half-hour jog has 2 voltage difference values recorded (L1 and L2). These are then averaged together in L ave. Notice the extra values squeezed in below 24:00 at the bottom of the page. This could be an example of a 49 jog day if the measurements are continuous through 8am the next day. There was also a tank change on this day which resulted in an interruption of the measurements.

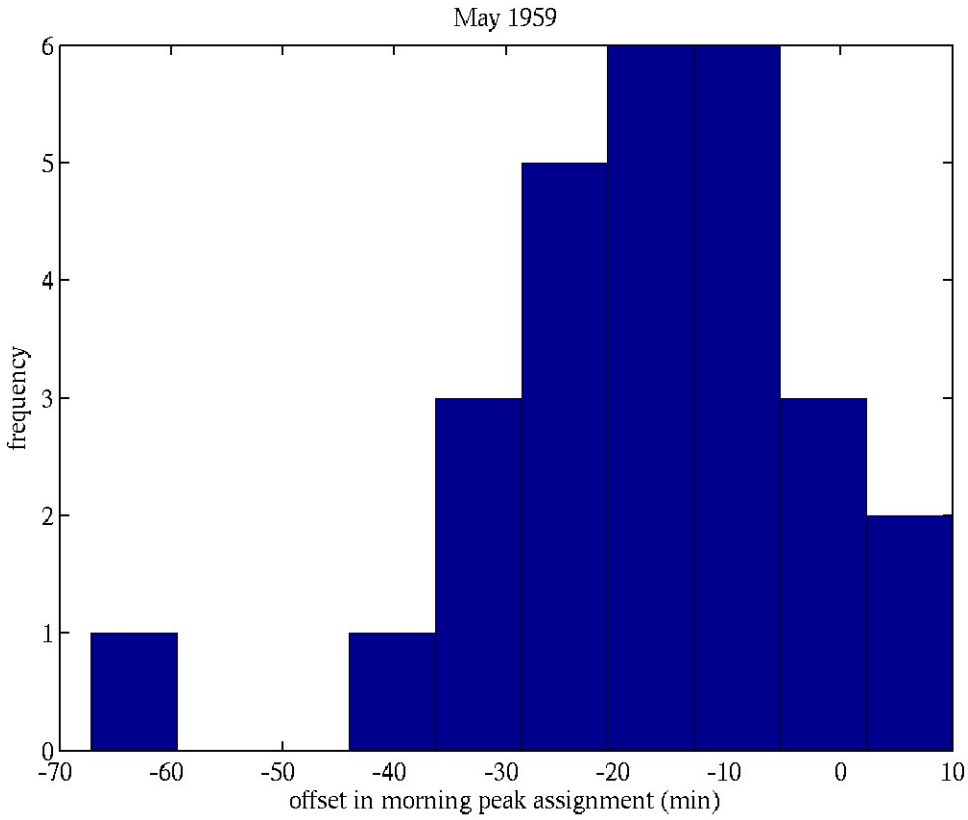



**Figure 5.** Difference between the assigned times of jogs and the adjusted time-ending time extrapolated from the morning times written on the chart traces. If the lowest value is omitted, the average is -15.8 min, indicating that the intent was for the half-hour values to represent time-centered averages.