Scripps Early Aircraft CO_2 Dataset

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Introduction

This file provides background information pertinent to the aircraft CO_2 data file, flx_aircraft.csv, which contains data from Weather Reconnaissance flights from 1958-1961. Results for the aircraft flights were originally described in Keeling et al. (1968a), and were included in the analyses in Bolin and Keeling (1963) and Pales and Keeling (1965). A data report (Keeling, 1968b) listed all of the individual flask data as well as zonal and monthly averages of the data. The data in the accompanying file incorporate corrections not known in the 1960s, including carrier gas effects and other smaller effects.

Flight Information

Air over the North Pacific and Arctic Oceans was sampled during Weather Reconnaissance flights of the U.S. Air Force from April 1958 to December 1961. Air samples were collected in evacuated 2 or 5 liter Pyrex flasks by meteorological observers from the 55th Weather Reconnaissance Squadron of the U.S. Air Force on four-engine military B-50 aircraft converted for weather observations and fitted with special CO_2 sampling apparatus.

Flask air samples were analyzed at Scripps Institution of Oceanography on a nondispersive infrared analyzer made by the Applied Physics Corporation (APC), and were calibrated against CO_2-in-nitrogen reference gases which in turn were calibrated on a constant volume mercury manometer (CMM) (Keeling et al., 1968a). Samples were analyzed with the analysis cell of the APC either at ambient pressure or at reduced pressure maintained by a Cartesian manostat. More details of sampling and analysis are described in Keeling et al. (1968a) and Pales and Keeling (1965).

During the aircraft program, five major flight tracks were sampled. A polar flight track designated Ptarmigan extended from Alaska to about 86°N. A series of tracks designated Stork A, B, C, G, K, J, and S, extended from Alaska to near 45°N, 150°W, and from there to the west coast of North America near 40°N. A track designated Loon H extended from Alaska to the Hawaiian Islands. A series designated Petralark F and Lark U, V, and Y extended from the west coast of the U.S. near 40°N to the Hawaiian Islands; both Petralark and Lark are referred to as Lark in the aircraft dataset. Finally, a series of tracks designated Loon K were located in the vicinity of the Hawaiian Islands.

Air sampling was performed primarily at three altitudes - 700, 500 and 300 hPa - usually with 12 samples taken per 10-15 hour flight. Sampling was scheduled to provide seasonal coverage resulting in 19 flights in Winter, 24 Spring, 16 Summer and 31 Autumn over the 4 year project.

Data Reduction Procedures Applied in the Original Publications

Data published in Keeling et al (1968a) were initially worked up as "index values" (referred to as I index) which are linear in APC analyzer response. Manometric calibrations from 1959-1961 were then used to produce a new provisional manometric mole fraction scale also linear with the APC response, called the "adjusted index" or "J index". The adjusted index J is calculated from the I index as follows:

$J = (I - 311.51)*1.2188 + 311.51$

Assets Used for Generating Updated Data

In addition to information in the publications and reports of the 1960s, additional information and comments associated with sampling and analysis of the aircraft data were stored at Scripps in a variety of forms. Field data sheets with observer name, date, flask numbers, latitude, longitude, time, altitude, air speed, and comments on problems of sampling were completed for each flight. Ninety-three field data sheets in one folder stored at Scripps have been scanned into a pdf file for this report. Flask analysis log sheets were completed during analyses and were saved but at this time have not been located. APC analyzer paper traces generated during analysis were located and saved.

A list of input and output files stored in subdirectories are explained below. Input

Directory

bollenbacher1983-brown-book.pdf: file created by scanning the Bollenbacher brown book. Contains all aircraft data (as well as ship and land station data) as I index values to 2 decimal places.

keeling1968-aircraft_project_final_report_data_table1.pdf (extracted from file **keeling1968-aircraft_project_final_report.pdf**): scanned version of Keeling 1968 report. Contains version of aircraft data as J index values to 1 decimal place.

qflcor08a_pub.f: Fortran processing program that converts I index data values to final CO_2 values, with text line numbers added for reference.

pecor.dat: ascii file of period corrections used by qflcor08a_pub.f

SHPRES.DAT: ascii file listing pressure of sample cell of NDIR analyzer indexed to sample sheet numbers (SHPRES = sheet pressure) used by qflcor08a_pub.f

qflcor08a_pub.job: Unix script for executing program qflcor08a_pub.f

qflcor08a_pub-all.job: Unix script for executing qflcor08a_pub.job for a specified aircraft flight.

fli_aircraft_all.txt: quality-checked CO2 data in I index

checkdata.f: Fortran program used to perform one of the data checks of fli.all data

Output Directory

flx_aircraft.csv: quality-checked aircraft CO_2 data in 08A calibration scale

Production of the Corrected Aircraft Data Set

Analyses, lab experiments and calibrations after publications of the aircraft data revealed corrections that needed to be applied to the aircraft data to produce accurate CO_2 mole ratios.

The aircraft data used to prepare this submission were stored as part of a compilation of CO_2 data from the

1950s, 1960s and 1970s from land stations, ship cruises and aircraft flights. The compilation was available only in printed form; no digital backup was located. The printed form consisted of computer line printer paper that was bound into a notebook in September 1983 (Bollenbacher, 1983). Each page of aircraft data lists columns for flask ID number, flask size (2 or 5 liter), sampling date and time (UTC), latitude, longitude, observer name, CO_2 in I index to 2 decimal places, analysis date, analysis number of a single flask, station designation, and field and analysis sheet numbers.

The aircraft data pages from the binder of Bollenbacher (1983) were digitally scanned in order to generate digital files. Individual pages were scanned on a Fujitsu scanner and converted to digital files by optical character recognition (OCR) with the application ABBYY Finereader. OCR results were saved in Excel. The results required substantial reformatting and correction of translational problems such as number 0 to letter O, letter O to number 0, 0 to Q, 0 to 9, `.' to 1, etc. To detect more subtle errors, a Fortran program was written to read the file and check data in each data column against expected limits. This procedure identified in particular errors in sampling time and errors in transcription from
the field data sheets to the files printed in Bollenbacher (1983). The result is an essentially error-free file containing I index values with auxiliary sample and analysis information.

Dates on ten Ptarmigan records (PT5) where corrected to 591022 from 591021, and 8 records were flagged 8 based on flags in Keeling (1968).

Application of Corrections to the Data

The Scripps CO_2 program has retained computer programs for automatic reduction of data collected throughout the program history, extending back to the 1960s. The programs incorporate corrections for the carrier gas effect and other smaller corrections. In order to work up the aircraft data to CO_2 values, we applied one of these programs (QFLCOR08A.F) to the I index values generated above via the scanning process. A description of this program is provided below and a list of the corrections applied is as follows (presented in the order they appear in the program with program line number or location):

1) Two liter correction (Line 248)

Aircraft samples were taken in both 2 and 5 liter flasks. Two liter flasks tend to produce higher values of CO_2 owing presumably to diffusion of CO_2 through stopcock grease into evacuated flasks before sampling (Keeling, 1984). Lacking specific documentation for the aircraft data, we have set the correction to zero.

2) Pressure correction (Line 273)

All aircraft samples were analyzed at reduced pressure in the APC analyzer. A so-called carrier gas correction is larger at lower pressures (Bacastow et al., 1983b). The carrier gas correction is applied to data in two parts - the correction for the effect at full atmospheric pressure (applied later in (5)) and the correction for reduced pressure, applied here.

3) Period correction (Line 286)

Detectors in the Scripps APC analyzer were repaired or replaced several times from 1958 to 1968 producing changes in the response of the analyzer. Corrections were formulated by Keeling (1984, 1987).

4) Storage correction (Line 313, 347)

Flasks stored for abnormally long times between sampling and analysis showed a small increase in CO_2. This correction is applied only to data from Fanning and Christmas Islands and Mauna Loa, not to the aircraft data.

5) Drift correction (subroutines CORR1 to CORR3, Line 996).

Correction for drift in the reference gas system, as formulated for periods prior to 1983 (Bacastow et al., 1983a, Keeling et al. 1986).

6) Manometer volume correction (subroutines CORR4 and CORR5, Lines 999, 1002).

Redetermination of volumes in the constant volume manometer required the original results for dates prior to 1985 to be multiplied by a constant factor 1.000503 (Keeling et al., 2002).

7) Carrier gas correction (subroutine CORR5, Line 1002)

Aircraft samples were analyzed with CO_2-in-N_2 reference gases. The difference in the carrier of samples (air) and reference gases (N_2) produced CO_2 values that are about 1% too low. With the sample specified to be of type AIR (A), subroutine CORR5 is called and produces XAIR, which is CO_2 corrected for the carrier gas effect (Keeling et al., 2002).

Data Flagging

Data rejection flags were transcribed from the tabulation of Keeling et al. (1968b) to the data file. These were used by Keeling (1968b) to signify samples that were contaminated. We have not recovered daily analysis sheets or other documents that provide independent confirmation of contamination. In addition, several samples shown in the Bollenbacher (1983) printouts were not listed in Table 1 of Keeling et al. (1968b). We have flagged these as missing in the main input file.

References

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Appendix**. Brief Description of the Program qflcor08a_pub.f**

The program qflcor08a_pub.f calculates CO_2 mole fractions from APC analyzer index values according to the Scripps "X08A" CO_2 calibration scale, for either nitrogen or natural-air CO_2 reference gases. Comments are included in the program code related to updates of the calibration system since 1985 and to changes in the computing program. This version of the program is designed to calculate the mole fraction from input of the Scripps I index, the date of analysis on the APC analyzer, and indication of the type of the gas sample. The program applies several corrections discovered since publication of the data in 1968. The program is essentially the same as CORRECT99A.F documented in Keeling et al. (2002).

Here we document the points in the program where corrections are applied. A full description of the corrections is provided in the Appendix. In the program, the I index is referred to as DEX and the J index CMAN59. Depending on the date of analysis and type of gas specified, the program diverts to the appropriate subroutines.

SUBROUTINE CALDAY

Central dates for the calibration periods from 1960 to 2008 are listed here.

SUBROUTINE CALxx

The portion of the program that applies various calibration equations for specified time periods.

SUBROUTINES CORR1 to CORR3

These subroutines carry out calculations accounting for drift in the reference gas system, as formulated for periods prior to 1983.

SUBROUTINE CORR4

Cubic equations are applied to the data, beginning with the 1980 calibration, for nitrogen reference gases. Linear interpolations are performed for periods between central dates of calibration periods after 1983.

SUBROUTINE CORR5

Cubic equations are applied to the data, beginning with the 1983 calibration, for natural-air gases. Linear interpolations by date are done for periods between central dates of calibrations.

CUBIC FUNCTIONS FOR CO2-IN-AIR and CO2-IN-N2

Calibration equations applicable to central dates of each calibration are given as functions named ACUBYY (for example, ACUB85) for natural-air reference gases and CUBYY for nitrogen reference gases. Cubics prior to 1985 are reported in Keeling et al. (1986), and cubic functions for 1985 to 1999 in Keeling et al. (2002). Functions after 1999 were developed similarly to those in 1999.