

**Math 1901**  
**Freshman Seminar**  
**Mathematical Climate Models**

**Fall 2024**  
**1:00 - 2:15 Mondays and Wednesdays**  
**Vincent Hall 213**

Richard McGehee, Instructor  
458 Vincent Hall  
mcgehee@umn.edu  
[www-users.cse.umn.edu/~mcgehee/](http://www-users.cse.umn.edu/~mcgehee/)

course website  
<https://www-users.cse.umn.edu/~mcgehee/Course/Math1901/>

Math 1901 9/11/2024

**Math 1901**  
**Textbook**

Greta Thunberg  
*The Climate Book*  
Penguin Press 2023

<https://www.penguinrandomhouse.com/books/709837/the-climate-book-by-greta-thunberg/>

Math 1901 9/11/2024

**Math 1901**  
**Textbook**

**Mauna Loa Observatory**  
**Scripps Institution of Oceanography**

Math 1901 9/11/2024

**Math 1901**  
**Mauna Loa**

*Can we measure greenhouse gasses?*

Mauna Loa Observatory

[https://research.noaa.gov/Portals/0/EasyDNNnews/1502/200060p587EDNmain10061mlc\\_sign\\_miller.jpg](https://research.noaa.gov/Portals/0/EasyDNNnews/1502/200060p587EDNmain10061mlc_sign_miller.jpg)

Math 1901 9/11/2024

**Math 1901**  
**Mauna Loa**

**Carbon dioxide concentration at Mauna Loa Observatory\***

Math 1901 9/11/2024

**Math 1901**

MATH 1901 Mauna Loa Data

CO<sub>2</sub> data from Mauna Loa

Ways to get the Data

Download into a Google Sheet

- (1) Open a Google Sheet
- (2) Click on the cell where you want the upper right hand corner of your data.
- (3) Enter the following text into the cell:

```
=IMPORTDATA("https://scrippsco2.ucsd.edu/assets/data/atmospheric/stations/in_situ_co2/monthly/monthly_in_situ_co2_alo.csv",,"em_US")
```

Using your browser

- (1) Go to the Scripps CO<sub>2</sub> site [here](#).
- (2) Click on the link "monthly\_in\_situ\_co2\_mlo.csv". If you are using Chrome, the browser will offer you the opportunity to save the file locally on your computer.

Shortcut

To download the full data file directly to your computer, click [here](#).

Alternatively, here is the URL you can enter into a Google Sheet:

[https://www-users.cse.umn.edu/~mcgehee/course/Math1901/tutorial/monthly\\_in\\_situ\\_co2\\_alo.csv](https://www-users.cse.umn.edu/~mcgehee/course/Math1901/tutorial/monthly_in_situ_co2_alo.csv)

Math 1901 9/11/2024

**Math 1901**

MATH 1901 Mauna Loa Data

Untitled spreadsheet - Google

File Edit View Insert Format Data Tools Extensions Help

A1 =IMPORTDATA("https://scrippsco2.ucsd.edu/assets/data/atmospheric/stations/in\_situ\_co2/monthly/monthly\_in\_situ\_co2\_alo.csv",,"em\_US")

Math 1901 9/11/2024

**Math 1901**

MATH 1901 Mauna Loa Data

Untitled spreadsheet - Google

A2 Atmospheric CO<sub>2</sub> concentrations (ppm) derived from in situ air measurements

1  
2 Atmospheric CO<sub>2</sub> concentrations (ppm) derived from in situ air measurements  
3 at Mauna Loa, Observatory, Hawaii: Latitude 19.5°N Longitude 155.6°W Elevation 3397m  
4 Since December 2002 sampling has temporarily been relocated to MaunuaKea, Hawaii  
5 Latitude 19.8°N Longitude 155.3°W Elevation 4145m  
6  
7 Source: R. F. Keeling, S. J. Walker, S. C. Piper and A. F. Bollenbacher  
8 Scripps CO<sub>2</sub> Program (<http://scrippsco2.ucsd.edu>)  
9 Scripps Institution of Oceanography (SIO)  
10 University of California  
11 La Jolla, California USA 92093-0244  
12  
13 Status of data and correspondence:  
14  
15 These data are subject to revision based on recalibration of standard gases. Questions

Math 1901 9/11/2024

**Math 1901**

MATH 1901 Mauna Loa Data

Untitled spreadsheet - Google

1:1000

1  
2 Atmospheric CO<sub>2</sub> concentrations (ppm) derived from in situ air measurements  
3 at Mauna Loa, Observatory, Hawaii: Latitude 19.5°N Longitude 155.6°W Elevation 3397m  
4 Since December 2002 sampling has temporarily been relocated to MaunuaKea, Hawaii  
5 Latitude 19.8°N Longitude 155.3°W Elevation 4145m  
6  
7 Source: R. F. Keeling, S. J. Walker, S. C. Piper and A. F. Bollenbacher  
8 Scripps CO<sub>2</sub> Program (<http://scrippsco2.ucsd.edu>)  
9 Scripps Institution of Oceanography (SIO)  
10 University of California  
11 La Jolla, California USA 92093-0244  
12  
13 Status of data and correspondence:  
14  
15 These data are subject to revision based on recalibration of standard gases. Questions  
16 about the data should be directed to Dr. Ralph Keeling ([rkeeling@ucsd.edu](mailto:rkeeling@ucsd.edu)), Stephen Walker ([stephenwalker@uci.edu](mailto:stephenwalker@uci.edu)) and Rethan Stewart ([rrethans@uci.edu](mailto:rrethans@uci.edu)), Scripps CO<sub>2</sub> Program.

copy and paste values

Math 1901 9/11/2024

**Math 1901**

Mauna Loa Data - Google Sheet

Mauna Loa Data

1  
2 Atmospheric CO<sub>2</sub> concentrations (ppm) derived from in situ air measurements  
3 at Mauna Loa, Observatory, Hawaii: Latitude 19.5°N Longitude 155.6°W Elevation 3397m  
4 Since December 2002 sampling has temporarily been relocated to MaunuaKea, Hawaii  
5 Latitude 19.8°N Longitude 155.3°W Elevation 4145m  
6  
7 Source: R. F. Keeling, S. J. Walker, S. C. Piper and A. F. Bollenbacher  
8 Scripps CO<sub>2</sub> Program (<http://scrippsco2.ucsd.edu>)  
9 Scripps Institution of Oceanography (SIO)  
10 University of California  
11 La Jolla, California USA 92093-0244  
12  
13 Status of data and correspondence:  
14  
15 These data are subject to revision based on recalibration of standard gases. Questions

rename

MLdata

Math 1901 9/11/2024

**Math 1901**

Mauna Loa Data - Google Sheet

Mauna Loa Data

D10

1  
2 Delete  
3 Duplicate  
4 Copy to  
5 Rename  
6 Change color  
7 Protect sheet  
8 Hide sheet  
9 View comments  
10  
11  
12  
13  
14  
15  
16  
17

duplicate

Copy of MLdata

Math 1901 9/11/2024

**Math 1901**

The data file below contains 10 columns. Columns 1-4 give the dates in several redundant formats. Column 5 below gives monthly Mauna Loa CO2 concentrations in micro-mol CO2 per mole (ppm), reported on the 2012 SI0 manometric mole fraction scale. This is the standard version of the data most often sought. The monthly values have been adjusted to 24.00 hours on the 15th of each month. Column 6 gives the same data after a seasonal adjustment to remove the quasi-regular seasonal cycle. The adjustment involves subtracting from the data a 4-harmonic fit with a linear gain factor. Column 7 is a smoothed version of the data generated from a stiff cubic spline function plus 4-harmonic functions with linear gain. Column 8 is the same smoothed version with the seasonal cycle removed. Column 9 is identical to Column 8 except that the missing values from Column 5 have been filled with values from Column 7. Column 10 is identical to Column 6 except missing values have been filled with values from Column 8. Missing values are denoted by -99.99

Math 1901 9/11/2024

**Math 1901**

Math 1901 9/11/2024

**Math 1901**

The data file below contains 10 columns. Columns 1-4 give the dates in several redundant formats. Column 5 below gives monthly Mauna Loa CO2 concentrations in micro-mol CO2 per mole (ppm), reported on the 2012 SI0 manometric mole fraction scale. This is the standard version of the data most often sought. The monthly values have been adjusted to 24.00 hours on the 15th of each month. Column 6 gives the same data after a seasonal adjustment to remove the quasi-regular seasonal cycle. The adjustment involves subtracting from the data a 4-harmonic fit with a linear gain factor. Column 7 is a smoothed version of the data generated from a stiff cubic spline function plus 4-harmonic functions with linear gain. Column 8 is the same smoothed version with the seasonal cycle removed. Column 9 is identical to Column 7. Column 10 is identical to Column 6 except missing values have been filled with values from Column 8. Missing values are denoted by -99.99

Math 1901 9/11/2024

**Math 1901**

Math 1901 9/11/2024

**Math 1901**

The data file below contains 10 columns. Columns 1-4 give the dates in several redundant formats. Column 5 below gives monthly Mauna Loa CO2 concentrations in micro-mol CO2 per mole (ppm), reported on the 2012 SI0 manometric mole fraction scale. This is the standard version of the data most often sought. The monthly values have been adjusted to 24.00 hours on the 15th of each month. Column 6 gives the same data after a seasonal adjustment to remove the quasi-regular seasonal cycle. The adjustment involves subtracting from the data a 4-harmonic fit with a linear gain factor. Column 7 is a smoothed version of the data generated from a stiff cubic spline function plus 4-harmonic functions with linear gain. Column 8 is the same smoothed version with the seasonal cycle removed. Column 9 is identical to Column 7. Column 10 is identical to Column 6 except missing values have been filled with values from Column 8. Missing values are denoted by -99.99

Math 1901 9/11/2024

**Math 1901**

Math 1901 9/11/2024

**Math 1901**

The data file below contains 10 columns. Columns 1-4 give the dates in several redundant formats. Column 5 below gives monthly Mauna Loa CO2 concentrations in micro-mol CO2 per mole (ppm), reported on the 2012 SI0 monometric mole fraction scale. This is the standard version of the data most often sought. The monthly values have been adjusted to 24,000 hours on the 15th of each month. Column 6 gives the same data after a seasonal adjustment to remove the quasi-regular seasonal cycle. The adjustment involves subtracting from the data a 4-harmonic fit with a linear gain factor. Column 7 is a smoothed version of the data generated from a stiff cubic spline function plus 4-harmonic functions with linear gain. Column 8 is the same smoothed version with the seasonal cycle removed. Column 9 is identical to Column 5 except that the missing values from Column 5 have been filled with values from Column 7. Column 10 is identical to Column 6 except missing values have been filled with values from Column 8. Missing values are denoted by -99.99. Column 11 is the 3-digit sampling station identifier. MLO refers to the Mauna Loa Observatory. MKO refers the summit of nearby Maunakea. MKO data are used to a fill a file created by the 2022

Yr	Mn	Date	CO2	seasonally adjusted	seasonally adjusted fit	CO2 fit	seasonally adjusted fit	Stations
1958	3	1958 2027	315.71	314.43	316.2	314.9	314.71	314.43 MLO
1958	4	1958 2877	317.45	315.16	317.3	314.9	317.45	315.16 MLO
1958	5	1958 3699	317.51	314.69	317.88	315.0	317.51	314.69 MLO
1958	6	1958 4548	-99.99	-99.99	317.27	315.11	317.27	315.14 MLO
1958	7	1958 537	315.87	315.2	315.86	315.2	315.87	315.2 MLO
1958	8	1958 6219	314.93	316.22	313.96	315.2	314.93	316.22 MLO
1958	9	1958 7088	315.24	316.42	312.43	315.3	315.24	316.42 MLO
1958	10	1958 789	-99.99	-99.99	312.42	315.4	312.42	315.41 MLO
1958	11	1958 874	313.33	315.21	313.8	315.4	313.33	315.21 MLO
1958	12	1958 9562	314.67	315.43	314.76	315.5	314.67	315.43 MLO
1959	1	1959 0411	315.58	315.52	315.84	315.5	315.58	315.52 MLO
1959	2	1959 126	316.49	315.84	316.29	315.6	316.49	315.84 MLO
1959	3	1959 2027	316.65	315.37	316.99	315.6	316.65	315.37 MLO

**Math 1901**

The data file below contains 10 columns. Columns 1-4 give the dates in several redundant formats. Column 5 below gives monthly Mauna Loa CO2 concentrations in micro-mol CO2 per mole (ppm), reported on the 2012 SI0 monometric mole fraction scale. This is the standard version of the data most often sought. The monthly values have been adjusted to 24,000 hours on the 15th of each month. Column 6 gives the same data after a seasonal adjustment to remove the quasi-regular seasonal cycle. The adjustment involves subtracting from the data a 4-harmonic fit with a linear gain factor. Column 7 is a smoothed version of the data generated from a stiff cubic spline function plus 4-harmonic functions with linear gain. Column 8 is the same smoothed version with the seasonal cycle removed. Column 9 is identical to Column 5 except that the missing values from Column 5 have been filled with values from Column 7. Column 10 is identical to Column 6 except missing values have been filled with values from Column 8. Missing values are denoted by -99.99. Column 11 is the 3-digit sampling station identifier. MLO refers to the Mauna Loa Observatory. MKO refers the summit of nearby Maunakea. MKO data are used to a fill a file created by the 2022

Yr	Mn	Date	CO2	seasonally adjusted	seasonally adjusted fit	CO2 fit	seasonally adjusted fit	Stations
1958	3	1958 2027	315.71	314.43	316.2	314.9	314.71	314.43 MLO
1958	4	1958 2877	317.45	315.16	317.3	314.9	317.45	315.16 MLO
1958	5	1958 3699	317.51	314.69	317.88	315.0	317.51	314.69 MLO
1958	6	1958 4548	-99.99	-99.99	317.27	315.11	317.27	315.14 MLO
1958	7	1958 537	315.87	315.2	315.86	315.2	315.87	315.2 MLO
1958	8	1958 6219	314.93	316.22	313.96	315.2	314.93	316.22 MLO
1958	9	1958 7088	315.24	316.42	312.43	315.3	315.24	316.42 MLO
1958	10	1958 789	-99.99	-99.99	312.42	315.4	312.42	315.41 MLO
1958	11	1958 874	313.33	315.21	313.8	315.4	313.33	315.21 MLO
1958	12	1958 9562	314.67	315.43	314.76	315.5	314.67	315.43 MLO
1959	1	1959 0411	315.58	315.52	315.84	315.5	315.58	315.52 MLO
1959	2	1959 126	316.49	315.84	316.29	315.6	316.49	315.84 MLO
1959	3	1959 2027	316.65	315.37	316.99	315.6	316.65	315.37 MLO

**Math 1901**

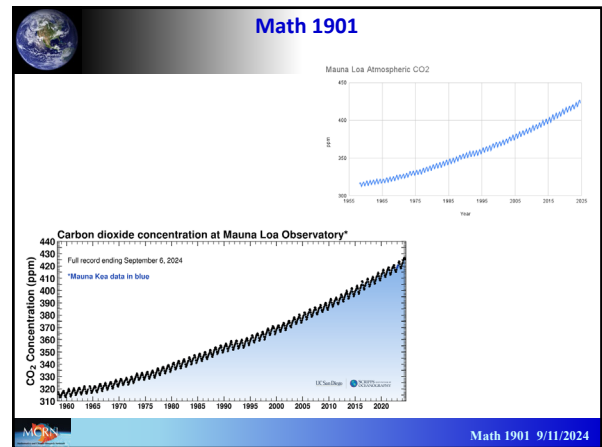
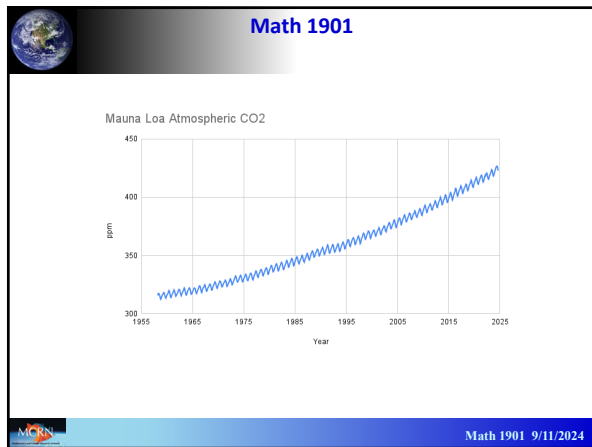
The data file below contains 10 columns. Columns 1-4 give the dates in several redundant formats. Column 5 below gives monthly Mauna Loa CO2 concentrations in micro-mol CO2 per mole (ppm), reported on the 2012 SI0 monometric mole fraction scale. This is the standard version of the data most often sought. The monthly values have been adjusted to 24,000 hours on the 15th of each month. Column 6 gives the same data after a seasonal adjustment to remove the quasi-regular seasonal cycle. The adjustment involves subtracting from the data a 4-harmonic fit with a linear gain factor. Column 7 is a smoothed version of the data generated from a stiff cubic spline function plus 4-harmonic functions with linear gain. Column 8 is the same smoothed version with the seasonal cycle removed. Column 9 is identical to Column 5 except that the missing values from Column 5 have been filled with values from Column 7. Column 10 is identical to Column 6 except missing values have been filled with values from Column 8. Missing values are denoted by -99.99. Column 11 is the 3-digit sampling station identifier. MLO refers to the Mauna Loa Observatory. MKO refers the summit of nearby Maunakea. MKO data are used to a fill a file created by the 2022

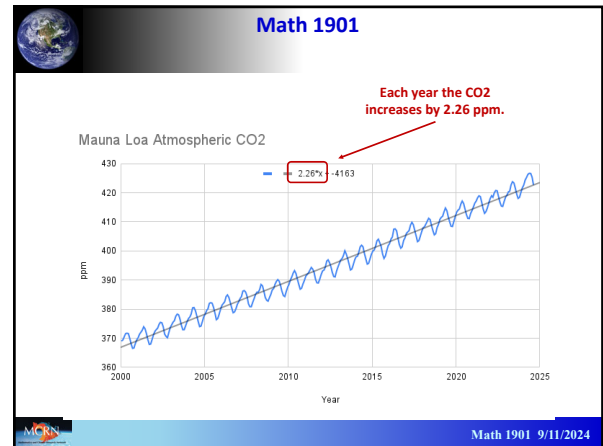
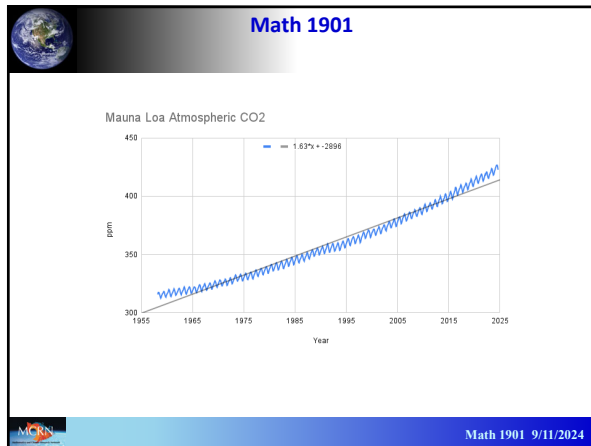
Yr	Mn	Date	CO2	seasonally adjusted	seasonally adjusted fit	CO2 fit	seasonally adjusted fit	Stations
1958	3	1958 2027	315.71	314.43	316.2	314.9	314.71	314.43 MLO
1958	4	1958 2877	317.45	315.16	317.3	314.9	317.45	315.16 MLO
1958	5	1958 3699	317.51	314.69	317.88	315.0	317.51	314.69 MLO
1958	6	1958 4548	-99.99	-99.99	317.27	315.11	317.27	315.14 MLO
1958	7	1958 537	315.87	315.2	315.86	315.2	315.87	315.2 MLO
1958	8	1958 6219	314.93	316.22	313.96	315.2	314.93	316.22 MLO
1958	9	1958 7088	315.24	316.42	312.43	315.3	315.24	316.42 MLO
1958	10	1958 789	-99.99	-99.99	312.42	315.4	312.42	315.41 MLO
1958	11	1958 874	313.33	315.21	313.8	315.4	313.33	315.21 MLO
1958	12	1958 9562	314.67	315.43	314.76	315.5	314.67	315.43 MLO
1959	1	1959 0411	315.58	315.52	315.84	315.5	315.58	315.52 MLO
1959	2	1959 126	316.49	315.84	316.29	315.6	316.49	315.84 MLO
1959	3	1959 2027	316.65	315.37	316.99	315.6	316.65	315.37 MLO

**Math 1901**

The data file below contains 10 columns. Columns 1-4 give the dates in several redundant formats. Column 5 below gives monthly Mauna Loa CO2 concentrations in micro-mol CO2 per mole (ppm), reported on the 2012 SI0 monometric mole fraction scale. This is the standard version of the data most often sought. The monthly values have been adjusted to 24,000 hours on the 15th of each month. Column 6 gives the same data after a seasonal adjustment to remove the quasi-regular seasonal cycle. The adjustment involves subtracting from the data a 4-harmonic fit with a linear gain factor. Column 7 is a smoothed version of the data generated from a stiff cubic spline function plus 4-harmonic functions with linear gain. Column 8 is the same smoothed version with the seasonal cycle removed. Column 9 is identical to Column 5 except that the missing values from Column 5 have been filled with values from Column 7. Column 10 is identical to Column 6 except missing values have been filled with values from Column 8. Missing values are denoted by -99.99. Column 11 is the 3-digit sampling station identifier. MLO refers to the Mauna Loa Observatory. MKO refers the summit of nearby Maunakea. MKO data are used to a fill a file created by the 2022

Yr	Mn	Date	CO2	seasonally adjusted	seasonally adjusted fit	CO2 fit	seasonally adjusted fit	Stations
1958	3	1958 2027	315.71	314.43	316.2	314.9	314.71	314.43 MLO
1958	4	1958 2877	317.45	315.16	317.3	314.9	317.45	315.16 MLO
1958	5	1958 3699	317.51	314.69	317.88	315.0	317.51	314.69 MLO
1958	6	1958 4548	-99.99	-99.99	317.27	315.11	317.27	315.14 MLO
1958	7	1958 537	315.87	315.2	315.86	315.2	315.87	315.2 MLO
1958	8	1958 6219	314.93	316.22	313.96	315.2	314.93	316.22 MLO
1958	9	1958 7088	315.24	316.42	312.43	315.3	315.24	316.42 MLO
1958	10	1958 789	-99.99	-99.99	312.42	315.4	312.42	315.41 MLO
1958	11	1958 874	313.33	315.21	313.8	315.4	313.33	315.21 MLO
1958	12	1958 9562	314.67	315.43	314.76	315.5	314.67	315.43 MLO
1959	1	1959 0411	315.58	315.52	315.84	315.5	315.58	315.52 MLO
1959	2	1959 126	316.49	315.84	316.29	315.6	316.49	315.84 MLO
1959	3	1959 2027	316.65	315.37	316.99	315.6	316.65	315.37 MLO





**Math 1901**

**The CO2 reached 425 ppm in 2024.  
The rate of increase is 2.26 ppm/year.**

**Assume that the current trend continues.**

***What will be the CO2 level in 2050?***

***When will the CO2 level reach 560 ppm?***

Math 1901 9/11/2024