Climate Data Visualization -

Atmospheric CO_2 Concentration / Temperature / Precipitation

Wolfgang Vollmer

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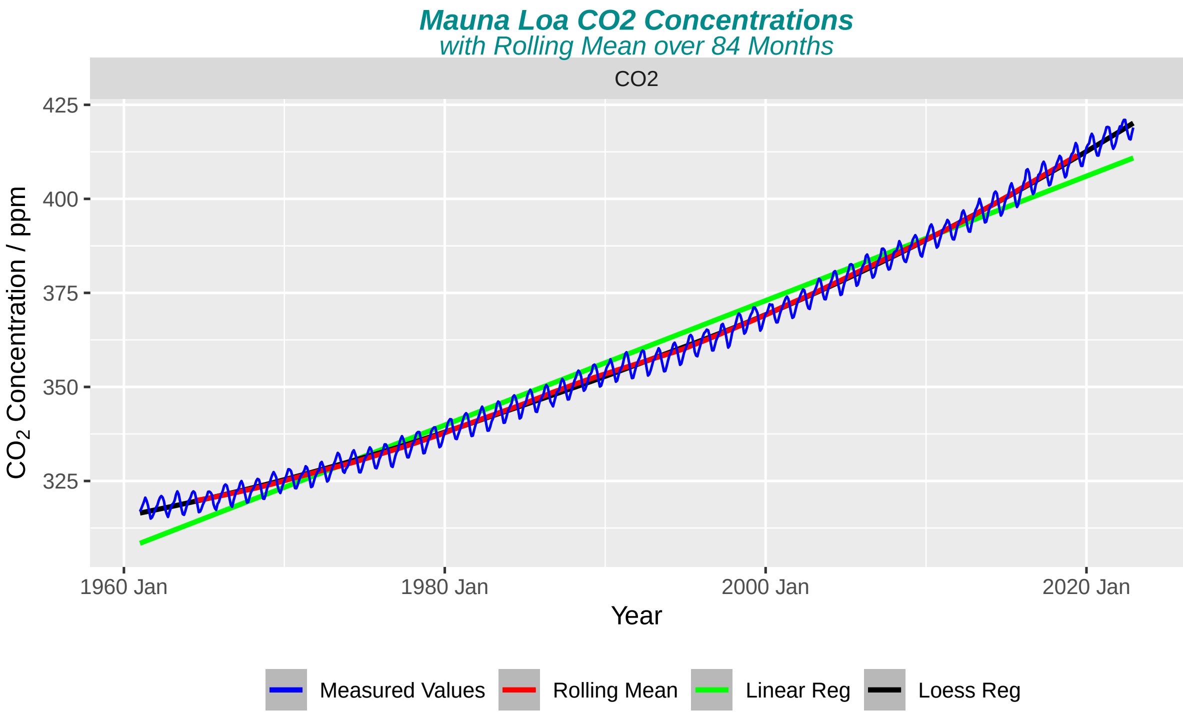
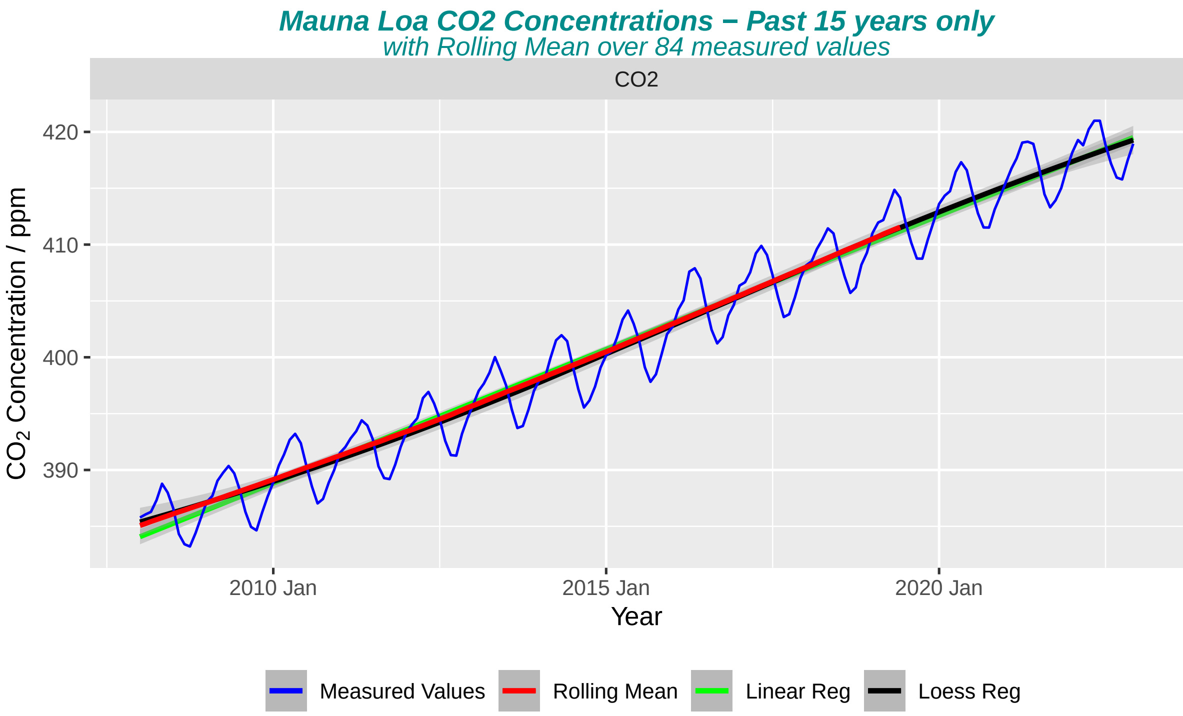
Contents

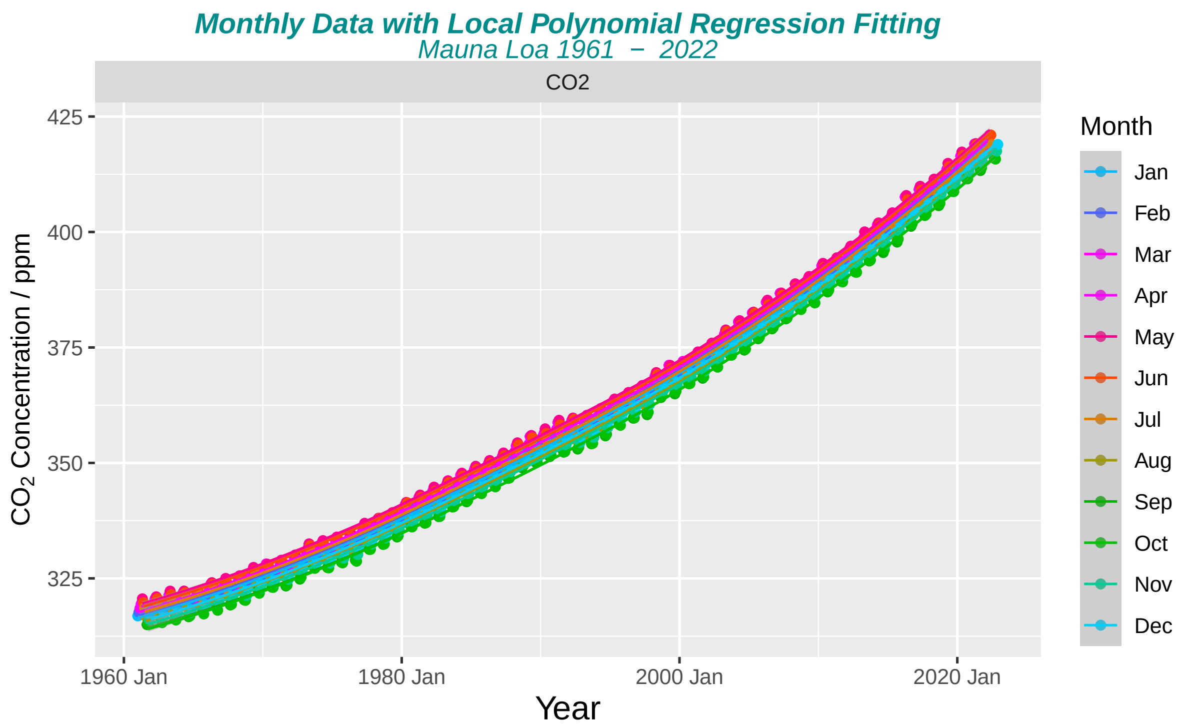
1 Mauna Loa - Visualization of CO2 Data 1961 - 2022

1.1 Monthly Time Plots with Rolling Mean





1.2 Yearly plots with monthly breakdown



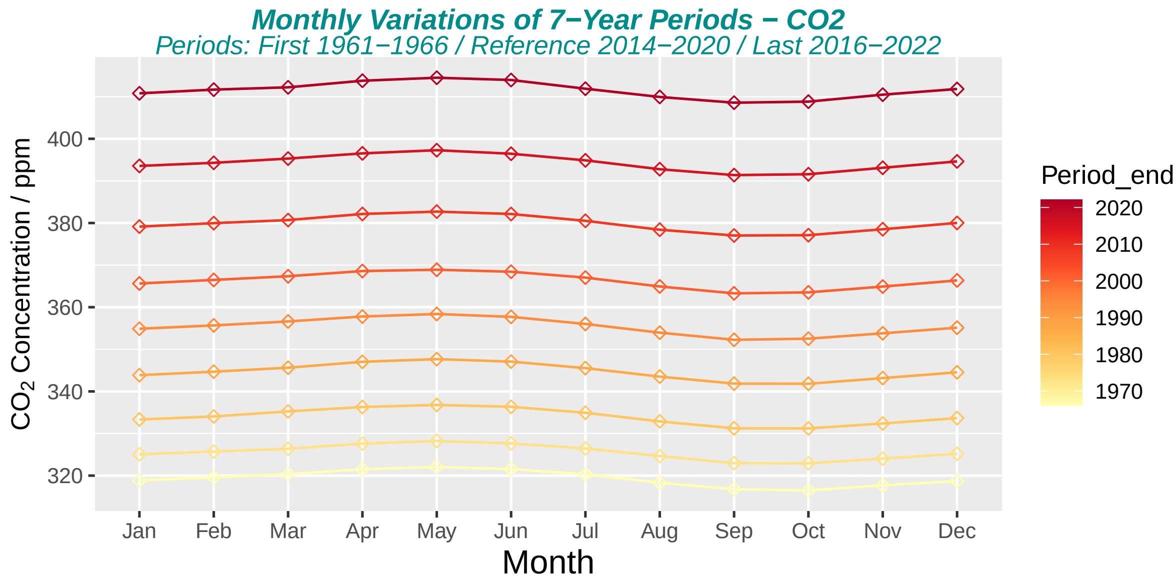
1.2.1 7-year period plots with monthly breakdown - Cartesian and Polar Coordinates

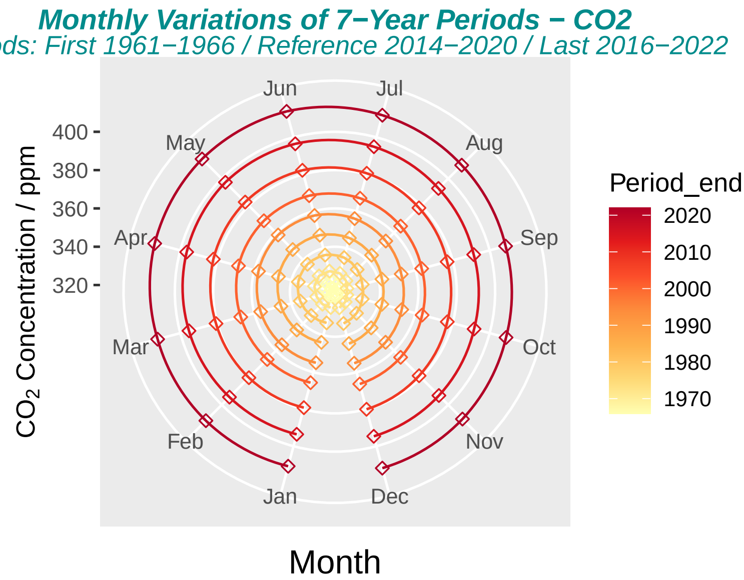
Table 1: 7-years Periods - Average Data (CO2 Concentration / ppm)

City	Period	CO2
Mauna Loa	1961-1966	319.4
Mauna Loa	1967-1973	325.6
Mauna Loa	1974-1980	334.0
Mauna Loa	1981-1987	344.7
Mauna Loa	1988-1994	355.4
Mauna Loa	1995-2001	366.3
Mauna Loa	2002-2008	379.9
Mauna Loa	2009-2015	394.3
Mauna Loa	2016-2022	411.5

City	Ref_Period	CO2
Mauna Loa	2014-2020	406.5

Note: First Period shorter in general (starts with first data year = 1961)


Monthly Variations of 7−Year Periods − CO2
Periods: First 1961−1966 / Reference 2014−2020 / Last 2016−2022
CO2 Concentration / ppm
400
380
360
340
320
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2020
2010
2000
1990
1980
1970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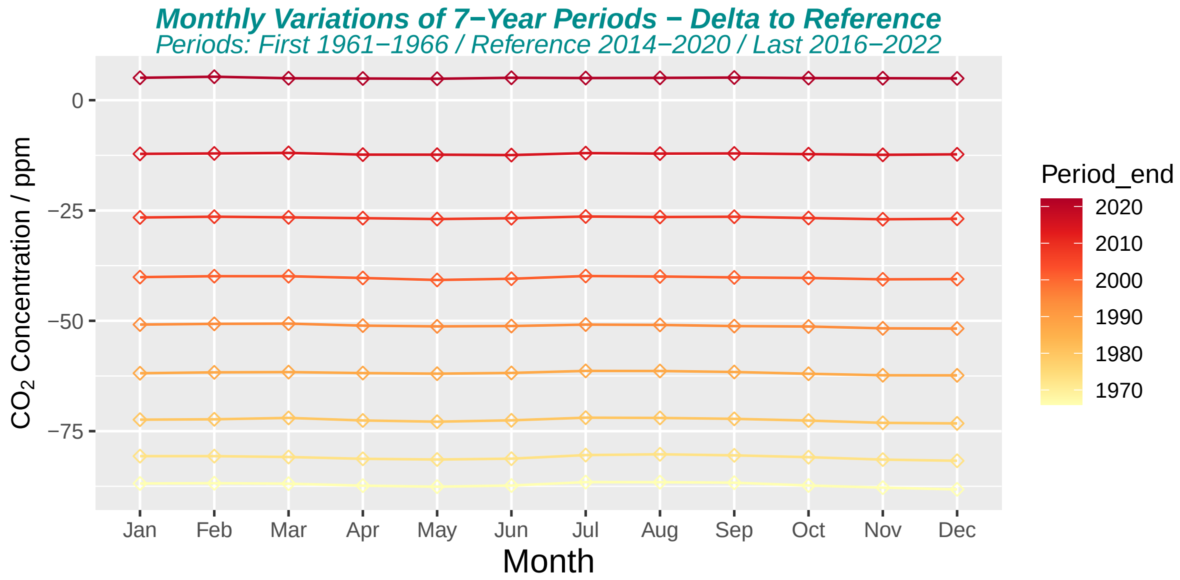
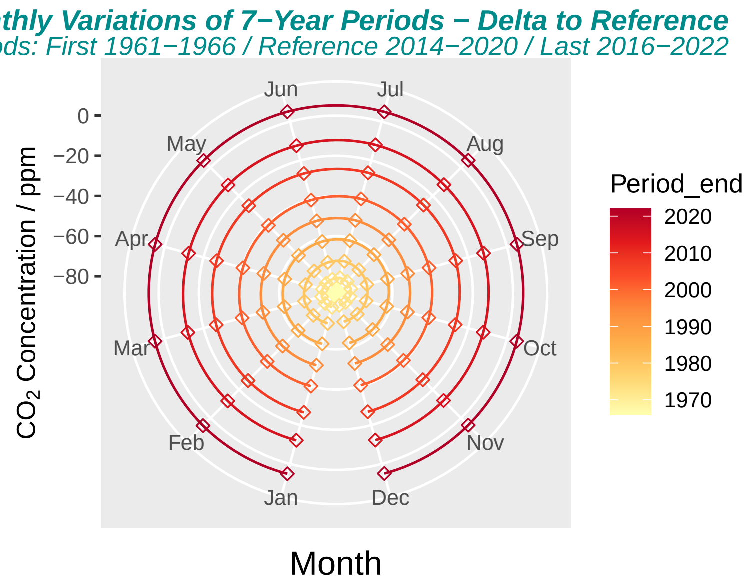
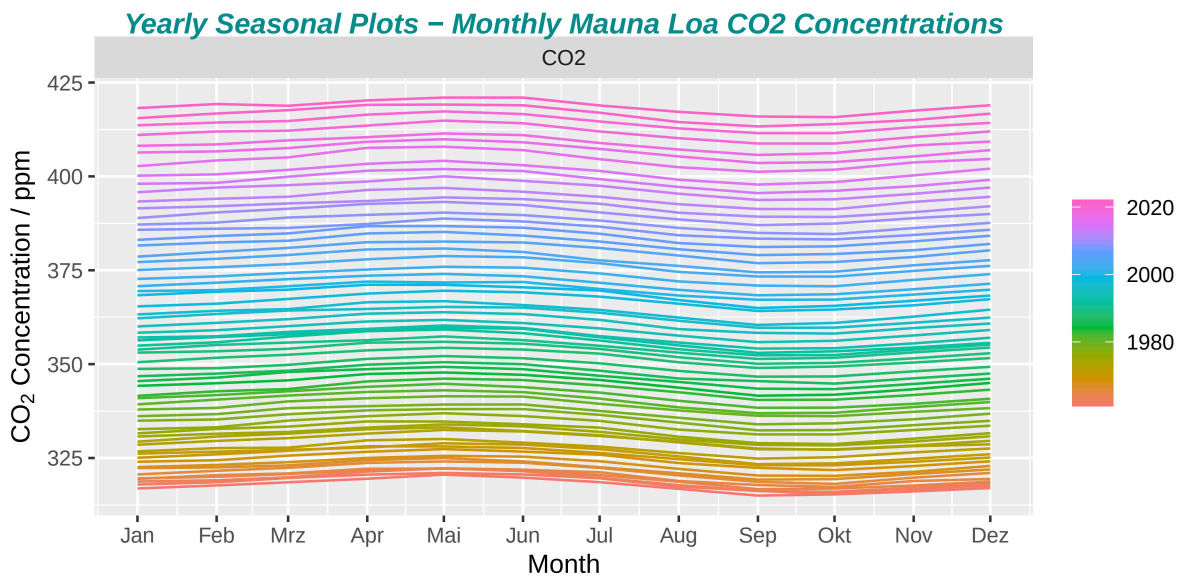
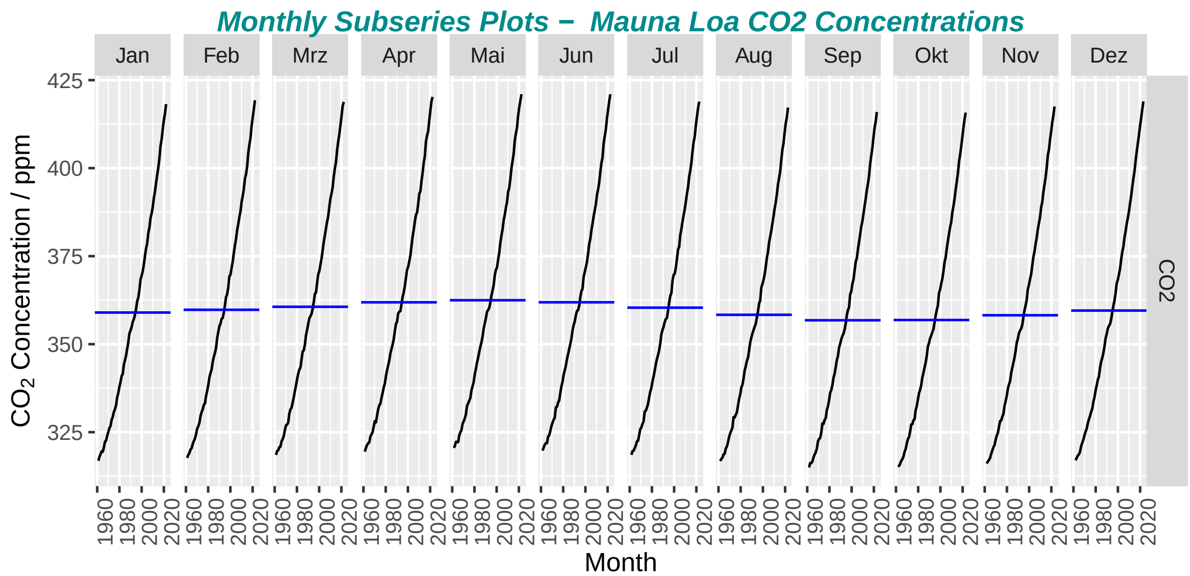
Oct
Feb
Nov
Jan
Dec
Month
Period_end
2020
2010
2000
1990
1980
1970

1.2.2 Plot Monthly Delta to Reference Period - Cartesian and Polar Coordinates



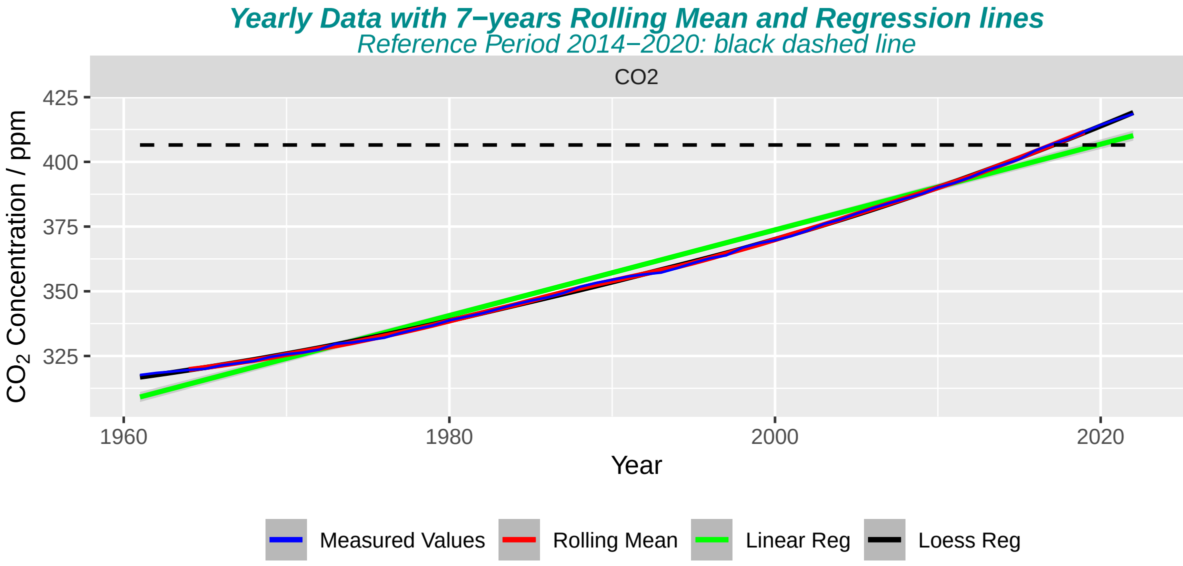




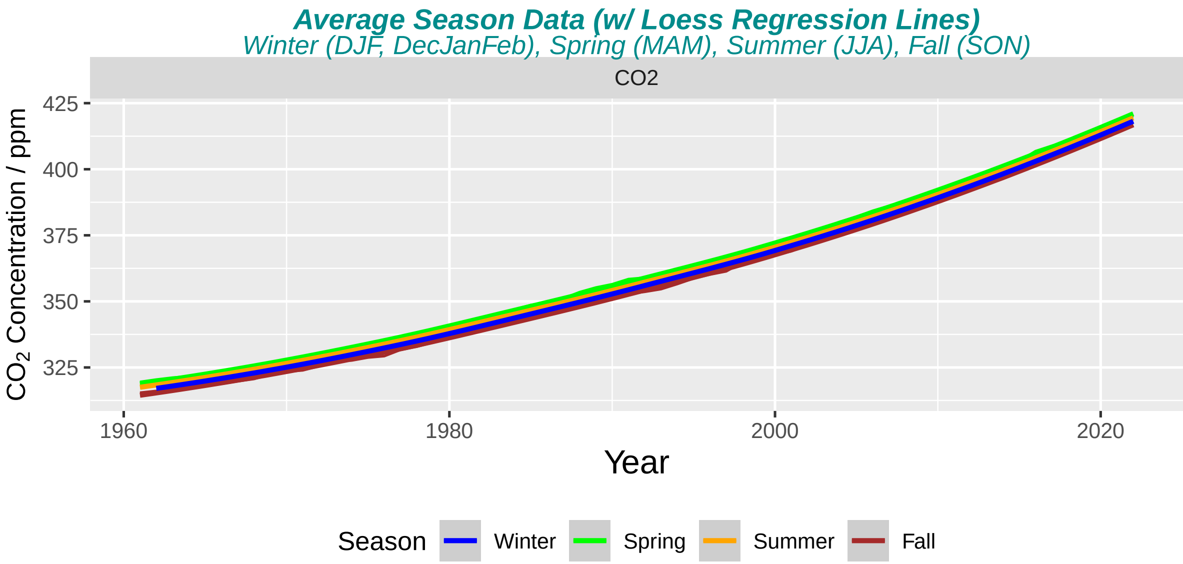


1.3 Yearly Mauna Loa CO2 Concentrations

1.3.1 Plot Yearly CO2



1.3.2 Plot Seasonal Yearly CO2



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2 Trend and Seasonal Analysis

2.1 Time Series Decomposition - Trend and Seasonal Components

An *additive model* would be used when the variations around the trend do not vary with the level of the time series whereas a *multiplicative model* would be appropriate if the trend is proportional to the level of the time series.

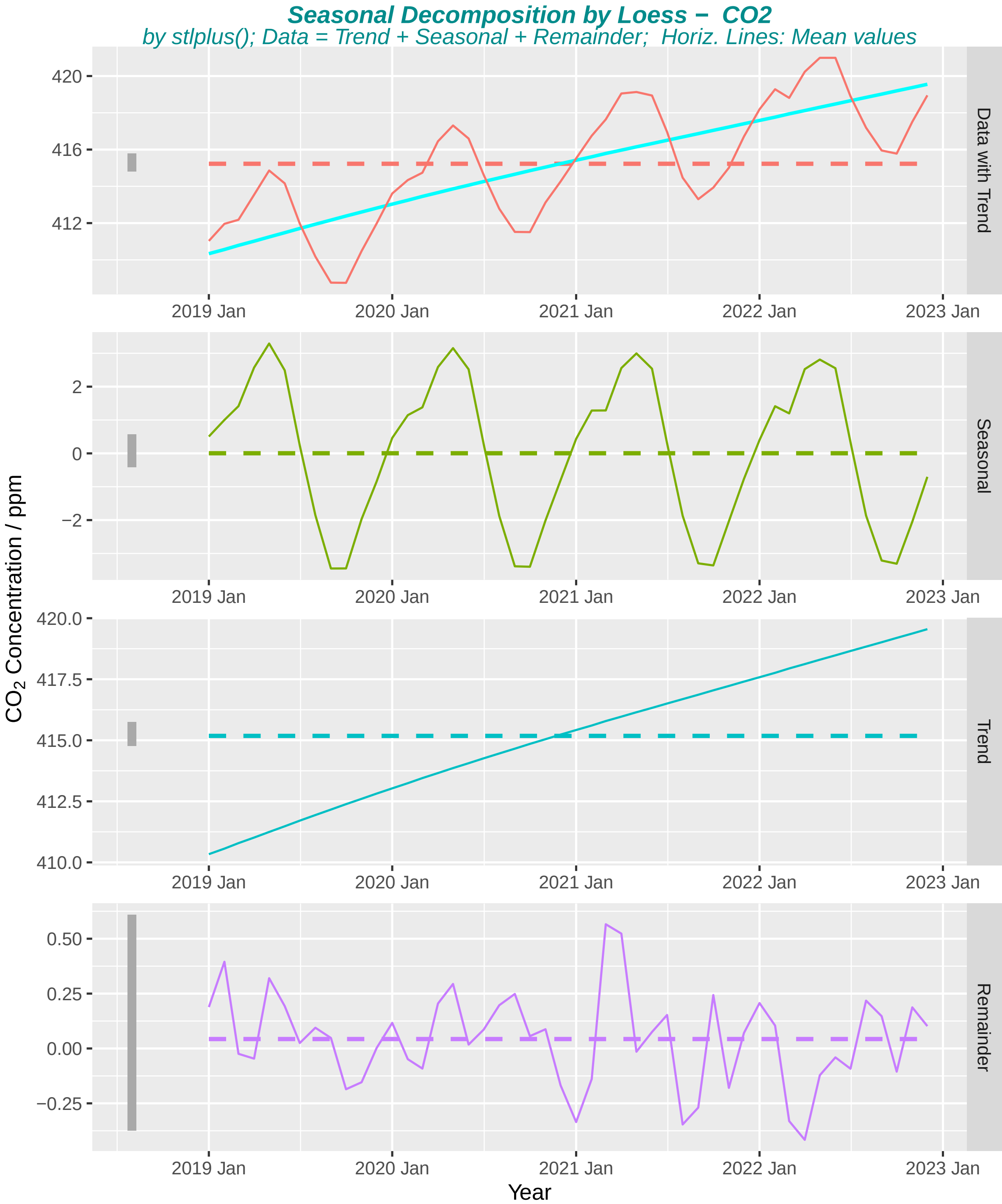
Time series using an

- additive model: $y_t = T_t + C_t + S_t + \epsilon_t$

- multiplicative model: $y_t = T_t * C_t * S_t * \epsilon_t$

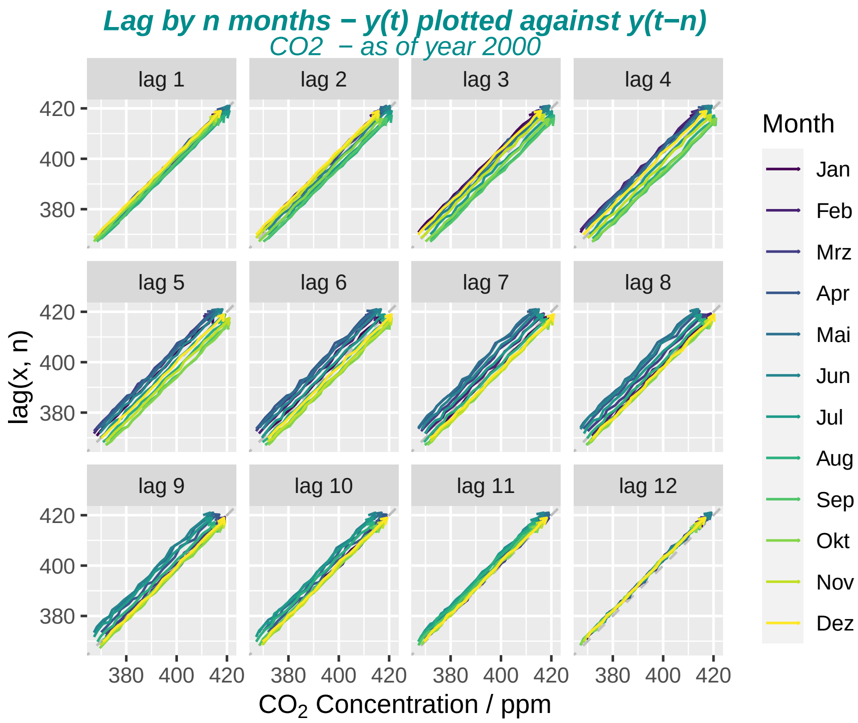
Trend / Cycle / Seasonal / Noise component
Cyclical components is often grouped into the Trend component

For *Seasonal decomposition of time series by Loess (stlplus)* uses in general an additive error modle, it only provides facilities for additive decompositions. It is possible to obtain a multiplicative decomposition by first taking logs of the data.



2.2 Periodicities - Season Frequency

2.2.1 Lag Plot - Differences



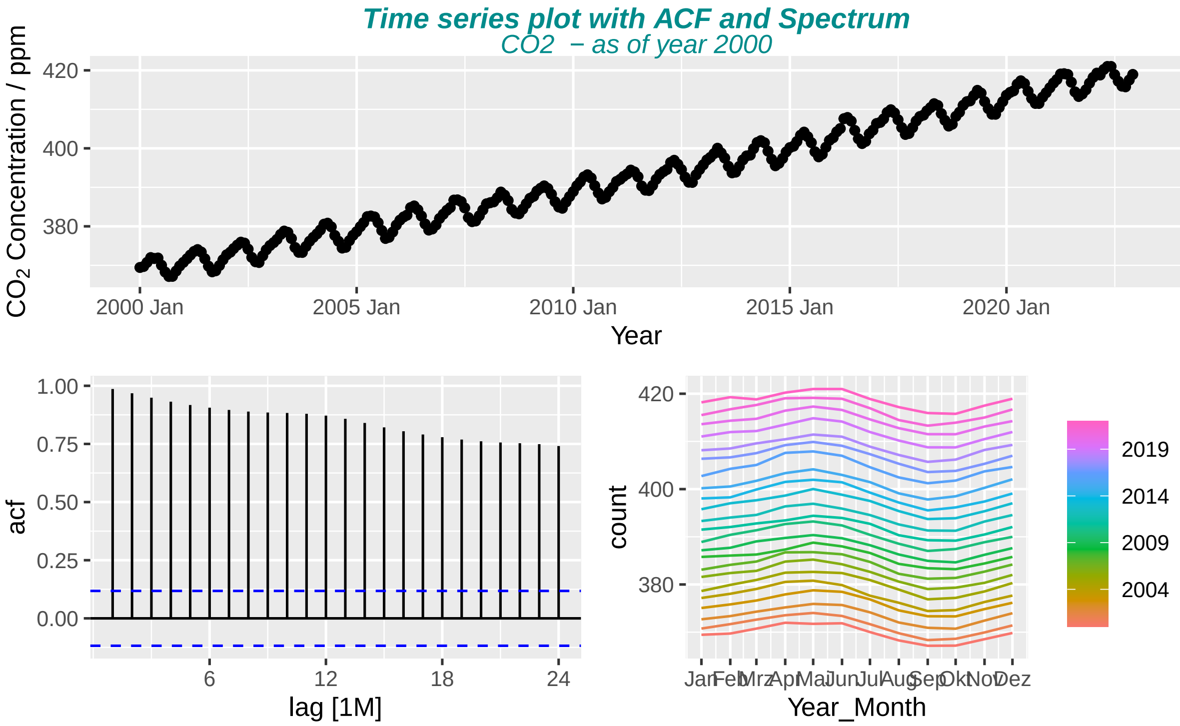
2.2.2 ACF / PACF Correlogram

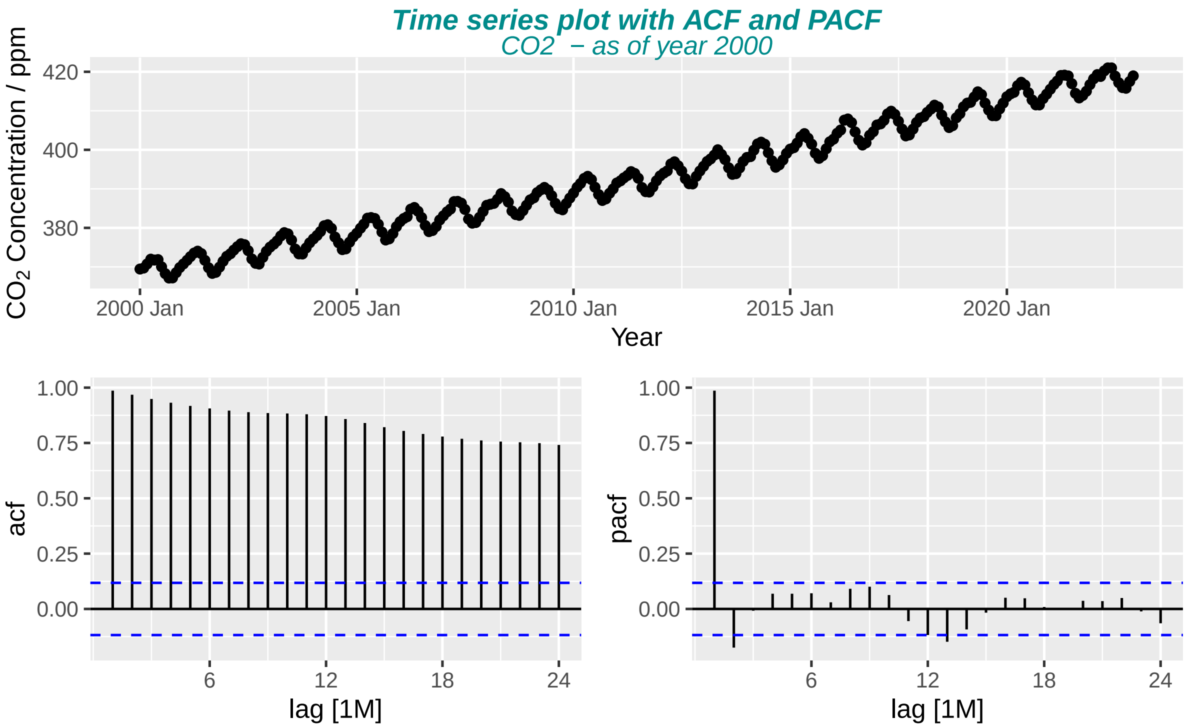
2.2.3 Periodogram - Spectral Density Estimation of a Time Series

The spectral density characterizes the frequency content of the signal. One purpose of estimating the spectral density is to detect any periodicities in the data, by observing peaks at the frequencies corresponding to these periodicities.

At frequency $\lambda = 1/12$ there is a significant peak => This pattern repeats every full frequency = every 12 months / every year

The remaining peaks are random and therefore cannot be assigned significantly.



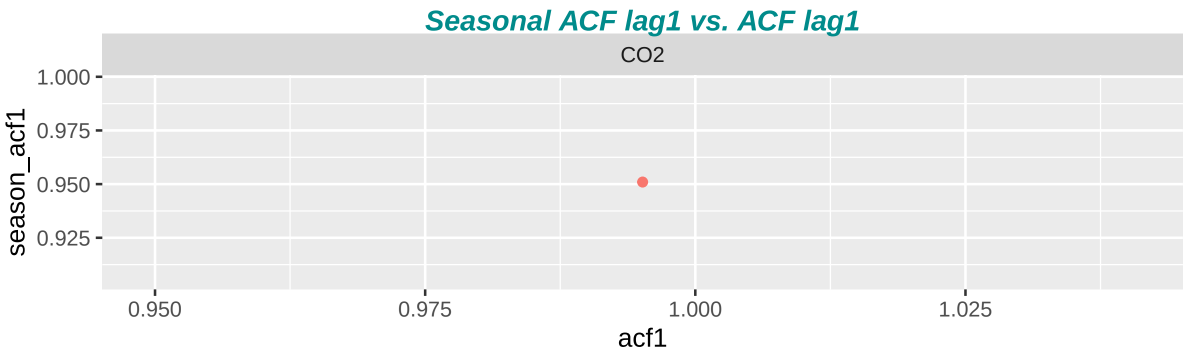


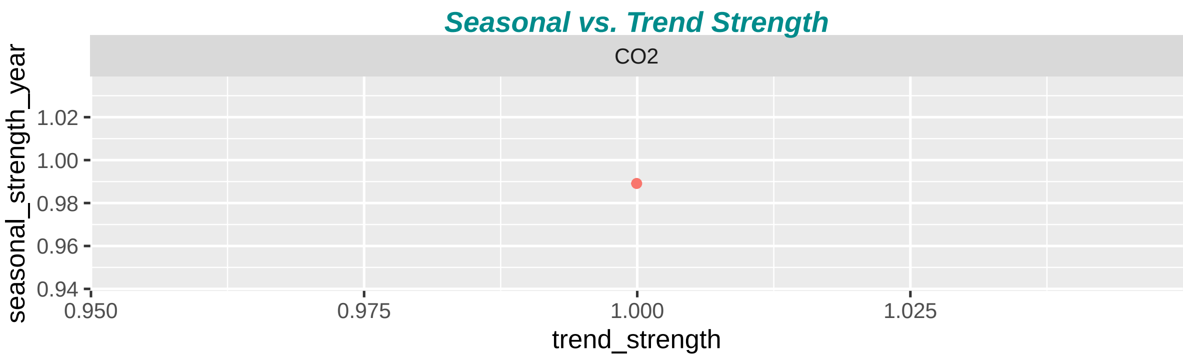
2.2.4 Seasonal vs non Seasonal ACF / Strength (Seasonal/Trend)

- Check acf1 and season_acf1 and compare with ACF Correlogram Plot
- acf1: first autocorrelation coefficient from the original data
- acf10: sum of square of the first ten autocorrelation coefficients from the original data
- diff1_acf1: first autocorrelation coefficient from the differenced data
- season_acf1: autocorrelation coefficient at the first seasonal lag

- Check Trend & Seasonal Strength close to 0 / 1 : weak / strong and compare them
- stl_e_acf1: first autocorrelation coefficient of the remainder series
- stl_e_acf10: sum of squares of the first ten autocorrelation coefficients of the remainder series
- linearity: linearity of the trend component of the STL decomposition. It is based on the coefficient of a linear regression applied to the trend component
- curvature: curvature of the trend component of the STL decomposition. It is based on the coefficient from an orthogonal quadratic regression applied to the trend component.

```
#> [1] "Check acf1 and season_acf1 and compare with ACF Correlogram Plot"
#> # A tibble: 1 x 8
#>   Measure  acf1 acf10 diff1_acf1 diff1_acf10 diff2_acf1 diff2_acf10 season_acf1
#>   <fct>   <dbl> <dbl>      <dbl>       <dbl>      <dbl>       <dbl>       <dbl>
#> 1 CO2     0.995  9.46      0.700        1.87      0.265       0.525       0.951
#> [1] "Check Trend & Seasonal Strength close to 0 / 1 : weak / strong and compare them"
#> # A tibble: 1 x 10
#>   Measure trend_strength seaso~1 seaso~2 seaso~3 spiki~4 linea~5 curva~6 stl_e~7
#>   <fct>            <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>
#> 1 CO2               1.00   0.989       5       9 1.11e-8    808.    101.   0.224
#> # ... with 1 more variable: stl_e_acf10 <dbl>, and abbreviated variable names
#> #   1: seasonal_strength_year, 2: seasonal_peak_year, 3: seasonal_trough_year,
#> #   4: spikiness, 5: linearity, 6: curvature, 7: stl_e_acf1
```





2.2.5 Spectral Entropy Test

- Entropy close to 0 => series has strong trend and seasonality (=> easy to forecast)
- Entropy close to 1 => series is very noisy (and so is difficult to forecast)

```
#> [1] "Check entropy close to 0 or 1"
#> # A tibble: 1 x 2
#>   Measure spectral_entropy
#>   <fct>              <dbl>
#> 1 CO2                0.130
```

2.3 Stationary Process Test

Strict-sense stationarity / Weak (wide-sense) stationarity

Augmented Dickey-Fuller test => type3, a linear model with both drift and linear trend

Trend Stationary - underlying trend (function solely of time) can be removed, leaving a stationary process

3 Backup

3.1 Mauna Loa - Average Yearly and Seasonal Data

Table 3: Annual paste(CO[2], " Concentration / ppm") (first and last 10 years)

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Mauna Loa	CO2	1961	NA	319.5	318.4	315.5	317.6
Mauna Loa	CO2	1962	317.8	320.4	319.2	316.1	318.5
Mauna Loa	CO2	1963	318.5	321.2	319.7	316.4	319.0
Mauna Loa	CO2	1964	319.3	321.6	320.3	317.1	319.6
Mauna Loa	CO2	1965	319.5	321.7	320.6	318.0	320.0
Mauna Loa	CO2	1966	320.5	323.4	322.2	318.8	321.4
Mauna Loa	CO2	1967	322.0	324.2	322.5	319.8	322.2
Mauna Loa	CO2	1968	322.6	324.8	323.9	320.6	323.0
Mauna Loa	CO2	1969	323.8	326.6	325.4	322.3	324.6
Mauna Loa	CO2	1970	325.1	327.7	326.2	323.4	325.7
Mauna Loa	CO2	2013	395.8	398.8	397.2	394.3	396.7
Mauna Loa	CO2	2014	397.8	401.1	399.3	396.4	398.8
Mauna Loa	CO2	2015	399.9	403.1	401.2	398.9	401.0
Mauna Loa	CO2	2016	403.0	406.9	404.7	402.2	404.4
Mauna Loa	CO2	2017	405.9	408.9	407.2	404.2	406.8
Mauna Loa	CO2	2018	407.9	410.5	409.0	406.7	408.7
Mauna Loa	CO2	2019	410.8	413.5	412.1	409.3	411.7
Mauna Loa	CO2	2020	413.3	416.2	414.7	412.0	414.2
Mauna Loa	CO2	2021	415.5	418.6	416.8	414.1	416.5
Mauna Loa	CO2	2022	418.1	420.0	419.0	416.4	418.6

Table 4: Monthly Means over all Years (CO2 Concentration / ppm)

City	Month	CO2
Mauna Loa	Jan	359.0
Mauna Loa	Feb	359.8
Mauna Loa	Mar	360.6
Mauna Loa	Apr	361.9
Mauna Loa	May	362.5
Mauna Loa	Jun	361.9
Mauna Loa	Jul	360.4
Mauna Loa	Aug	358.3
Mauna Loa	Sep	356.8
Mauna Loa	Oct	356.9
Mauna Loa	Nov	358.2
Mauna Loa	Dec	359.5

3.2 Data Sources

3.2.1 Temperatures and Precipitation

- Basel / Davos: **Federal Office of Meteorology and Climatology MeteoSwiss**

https://www.meteoswiss.admin.ch/home/climate/swiss-climate-in-detail/homogeneous-data-series-since-1864.html

- Cottbus/ Giessen/ Hohenpeissenberg/ Mannheim/ Potsdam: **DWD Archiv Monats- und Tageswerte**

https://www.dwd.de/DE/leistungen/klimadatendeutschland/klarchivtagmonat.html

(*Monatswerte historisch und aktuell*, column MO_TT (Temperature; Monatsmittel der Lufttemperatur in 2m Höhe in °C and MO_RR (Precipitation; Monatssumme der Niederschlagshoehe in mm))

- England **Met Office - National Meteorological Service for the UK**

https://www.metoffice.gov.uk/hadobs/hadcet/data/download.html Monthly_HadCET_mean.txt, 1659 to date

3.2.2 CO2 Concentrations

National Oceanic & Atmospheric Administration - Earth System Research Laboratory

NOAA ESRL https://www.esrl.noaa.gov/gmd/ccgg/trends/global.html

Data file: Mauna Loa CO2 monthly mean data

https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html

3.3 R code

Partially based on *c't Magazin* articles by *Andreas Krause*:
#3/2014 p.188 http://www.ct.de/1403188 & #6/2014 p.180 http://www.ct.de/1406180