Climate Data Visualization -

Atmospheric CO_2 Concentration / Temperature / Precipitation

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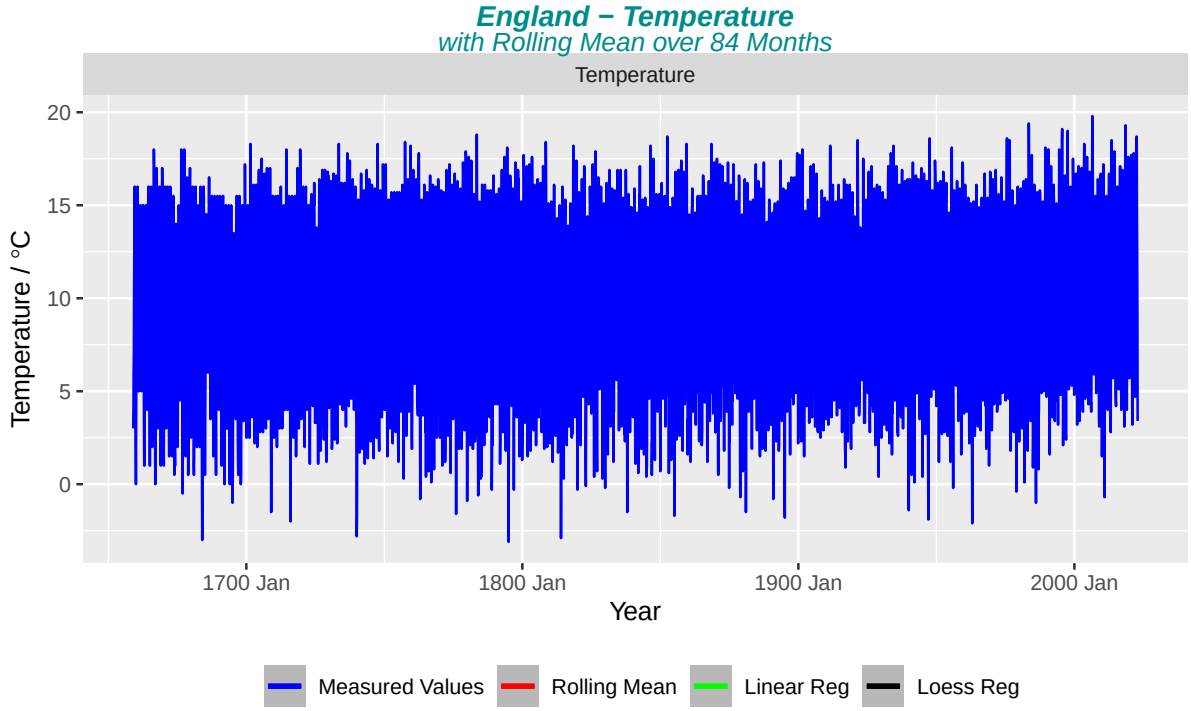
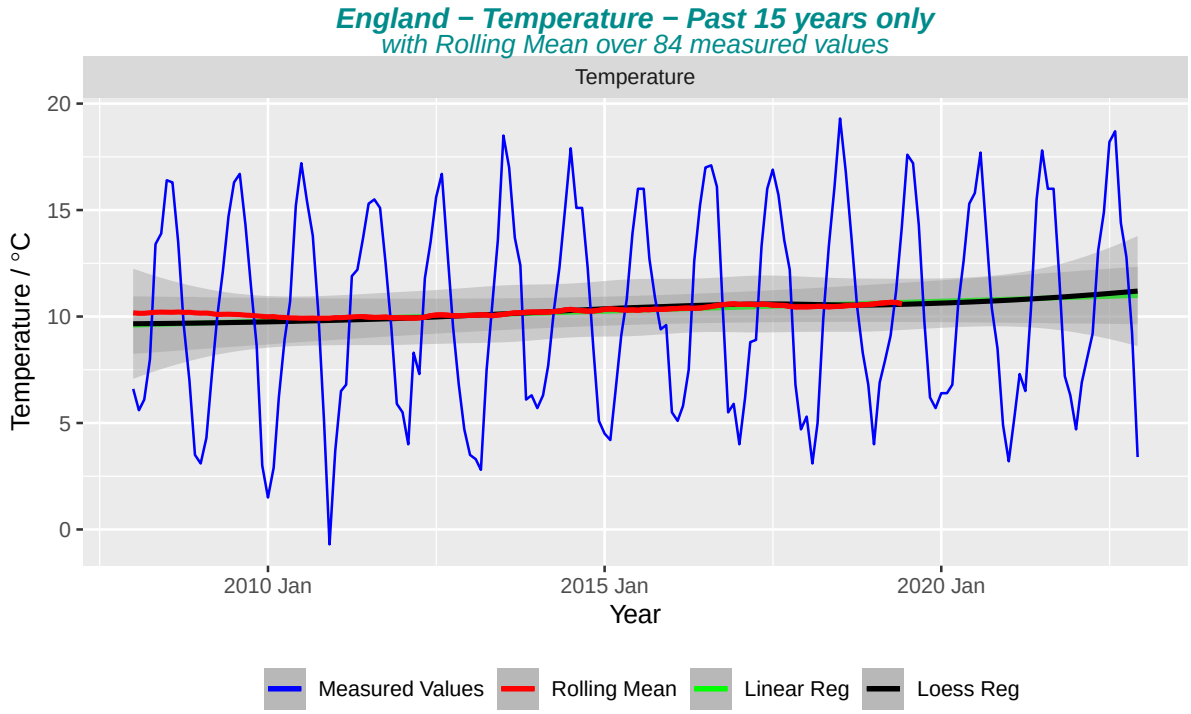
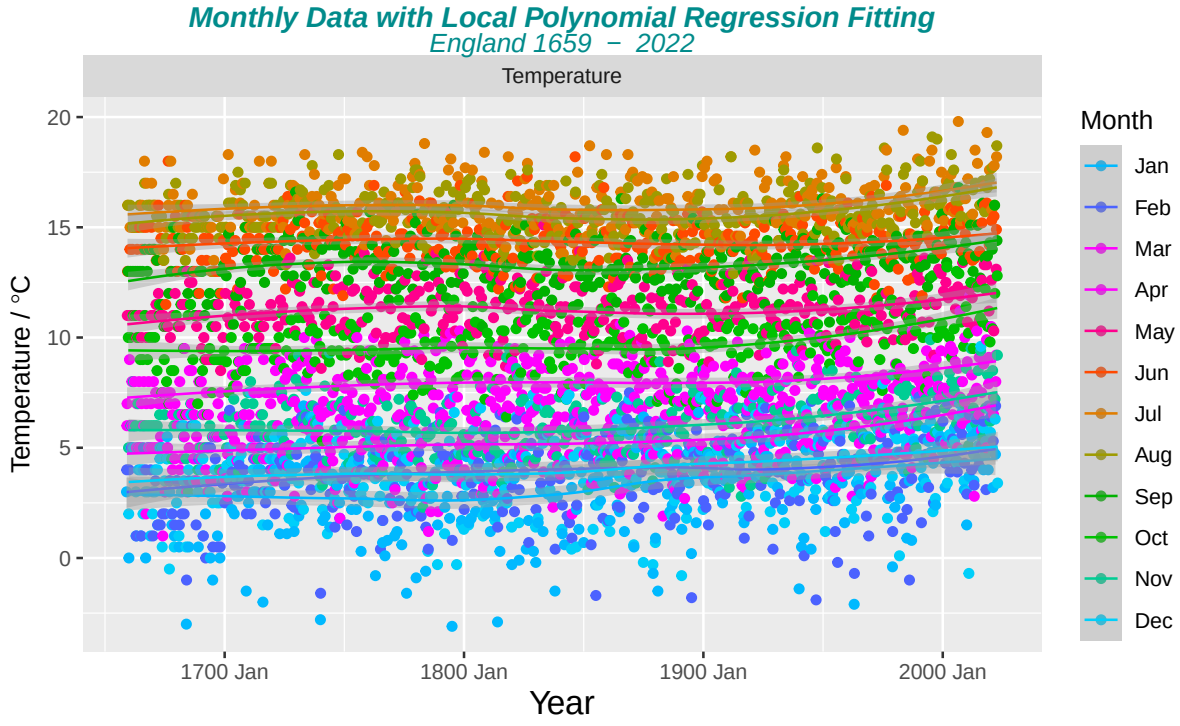
1 England - Visualization of Temperature Data 1659 - 2022

1.1 Monthly Time Plots with Rolling Mean





1.2 Yearly plots with monthly breakdown



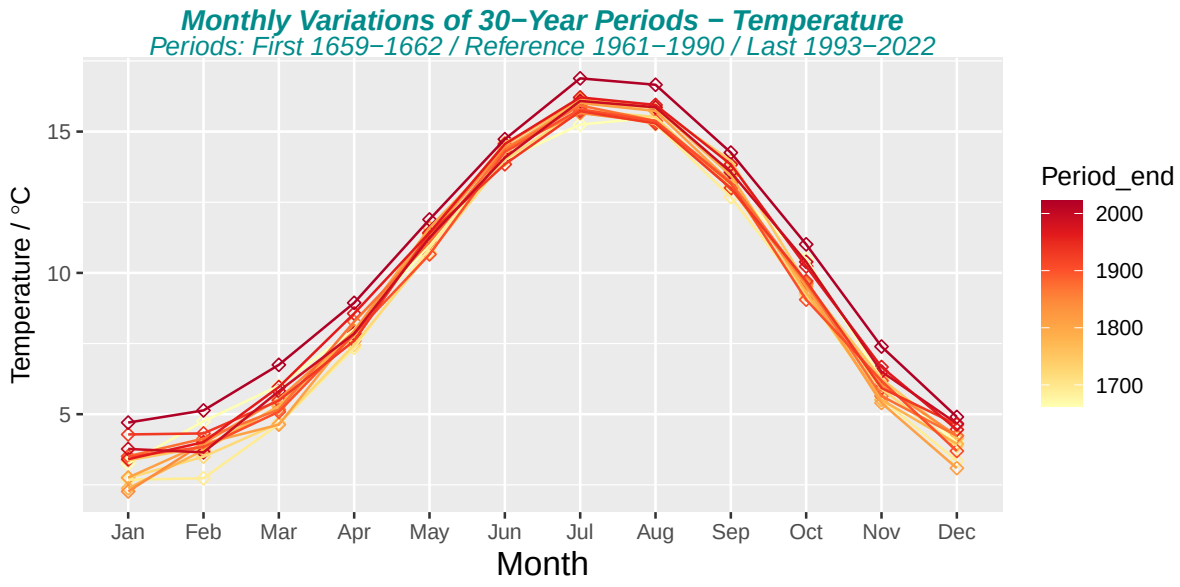
1.2.1 30-year period plots with monthly breakdown - Cartesian and Polar Coordinates

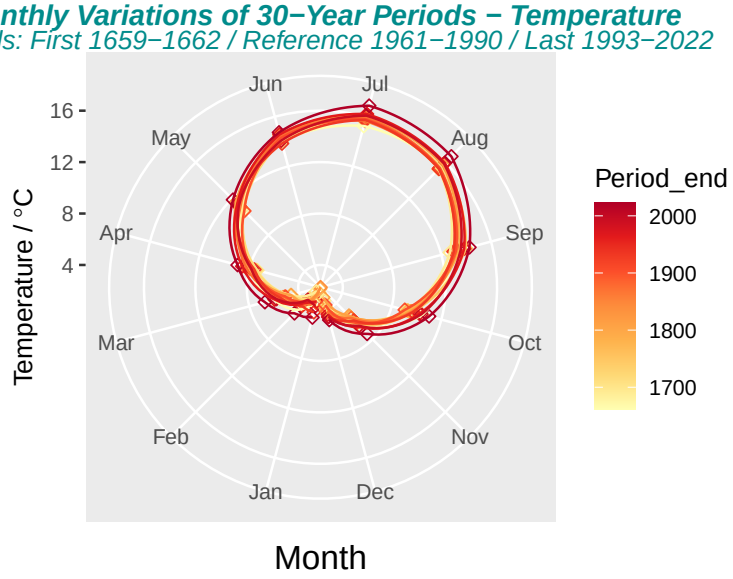
Table 1: 30-years Periods - Average Data (Temperature / degree C)

City	Period	Temperature
England	1659-1662	9.3
England	1663-1692	8.7
England	1693-1722	8.9
England	1723-1752	9.3
England	1753-1782	9.1
England	1783-1812	9.0
England	1813-1842	9.1
England	1843-1872	9.2
England	1873-1902	9.0
England	1903-1932	9.3
England	1933-1962	9.6
England	1963-1992	9.5
England	1993-2022	10.3

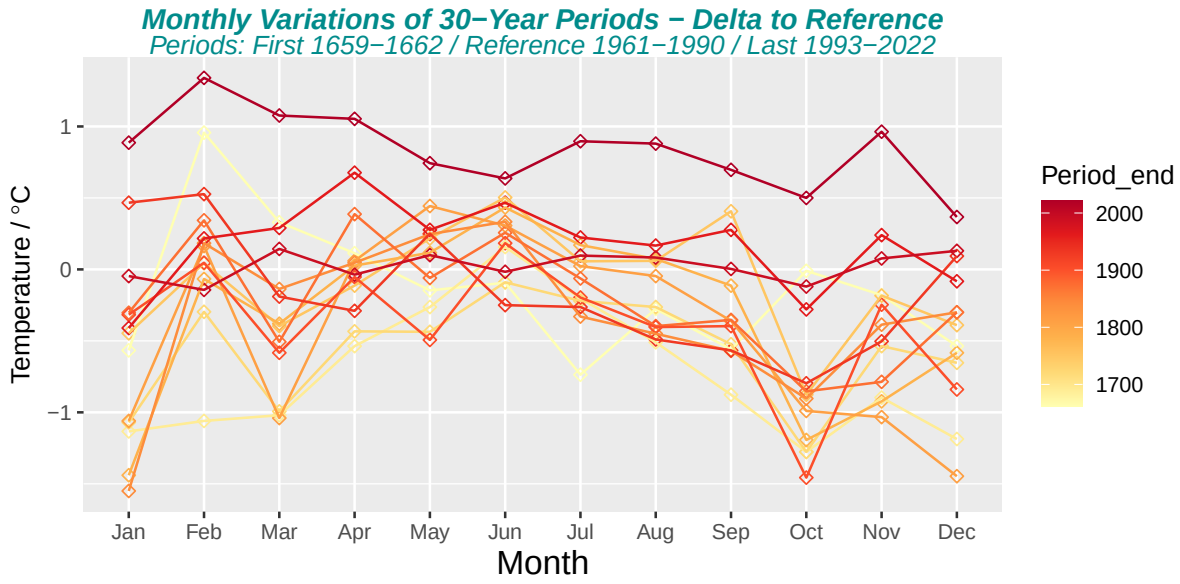
City	Ref_Period	Temperature
England	1961-1990	9.4

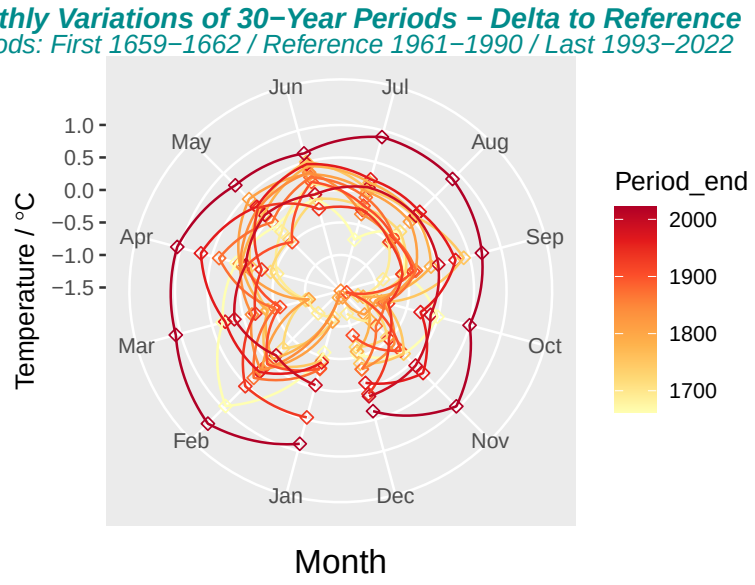
Note: First Period shorter in general (starts with first data year = 1659)

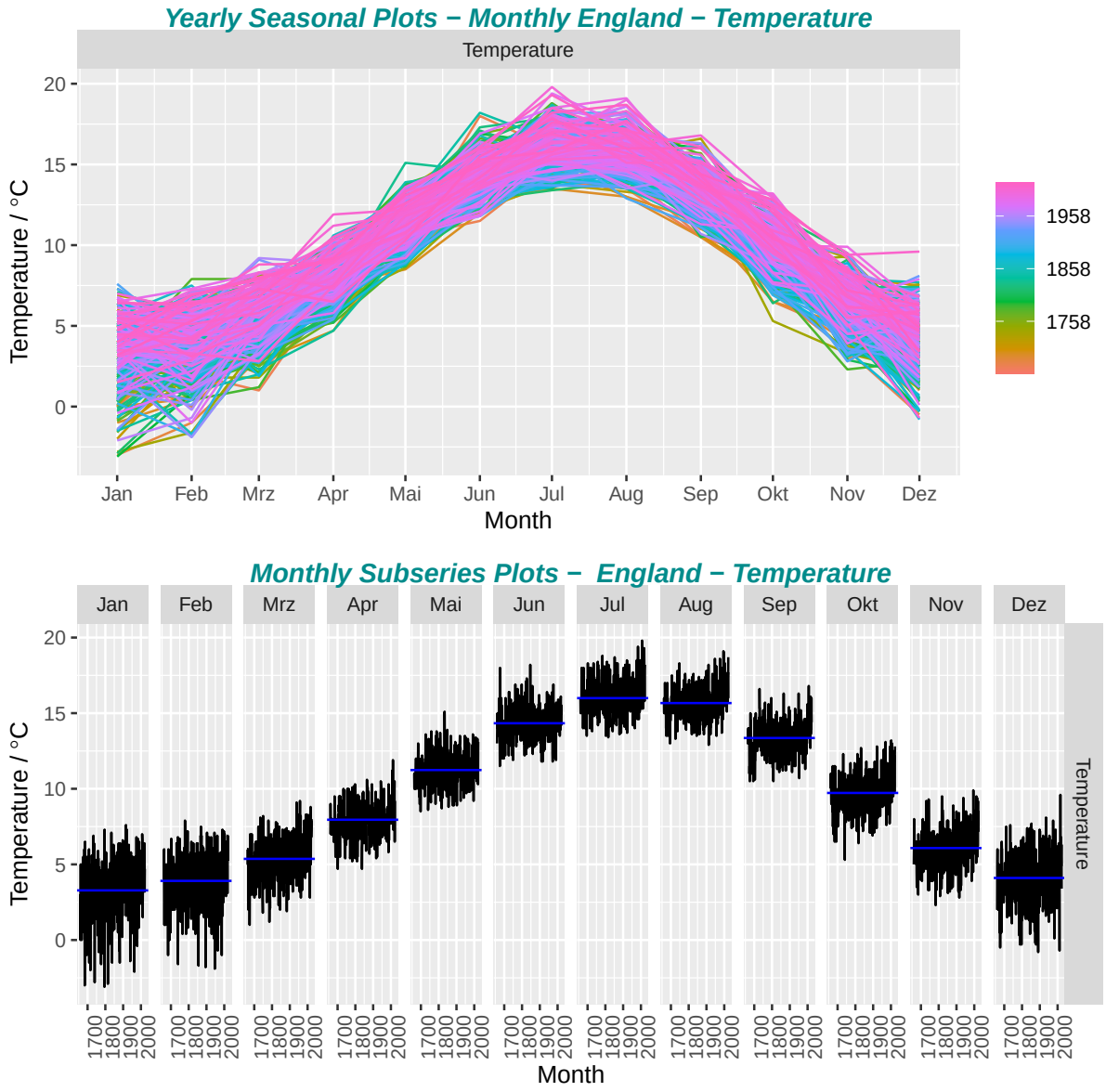

Monthly Variations of 30−Year Periods − Temperature
Periods: First 1659−1662 / Reference 1961−1990 / Last 1993−2022
Temperature / °C
15
10
5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2000
1900
1800
1700


Monthly Variations of 30−Year Periods − Temperature
Periods: First 1659−1662 / Reference 1961−1990 / Last 1993−2022
Temperature / °C
16
12
8
4
Jun
Jul
May
Aug
Apr
Sep
Mar
Oct
Feb
Nov
Jan
Dec
Month
Period_end
2000
1900
1800
1700

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

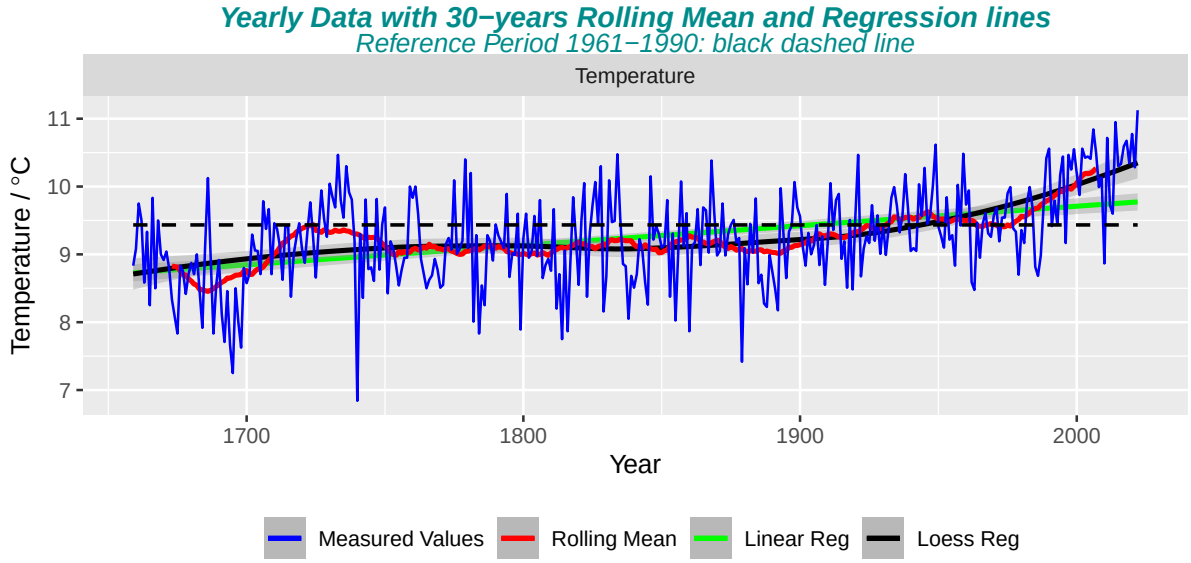




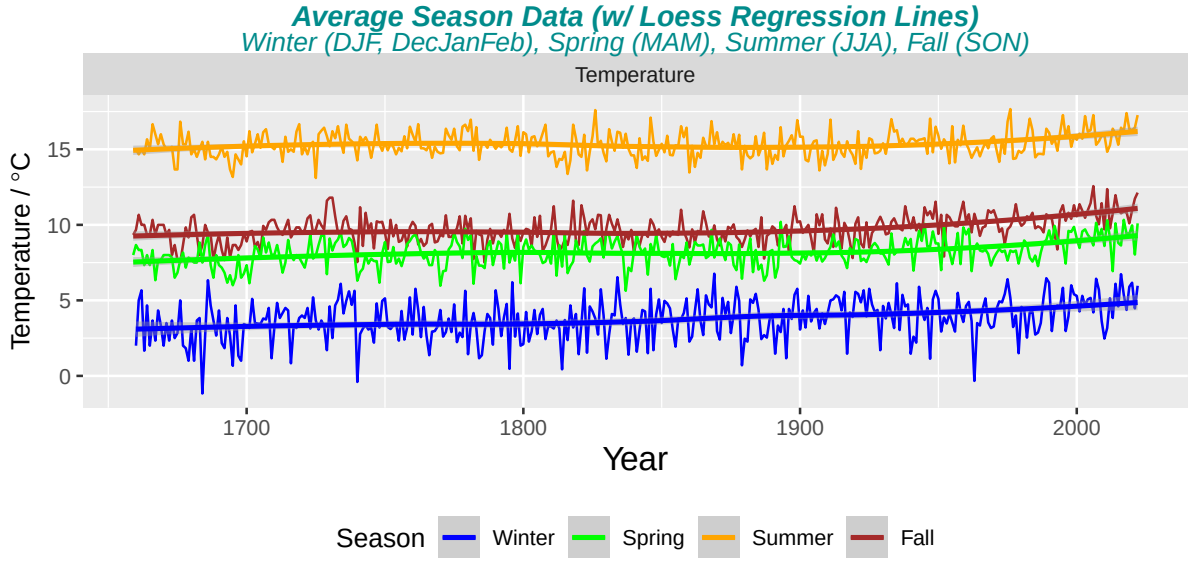


1.3 Yearly England - Temperature

1.3.1 Plot Yearly Temperature



1.3.2 Plot Seasonal Yearly Temperature



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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.

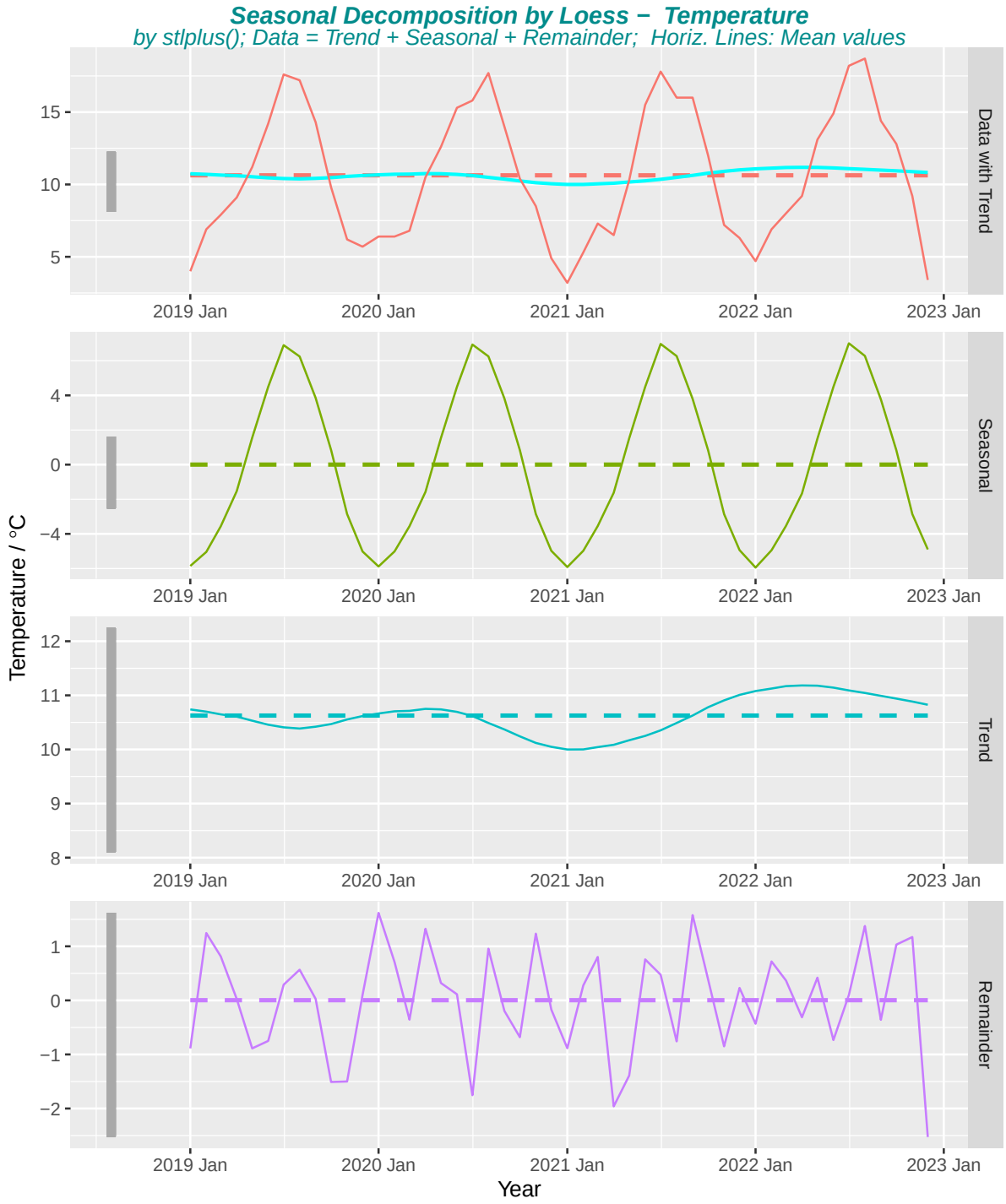
Time series using an

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

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

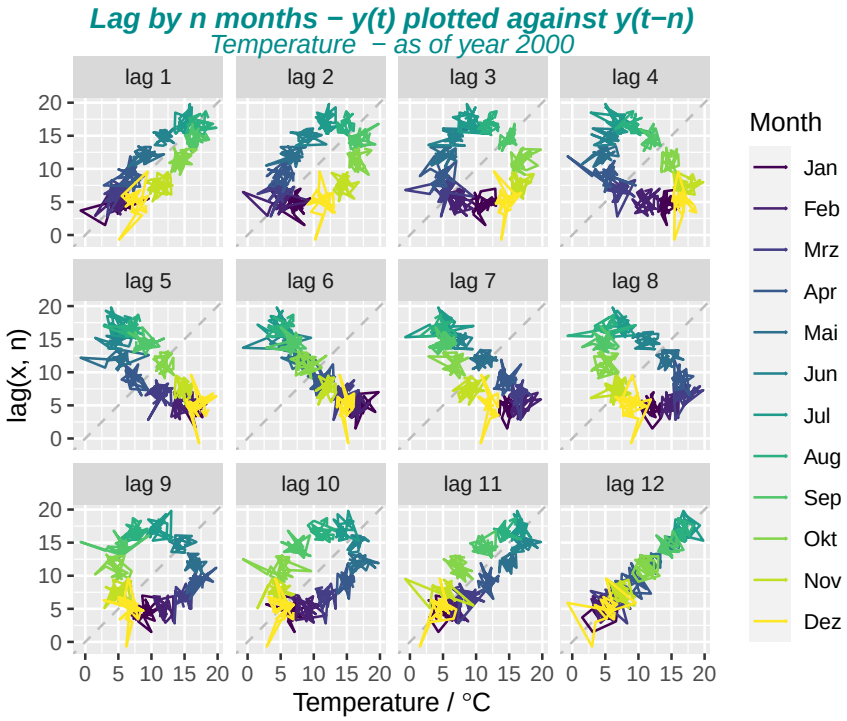
Trend / Cycle / Seasonal / Noise component
Cyclical components is often grouped into the Trend component

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



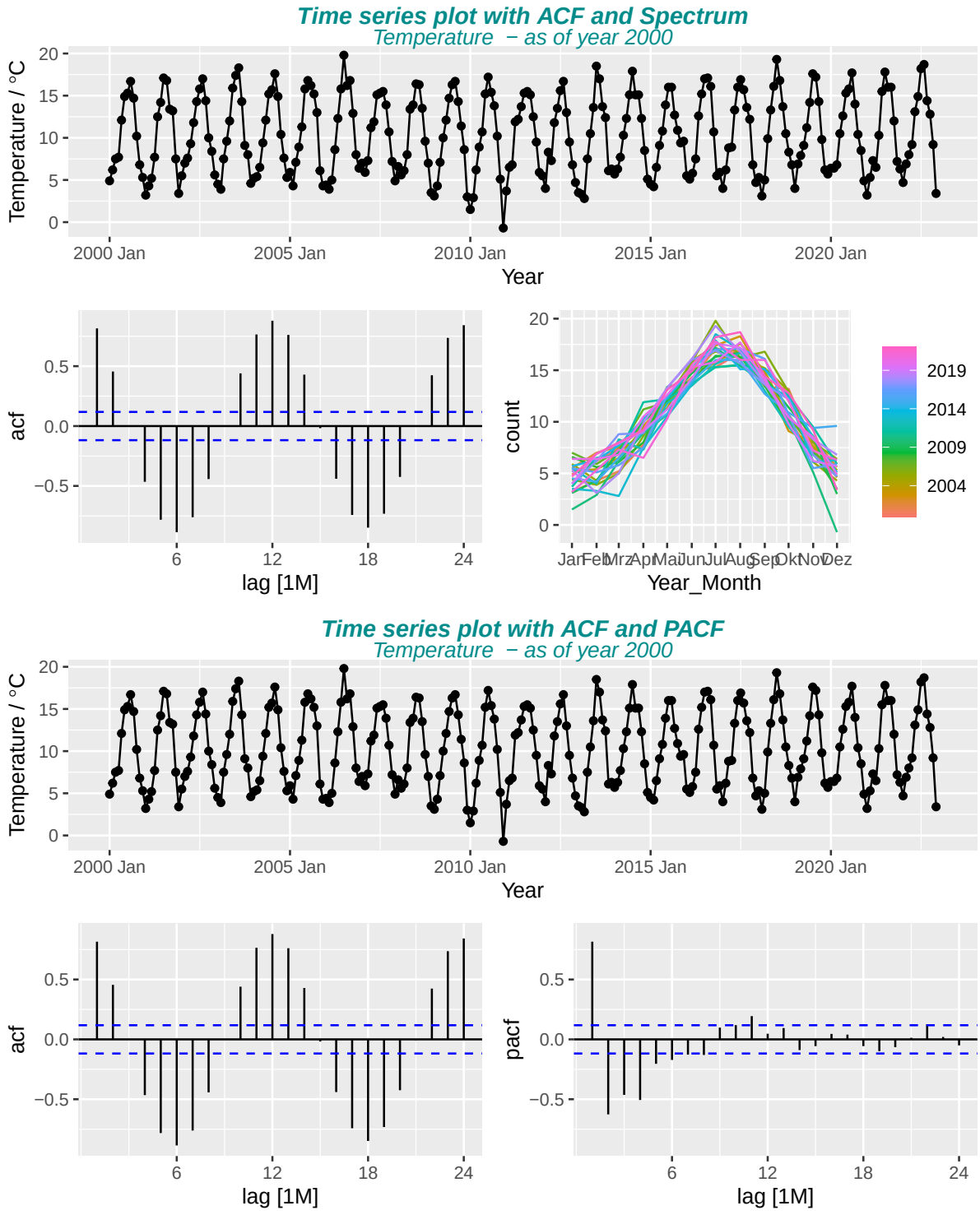
2.2.2 ACF / PACF Correlogram

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.

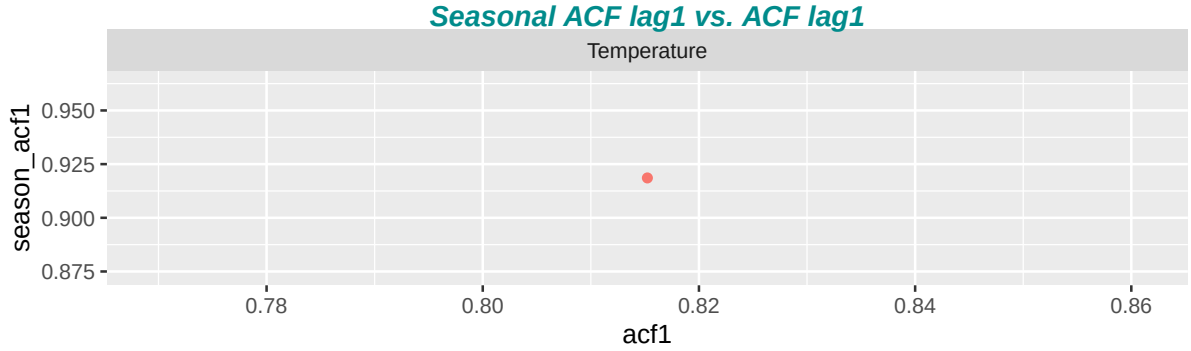


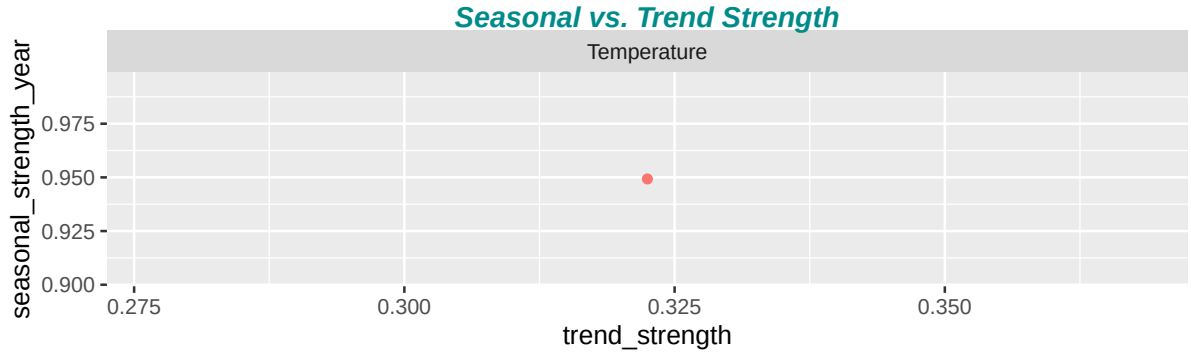
2.2.4 Seasonal vs non Seasonal ACF / Strength (Seasonal/Trend)

- 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~1
#>   <fct>       <dbl> <dbl>      <dbl>       <dbl>      <dbl>       <dbl>    <dbl>
#> 1 Temperature 0.815  3.46      0.447        1.66     -0.370       0.241    0.919
#> # ... with abbreviated variable name 1: season_acf1
#> [1] "Check Trend & Seasonal Strength close to 0 / 1 : weak / strong and compare them"
#> # A tibble: 1 x 10
#>   Measure     trend_st~1 seaso~2 seaso~3 seaso~4 spiki~5 linea~6 curva~7 stl_e~8
#>   <fct>            <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>
#> 1 Temperature      0.322   0.949       7       1 1.82e-7    20.0    8.34  0.0595
#> # ... with 1 more variable: stl_e_acf10 <dbl>, and abbreviated variable names
#> #   1: trend_strength, 2: seasonal_strength_year, 3: seasonal_peak_year,
#> #   4: seasonal_trough_year, 5: spikiness, 6: linearity, 7: curvature,
#> #   8: 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 Temperature            0.233
```

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 England - Average Yearly and Seasonal Data

Table 3: Annual paste("Temperature /", degree * C) (first and last 10 years)

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
England	Temperature	1659	NA	8.0	15.0	9.3	8.8
England	Temperature	1660	2.0	8.7	15.0	9.7	9.1
England	Temperature	1661	5.0	8.3	14.7	10.7	9.8
England	Temperature	1662	5.7	8.3	15.0	10.0	9.5
England	Temperature	1663	1.7	7.3	14.7	10.0	8.6
England	Temperature	1664	4.7	8.0	15.7	9.3	9.3
England	Temperature	1665	2.0	7.3	15.0	9.3	8.2
England	Temperature	1666	3.7	8.3	16.7	10.3	9.8
England	Temperature	1667	2.3	6.3	16.0	9.3	8.5
England	Temperature	1668	4.3	7.7	15.3	10.0	9.5
England	Temperature	2013	3.8	6.9	16.4	10.7	9.6
England	Temperature	2014	6.1	10.1	16.0	12.0	10.9
England	Temperature	2015	4.6	8.8	15.3	11.0	10.3
England	Temperature	2016	6.7	8.6	16.4	10.8	10.3
England	Temperature	2017	5.4	10.3	16.2	10.9	10.6
England	Temperature	2018	4.4	9.4	17.4	10.8	10.7
England	Temperature	2019	5.9	9.4	16.3	10.1	10.3
England	Temperature	2020	6.2	10.0	16.3	11.0	10.8
England	Temperature	2021	4.5	8.0	16.4	11.7	10.3
England	Temperature	2022	6.0	10.1	17.3	12.1	11.1

Table 4: Monthly Means over all Years (Temperature / degree C)

City	Month	Temperature
England	Jan	3.3
England	Feb	3.9
England	Mar	5.4
England	Apr	8.0
England	May	11.2
England	Jun	14.3
England	Jul	16.0
England	Aug	15.7

City	Month	Temperature
England	Sep	13.4
England	Oct	9.7
England	Nov	6.1
England	Dec	4.1

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