# Climate Data Visualization -

Atmospheric $CO_2$ Concentration / Temperature / Precipitation

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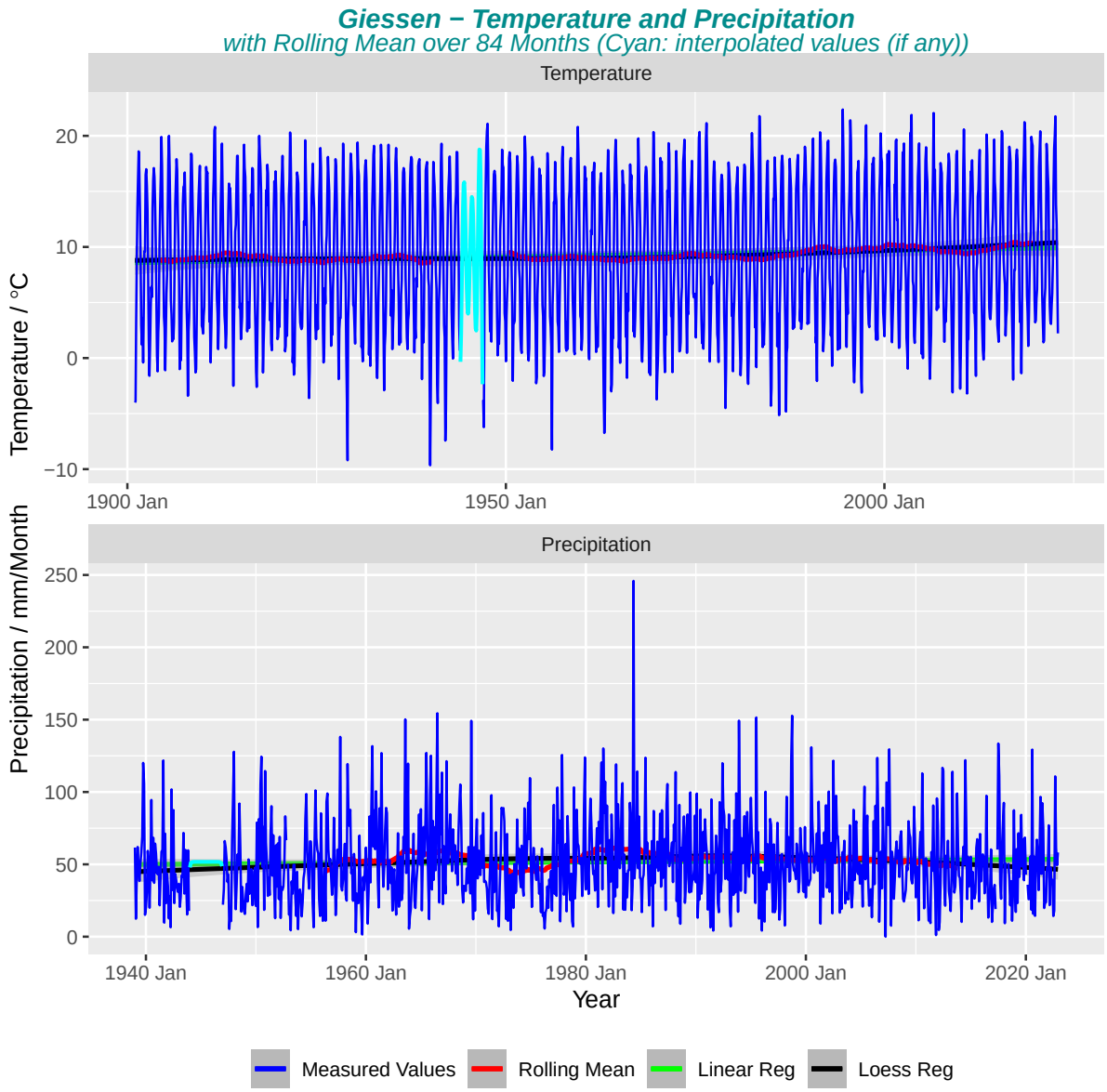
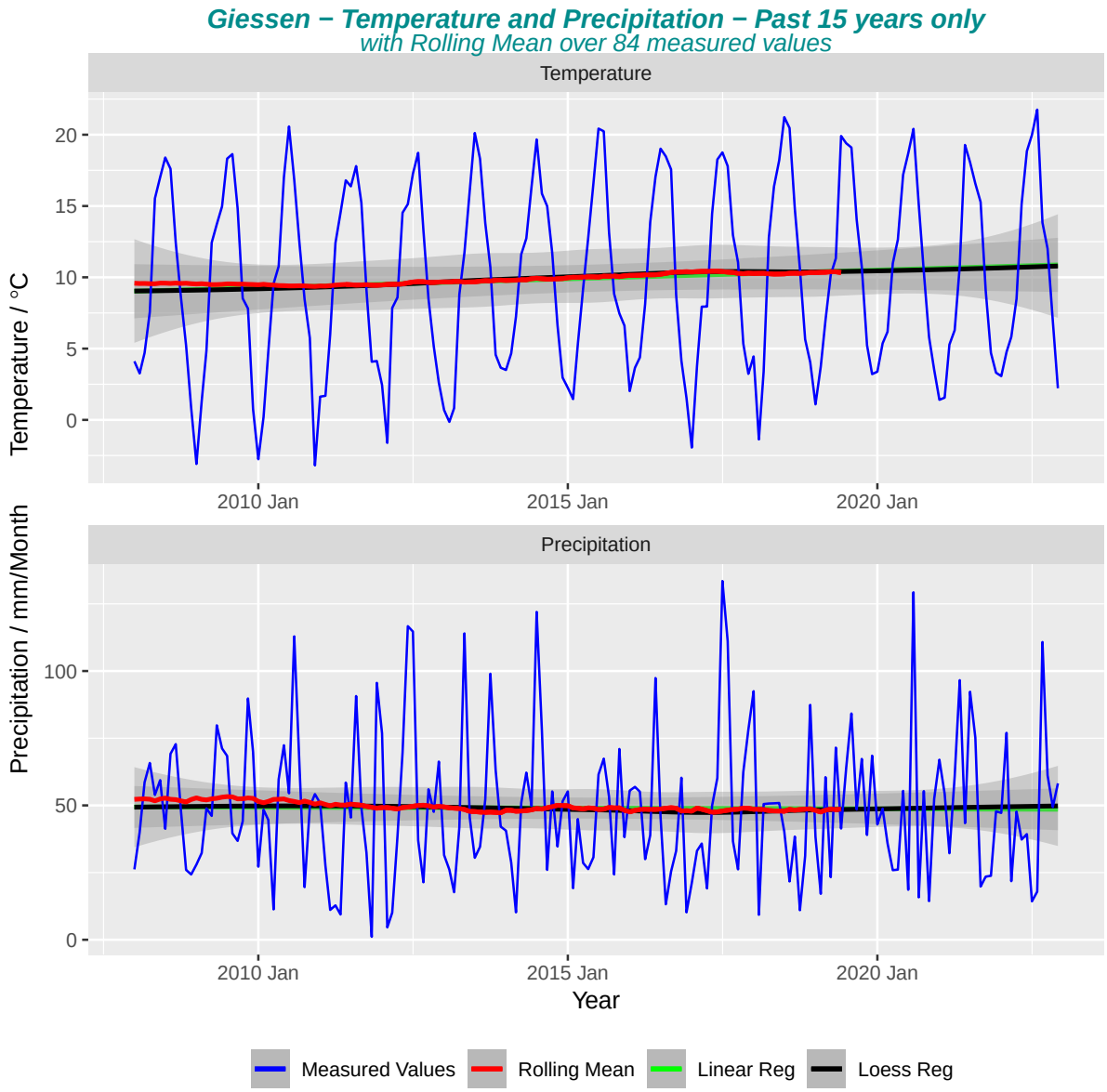
2023-02-20

## Contents

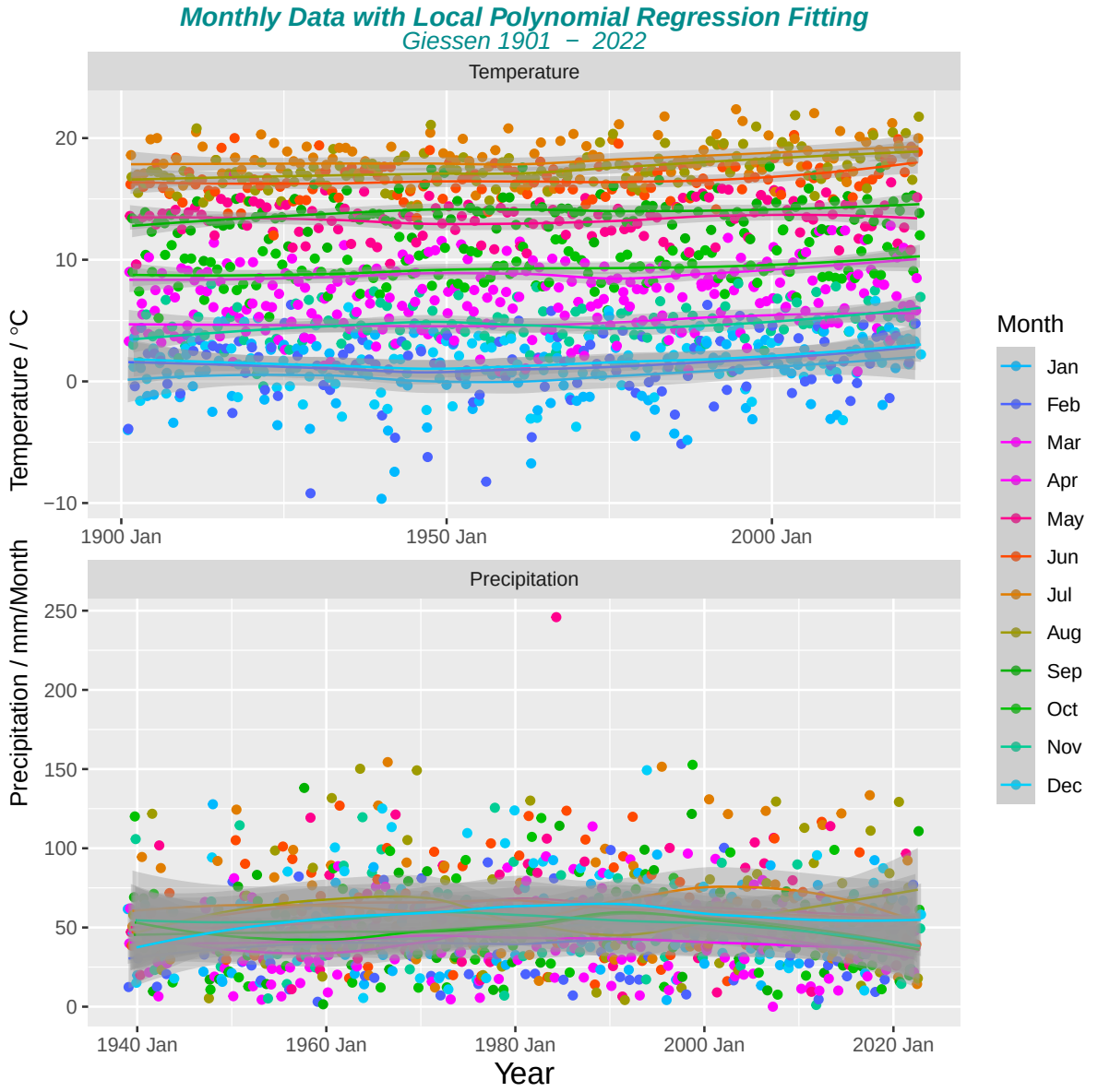
# 1 Giessen - Visualization of Temperature and Precipitation Data 1901 - 2022

## 1.1 Monthly Time Plots with Rolling Mean




Giessen − Temperature and Precipitation − Past 15 years only
with Rolling Mean over 84 measured values
Temperature
Temperature / °C
20
15
10
5
0
2010 Jan
2015 Jan
2020 Jan
Precipitation
Precipitation / mm/Month
100
50
0
2010 Jan
2015 Jan
2020 Jan
Year
Measured Values
Rolling Mean
Linear Reg
Loess Reg

## 1.2 Yearly plots with monthly breakdown



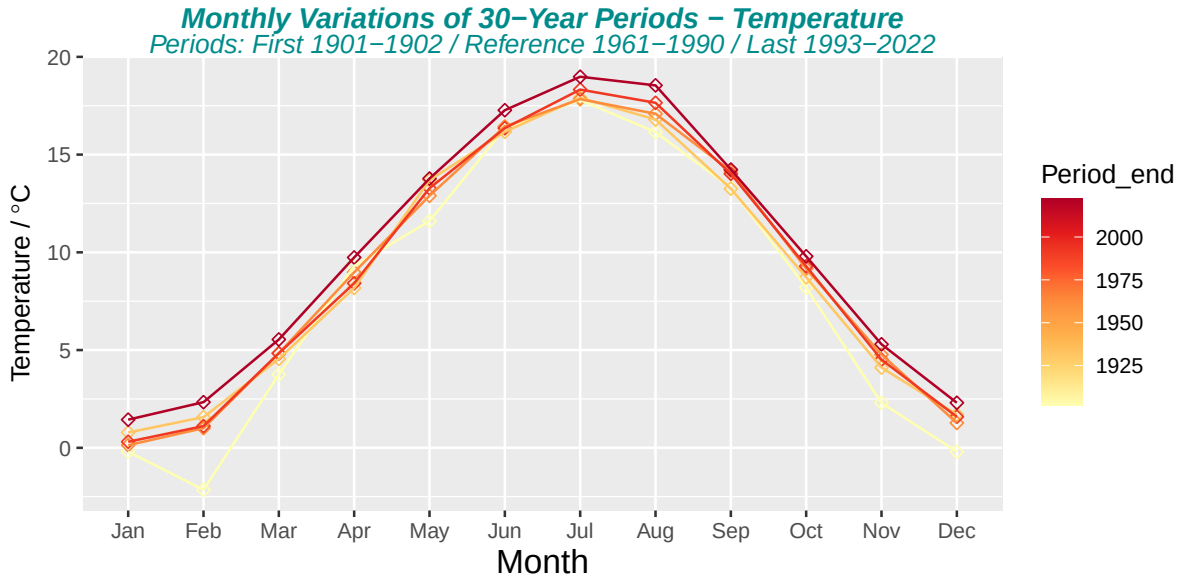

### 1.2.1 30-year period plots with monthly breakdown - Cartesian and Polar Coordinates

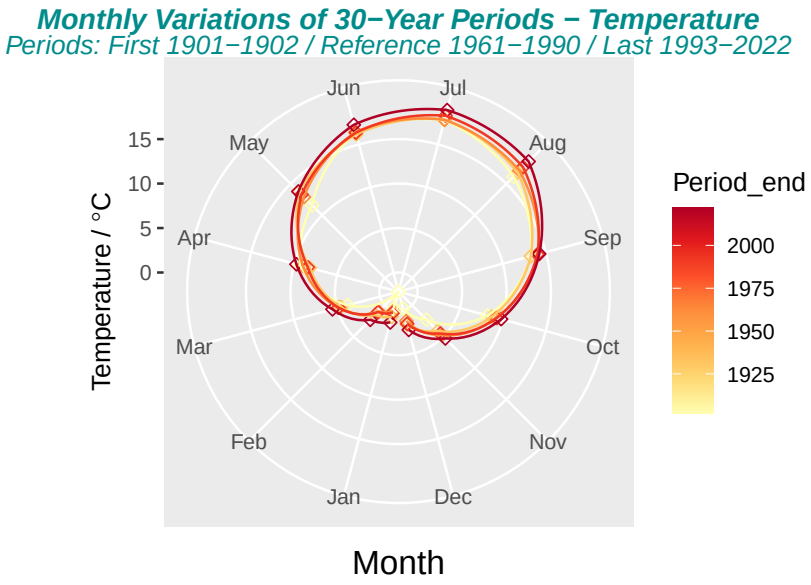
Table 1: 30-years Periods - Average Data (Temperature / degree C and Monthly Precipitation / mm)

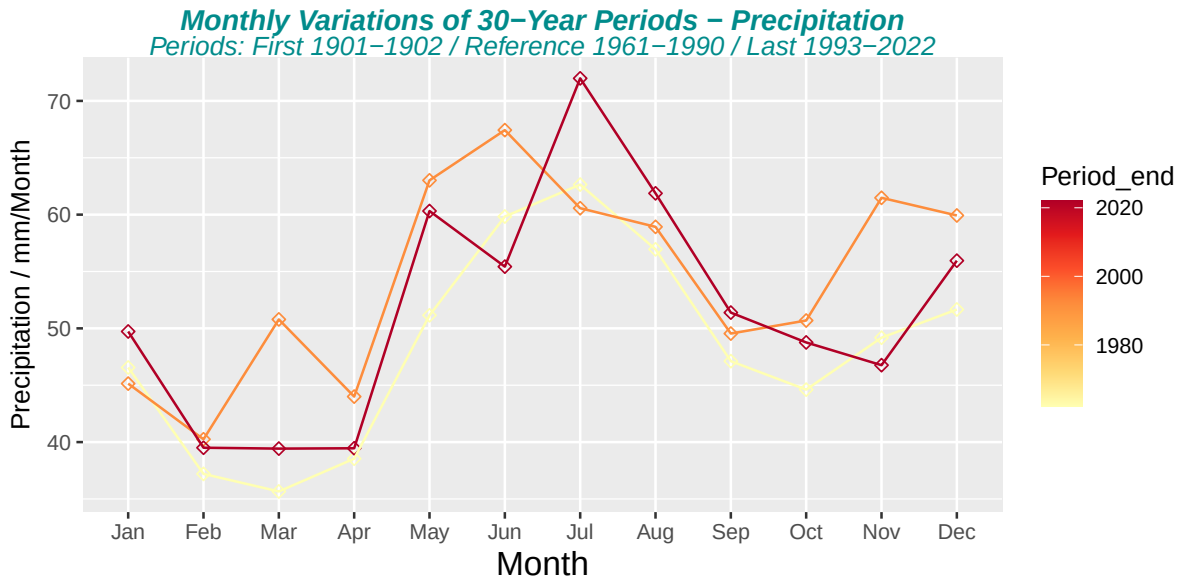
| City | Period | Temperature | Monthly Precipitation | Annual Precipitation |
|---|---|---|---|---|
| Giessen | 1901-1902 | 8.0 | NA | NA |
| Giessen | 1903-1932 | 9.0 | NA | NA |
| Giessen | 1933-1962 | 9.0 | 48.4 | 581.1 |
| Giessen | 1963-1992 | 9.1 | 54.3 | 651.8 |
| Giessen | 1993-2022 | 9.9 | 51.7 | 620.6 |

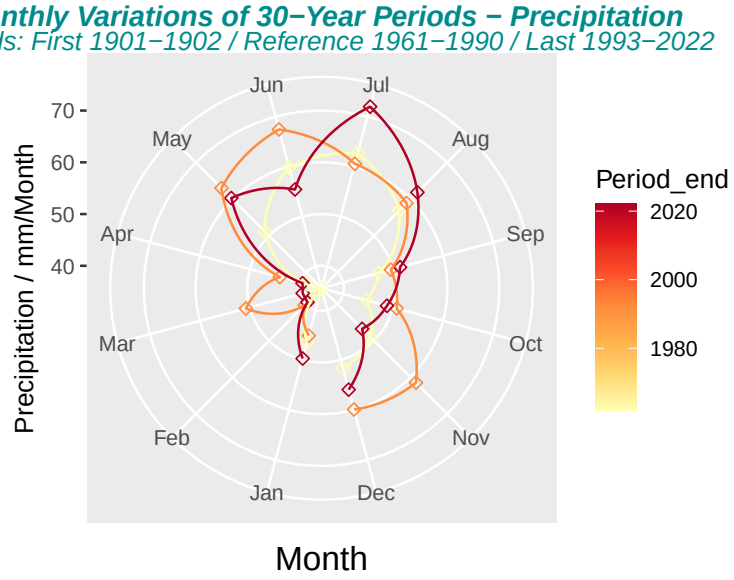
| City | Ref_Period | Temperature | Monthly Precipitation | Annual Precipitation |
|---|---|---|---|---|
| Giessen | 1961-1990 | 9.1 | 54.4 | 652.6 |

Note: First Period shorter in general (starts with first data year = 1901)

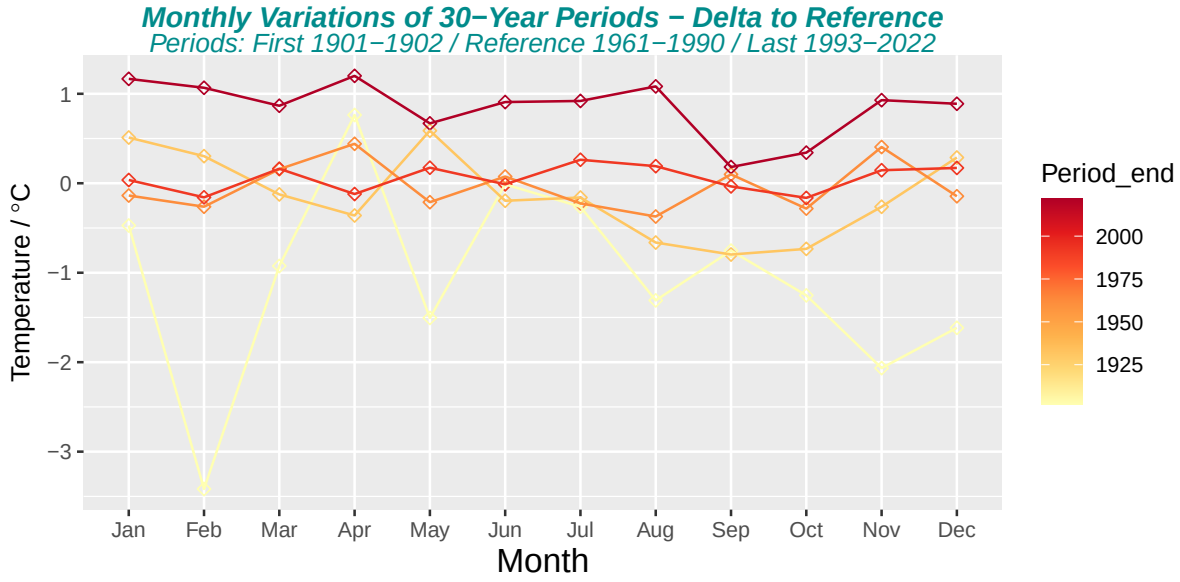


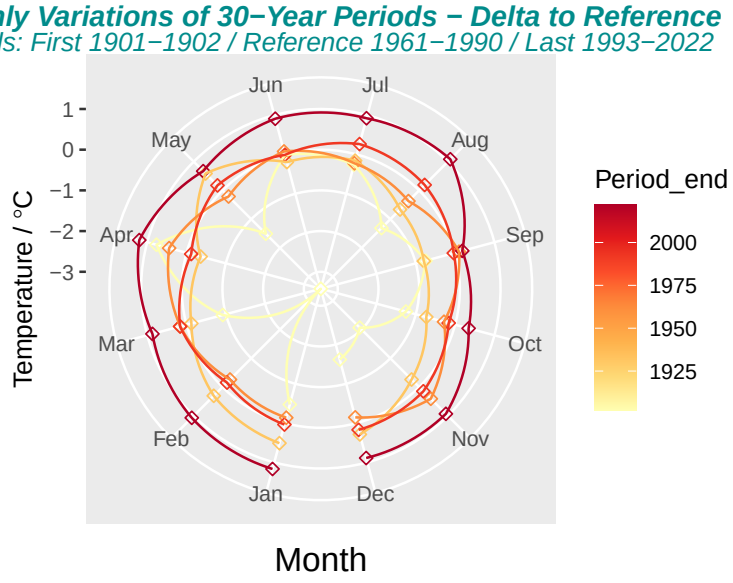



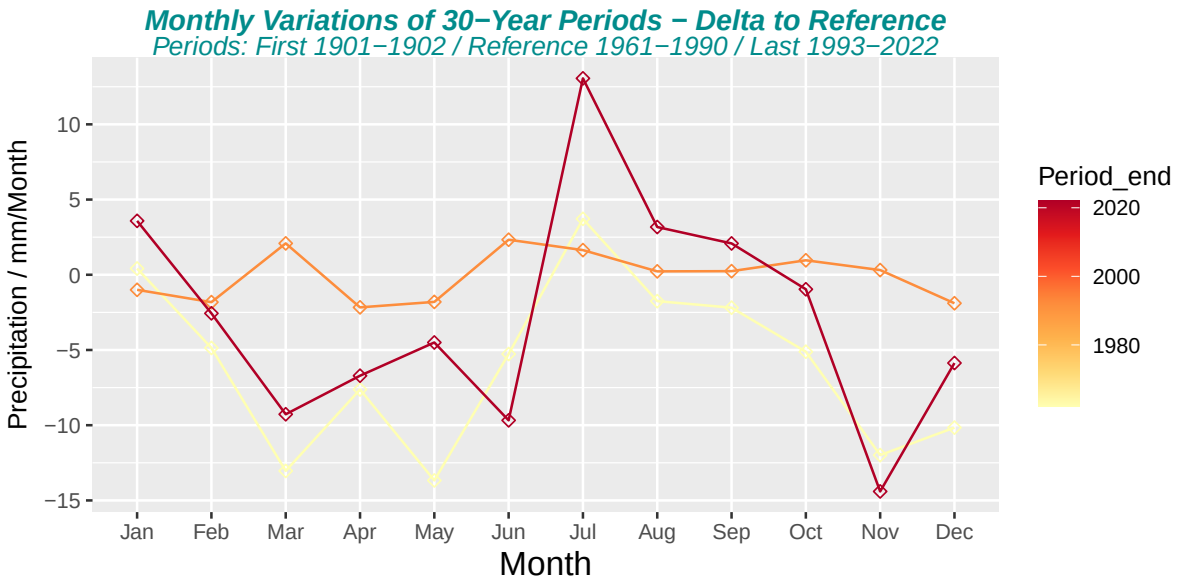

Monthly Variations of 30−Year Periods − Precipitation
Periods: First 1901−1902 / Reference 1961−1990 / Last 1993−2022
Precipitation / mm/Month
70
60
50
40
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2020
2000
1980

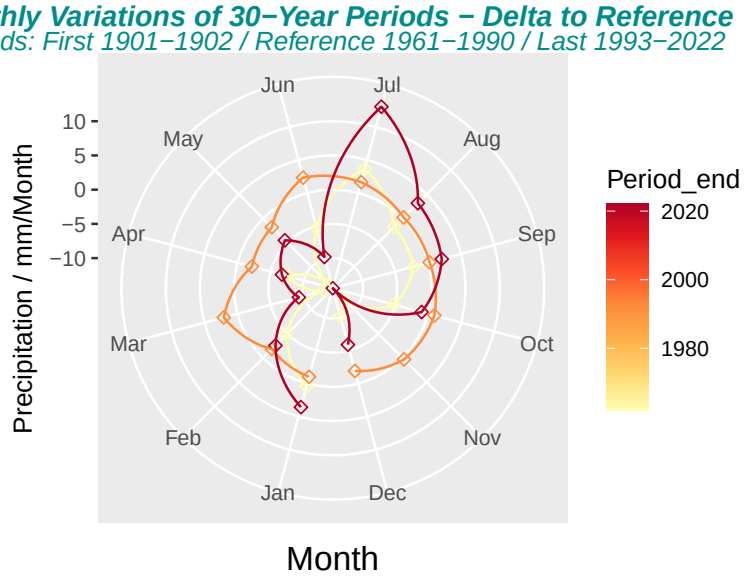

Monthly Variations of 30−Year Periods − Precipitation
Periods: First 1901−1902 / Reference 1961−1990 / Last 1993−2022
Precipitation / mm/Month
70
60
50
40
Jun
Jul
May
Aug
Apr
Sep
Mar
Oct
Feb
Nov
Jan
Dec
Month
Period_end
2020
2000
1980

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

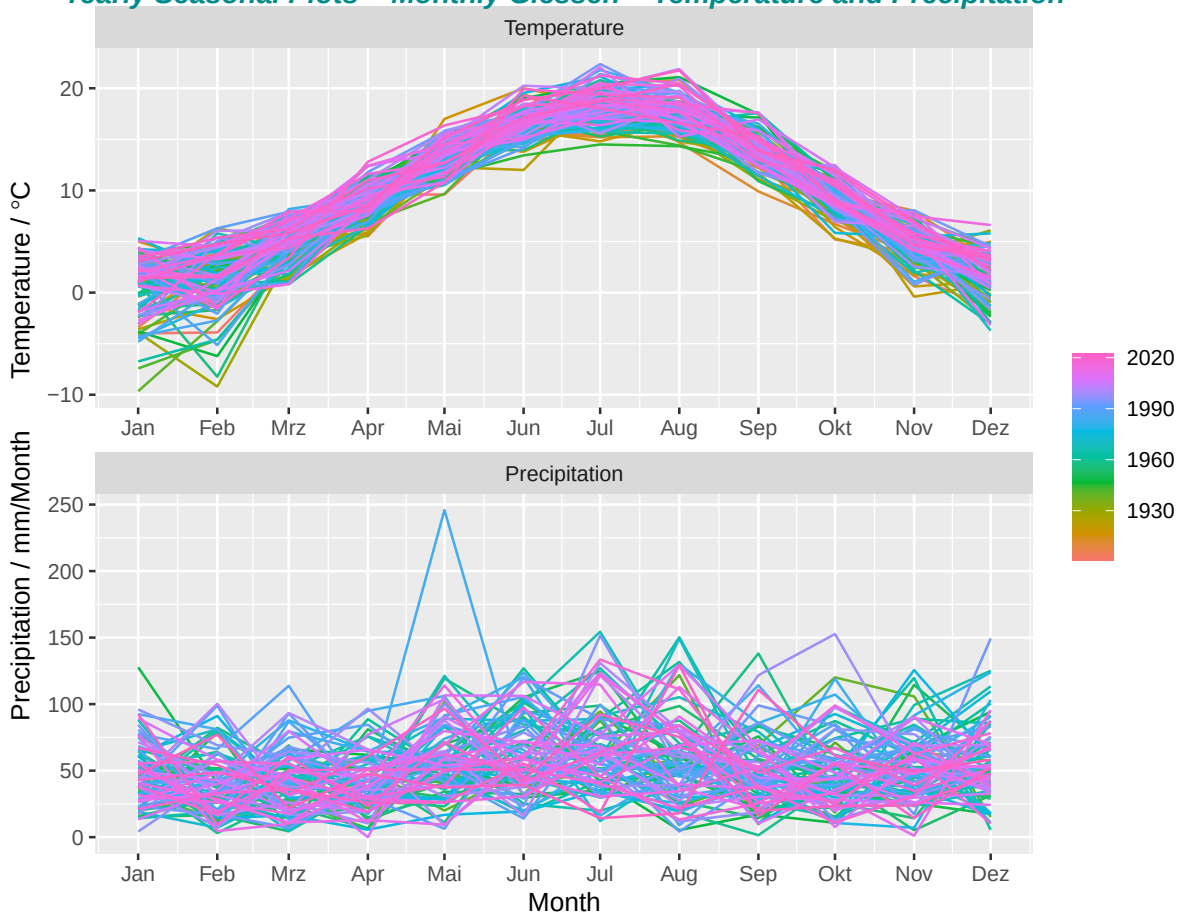


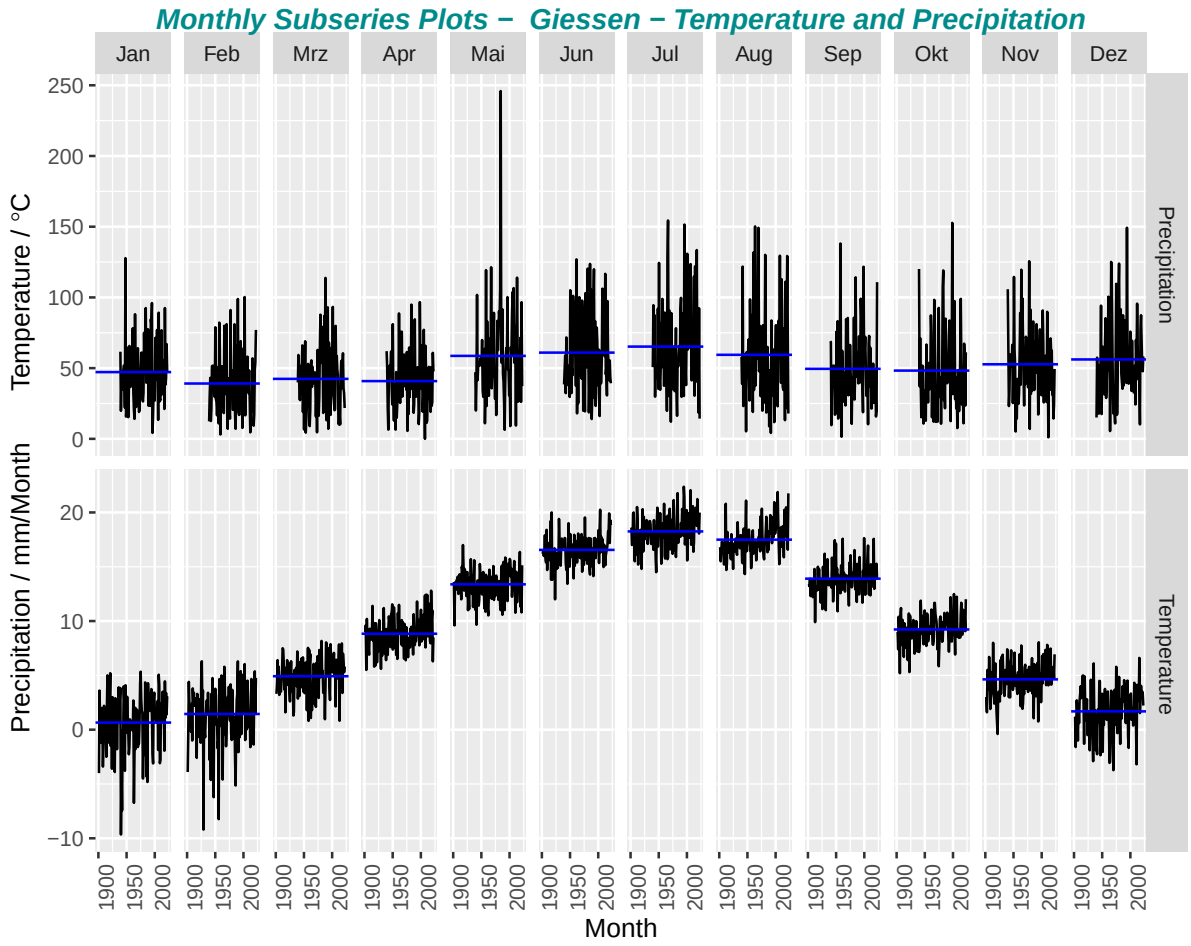




Monthly Variations of 30−Year Periods − Delta to Reference
Periods: First 1901−1902 / Reference 1961−1990 / Last 1993−2022
Precipitation / mm/Month
10
5
0
−5
−10
−15
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2020
2000
1980


Monthly Variations of 30−Year Periods − Delta to Reference
Periods: First 1901−1902 / Reference 1961−1990 / Last 1993−2022
Precipitation / mm/Month
10
5
0
−5
−10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2020
2000
1980

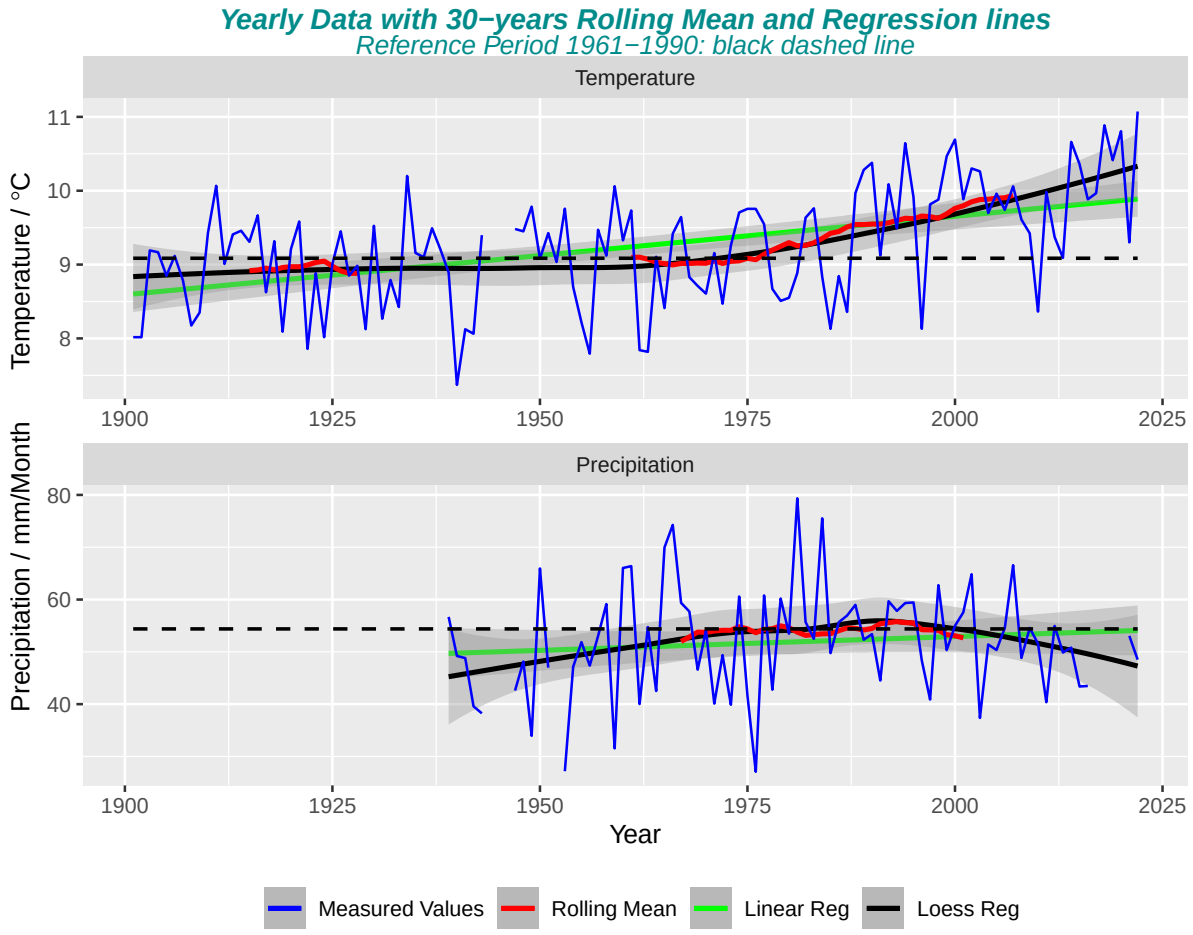
## *Yearly Seasonal Plots − Monthly Giessen − Temperature and Precipitation*



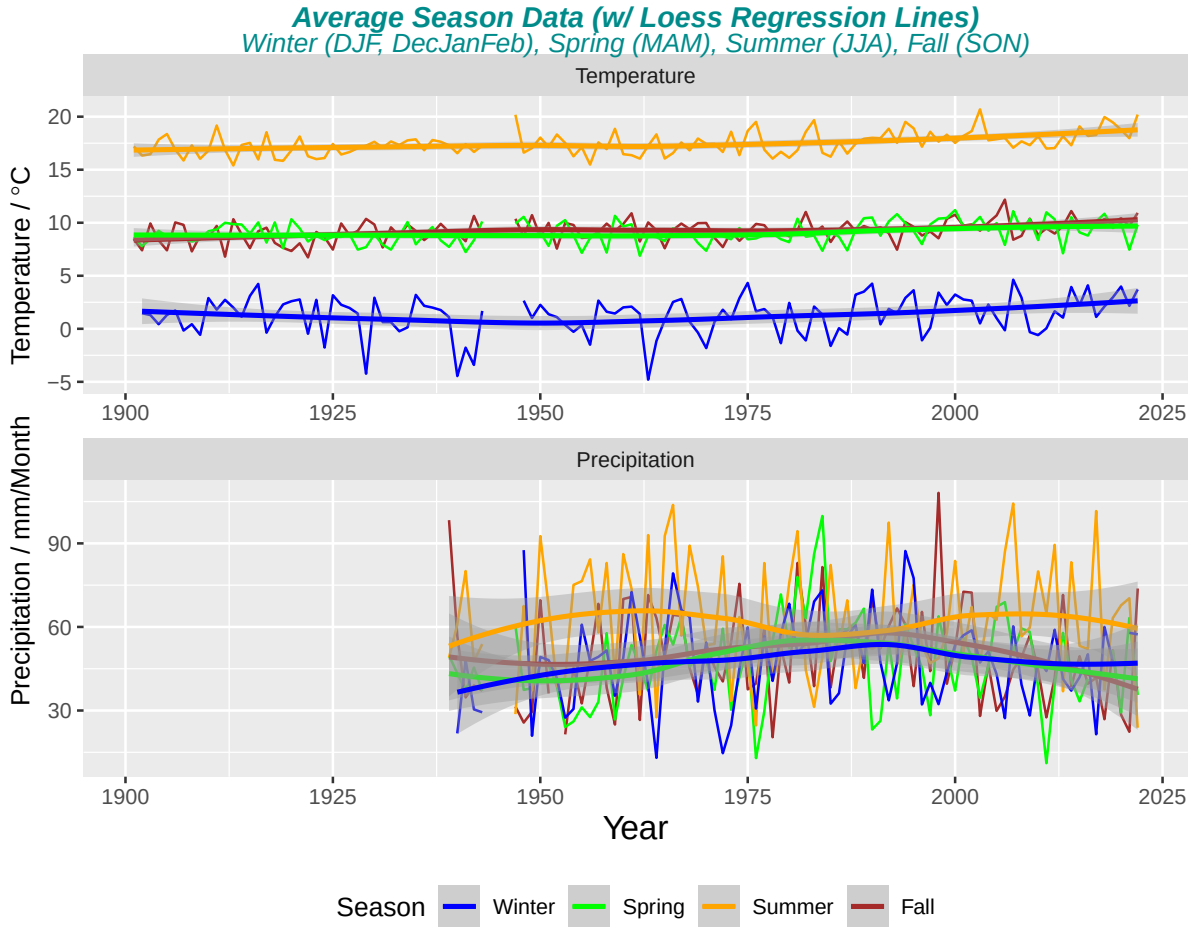



## 1.3 Yearly Giessen - Temperature and Precipitation

### 1.3.1 Plot Yearly Temperature and Precipitation



### 1.3.2 Plot Seasonal Yearly Temperature and Precipitation

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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

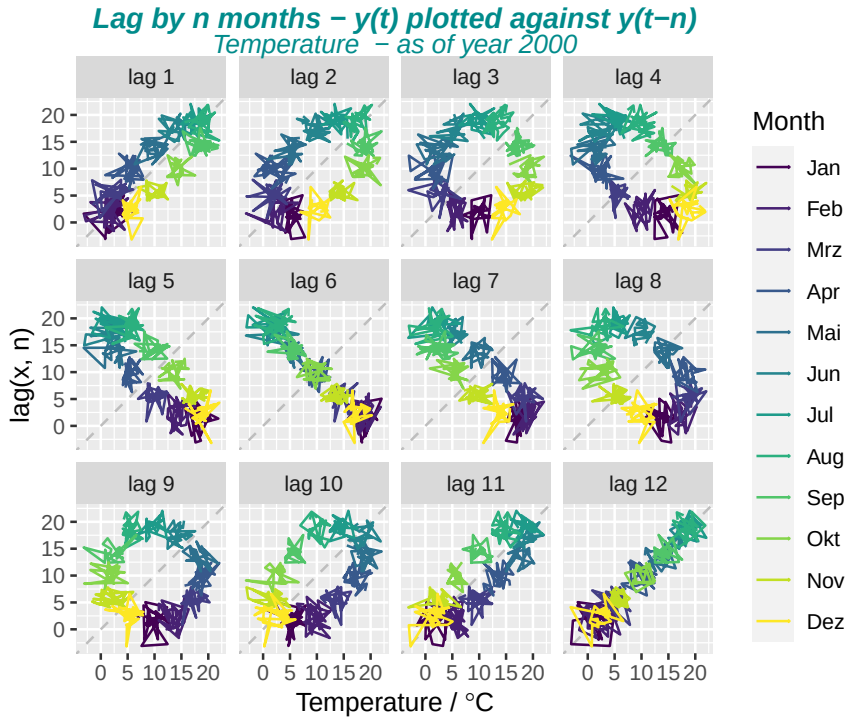
- additive model: $y_t = T_t + C_t + S_t + \epsilon_t$
- multiplicative model: $y_t = T_t * C_t * S_t * \epsilon_t$

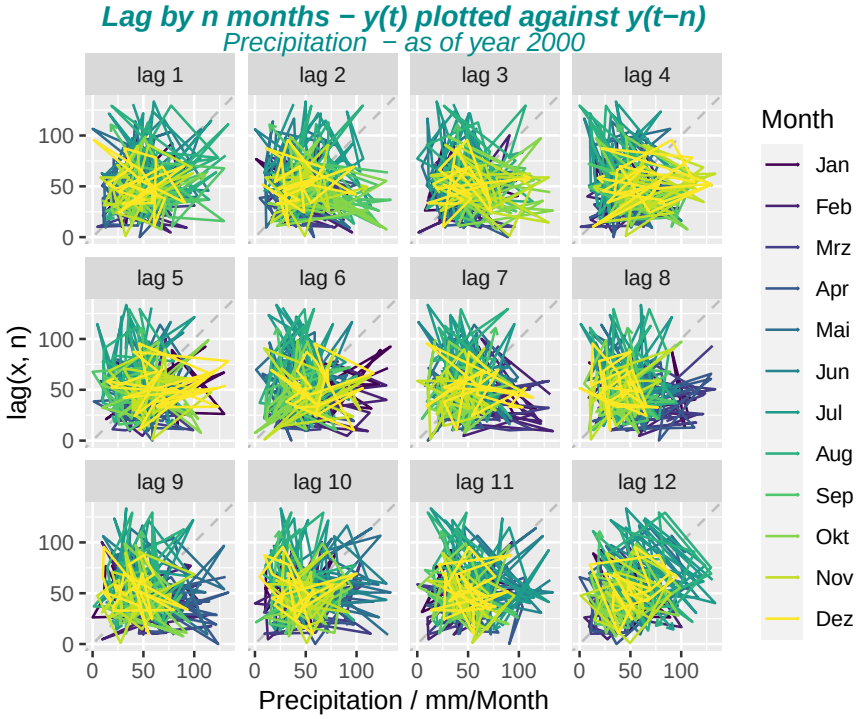
Trend / Cycle / Seasonal / Noise component
Cyclical components is often grouped into the Trend component

For *Seasonal decomposition of time series by Loess (stlplus)* uses in general an additive error model, 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

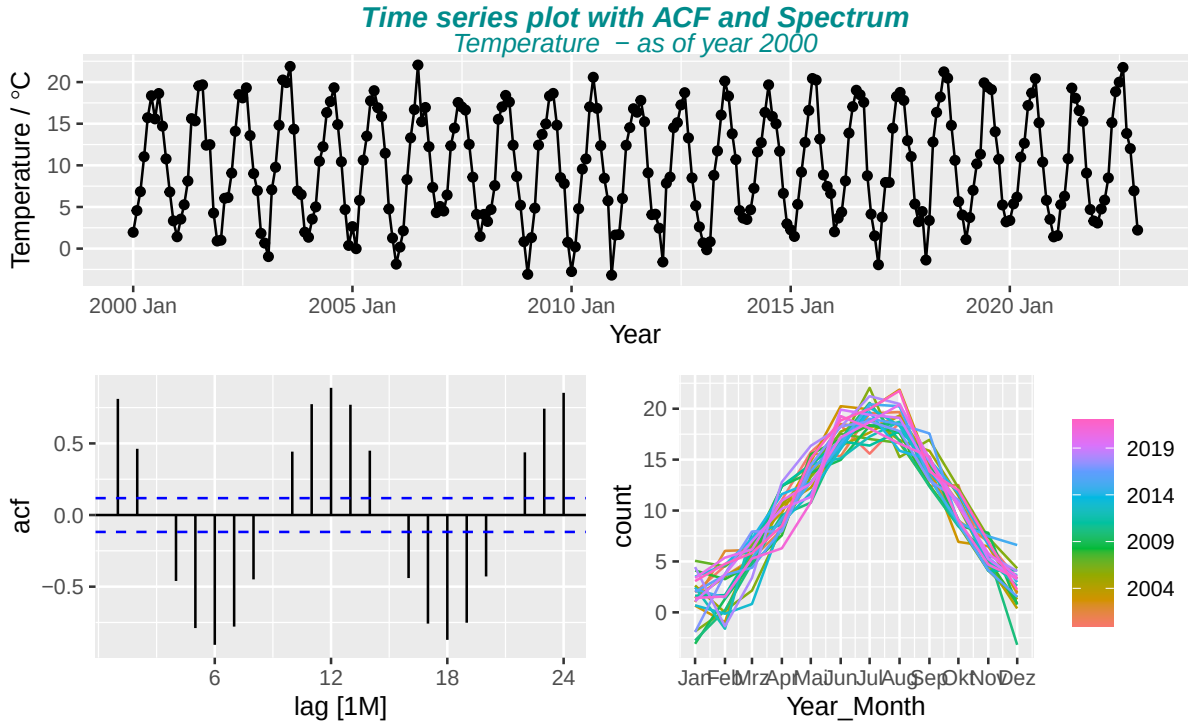
### 2.2.3 Periodogram - Spectral Density Estimation of a Time Series

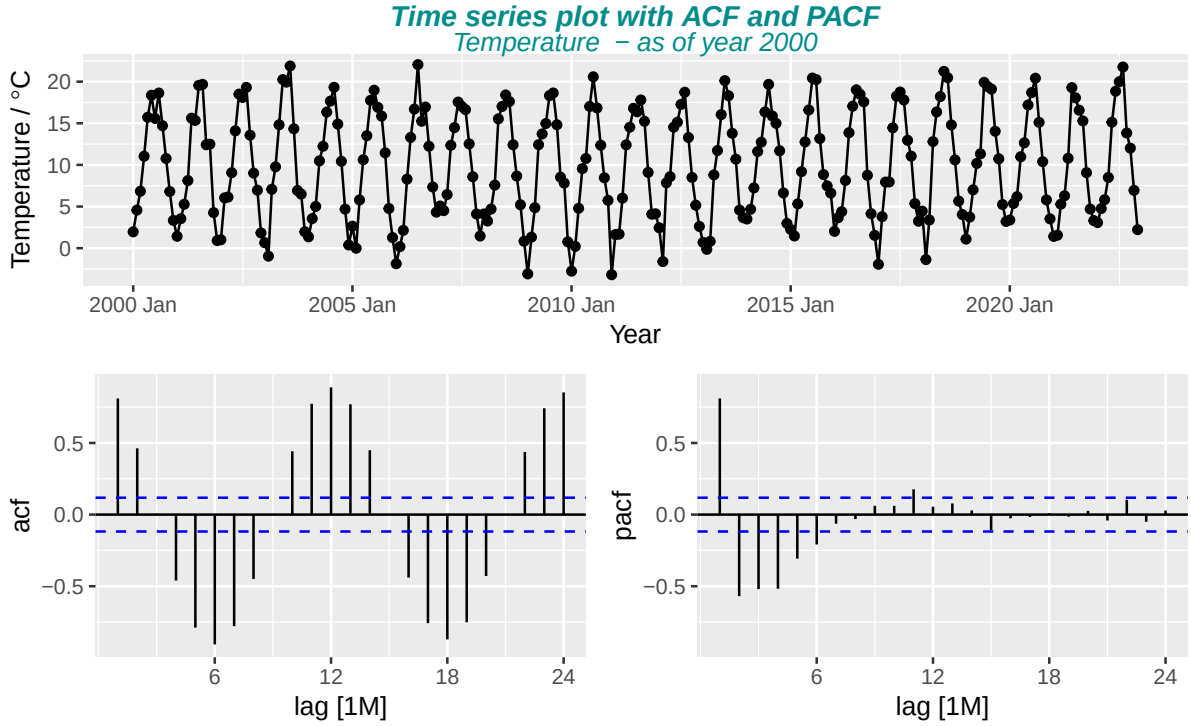
The spectral density characterizes the frequency content of the signal. One purpose of estimating the spectral density is to detect any periodicities in the data, by observing peaks at the frequencies corre-

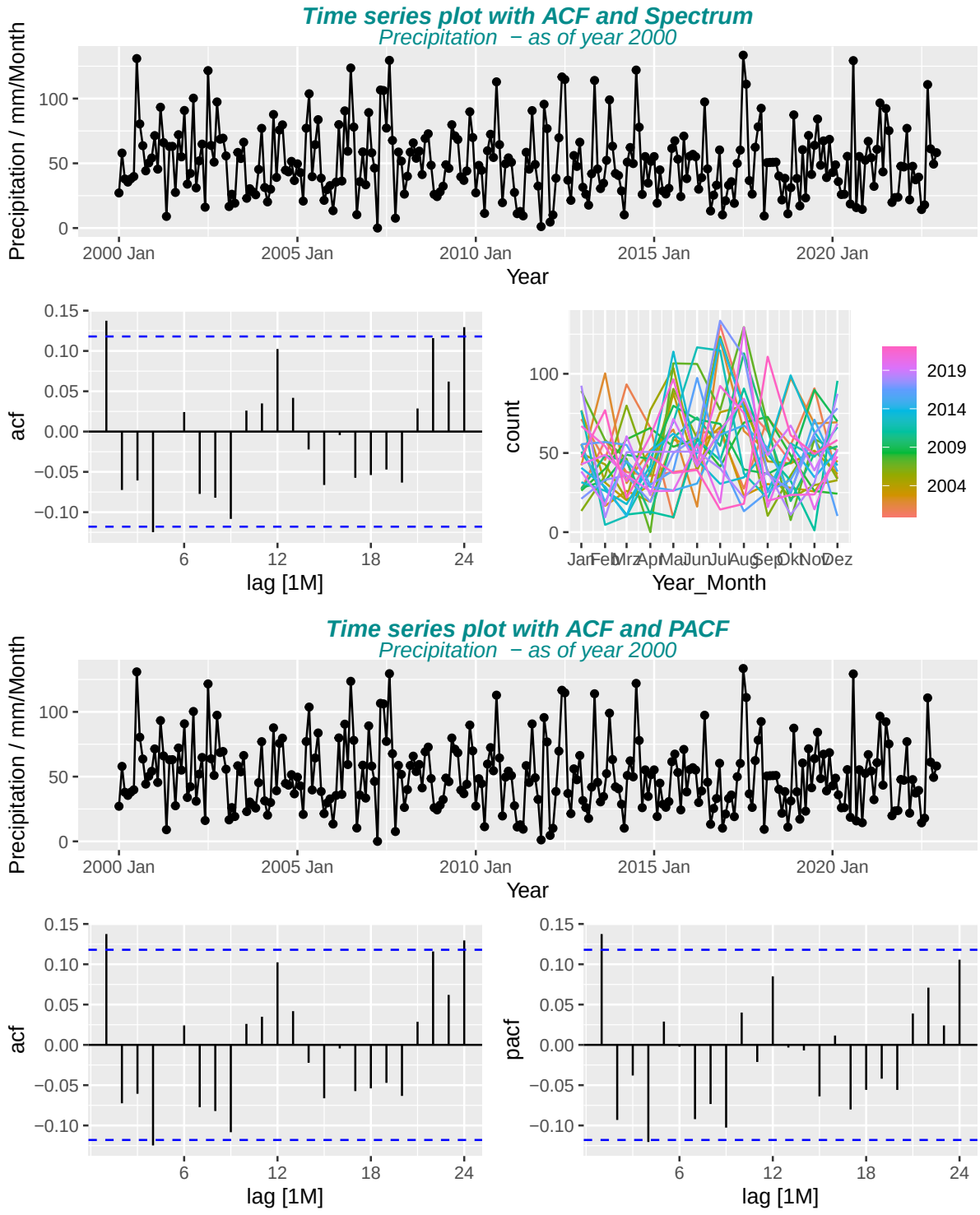
sponding to these periodicities.

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.



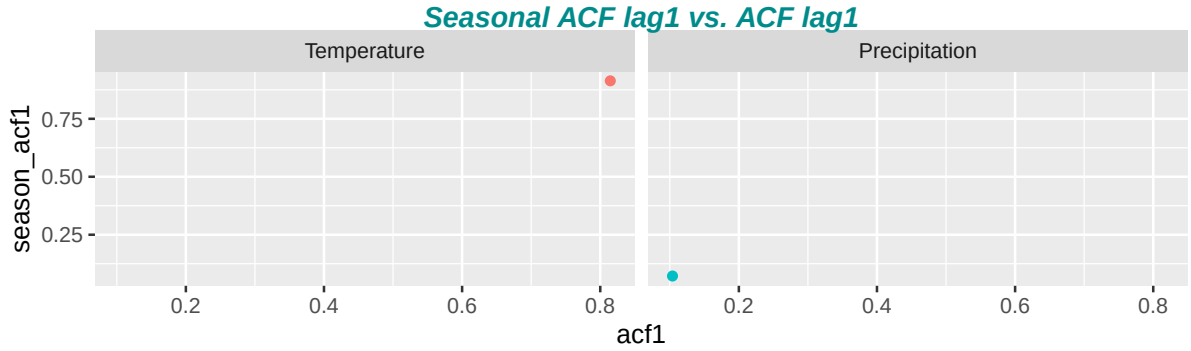


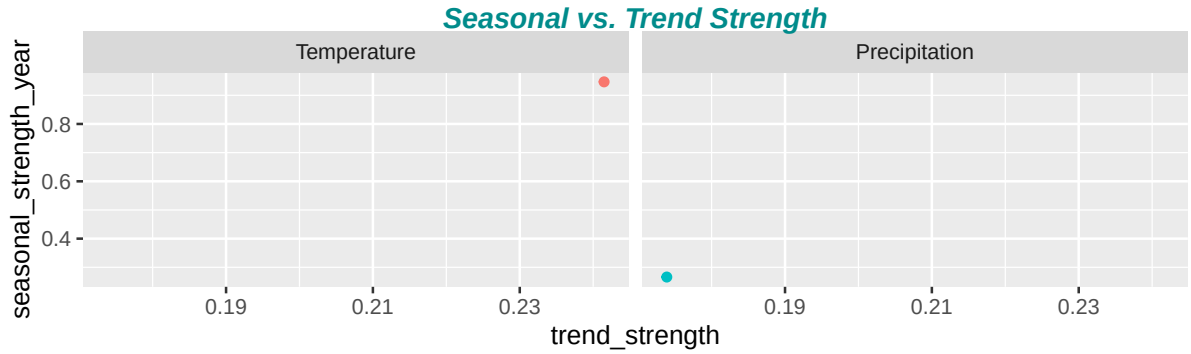

### 2.2.4 Seasonal vs non Seasonal ACF / Strength (Seasonal/Trend)

- 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: 2 x 8
#>   Measure        acf1  acf10 diff1_acf1 diff1_acf10 diff2_acf1 diff2_a~1 seaso~2
#>   <fct>         <dbl>  <dbl>      <dbl>       <dbl>      <dbl>     <dbl>   <dbl>
#> 1 Temperature   0.815 3.56        0.447       1.74      -0.379     0.257  0.914
#> 2 Precipitation 0.104 0.0200     -0.451       0.215     -0.639     0.434  0.0718
#> # ... with abbreviated variable names 1: diff2_acf10, 2: season_acf1
#> [1] "Check Trend & Seasonal Strength close to 0 / 1 : weak / strong and compare them"
#> # A tibble: 2 x 10
#>   Measure       trend_~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      0.241   0.947       7       1 7.69e-6    14.4    6.59  0.0703
#> 2 Precipitation    0.174   0.266       5       3 8.61e-1    29.8  -78.3  -0.119
#> # ... 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: 2 x 2
#>   Measure       spectral_entropy
#>   <fct>                    <dbl>
#> 1 Temperature              0.176
#> 2 Precipitation            0.999
```

### 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 Giessen - 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 |
|---|---|---|---|---|---|---|---|
| Giessen | Temperature | 1901 | NA | 8.6 | 17.2 | 8.5 | 8.0 |
| Giessen | Temperature | 1902 | 1.5 | 7.8 | 16.3 | 7.4 | 8.0 |
| Giessen | Temperature | 1903 | 1.3 | 8.5 | 16.5 | 9.9 | 9.2 |
| Giessen | Temperature | 1904 | 0.4 | 9.2 | 17.8 | 8.3 | 9.2 |
| Giessen | Temperature | 1905 | 1.3 | 8.7 | 18.4 | 7.4 | 8.8 |
| Giessen | Temperature | 1906 | 1.7 | 8.6 | 16.9 | 10.0 | 9.1 |
| Giessen | Temperature | 1907 | -0.2 | 8.5 | 15.9 | 9.8 | 8.8 |
| Giessen | Temperature | 1908 | 0.4 | 8.2 | 17.3 | 7.3 | 8.2 |
| Giessen | Temperature | 1909 | -0.6 | 8.4 | 16.0 | 8.8 | 8.3 |
| Giessen | Temperature | 1910 | 2.9 | 9.2 | 16.8 | 8.6 | 9.4 |
| Giessen | Temperature | 2013 | 1.1 | 7.1 | 18.2 | 9.7 | 9.1 |
| Giessen | Temperature | 2014 | 3.9 | 10.5 | 17.3 | 11.1 | 10.7 |
| Giessen | Temperature | 2015 | 2.2 | 9.1 | 19.1 | 9.8 | 10.4 |
| Giessen | Temperature | 2016 | 4.1 | 8.8 | 18.2 | 10.2 | 9.9 |
| Giessen | Temperature | 2017 | 1.1 | 10.1 | 18.3 | 9.8 | 10.0 |
| Giessen | Temperature | 2018 | 2.1 | 10.8 | 20.0 | 10.3 | 10.9 |
| Giessen | Temperature | 2019 | 3.0 | 9.5 | 19.5 | 10.0 | 10.4 |
| Giessen | Temperature | 2020 | 4.0 | 9.9 | 18.8 | 10.4 | 10.8 |
| Giessen | Temperature | 2021 | 2.2 | 7.5 | 18.0 | 9.7 | 9.3 |
| Giessen | Temperature | 2022 | 3.7 | 9.8 | 20.2 | 10.9 | 11.1 |

Table 4: Annual Precipitation / mm/Month (first and last 10 years)

| City | Measure | Year | Winter_avg | Spring_avg | Summer_avg | Fall_avg | Year_avg |
|---|---|---|---|---|---|---|---|
| Giessen | Precipitation | 1901 | NA | NA | NA | NA | NA |
| Giessen | Precipitation | 1902 | NA | NA | NA | NA | NA |
| Giessen | Precipitation | 1903 | NA | NA | NA | NA | NA |
| Giessen | Precipitation | 1904 | NA | NA | NA | NA | NA |
| Giessen | Precipitation | 1905 | NA | NA | NA | NA | NA |
| Giessen | Precipitation | 1906 | NA | NA | NA | NA | NA |
| Giessen | Precipitation | 1907 | NA | NA | NA | NA | NA |

| City | Measure | Year | Winter_avg | Spring_avg | Summer_avg | Fall_avg | Year_avg |
|---|---|---|---|---|---|---|---|
| Giessen | Precipitation | 1908 | NA | NA | NA | NA | NA |
| Giessen | Precipitation | 1909 | NA | NA | NA | NA | NA |
| Giessen | Precipitation | 1910 | NA | NA | NA | NA | NA |
| Giessen | Precipitation | 2013 | 41.3 | 57.9 | 36.9 | 71.5 | 49.9 |
| Giessen | Precipitation | 2014 | 37.1 | 41.1 | 83.2 | 38.6 | 50.8 |
| Giessen | Precipitation | 2015 | 42.0 | 33.3 | 53.2 | 49.5 | 43.4 |
| Giessen | Precipitation | 2016 | 50.2 | 41.3 | 52.1 | 39.6 | 43.5 |
| Giessen | Precipitation | 2017 | 21.5 | NA | 101.6 | 41.8 | NA |
| Giessen | Precipitation | 2018 | 60.0 | NA | 37.6 | 26.9 | NA |
| Giessen | Precipitation | 2019 | 47.6 | 51.8 | 63.2 | 51.6 | 52.0 |
| Giessen | Precipitation | 2020 | NA | 29.3 | 67.8 | 28.5 | NA |
| Giessen | Precipitation | 2021 | 57.9 | 63.2 | 70.3 | 22.4 | 53.1 |
| Giessen | Precipitation | 2022 | 57.3 | 35.6 | 23.8 | 73.8 | 48.5 |

Table 5: Monthly Means over all Years (Temperature / degree C and Monthly Precipitation / mm)

| City | Month | Temperature | Precipitation |
|---|---|---|---|
| Giessen | Jan | 0.7 | 47.2 |
| Giessen | Feb | 1.4 | 39.1 |
| Giessen | Mar | 4.9 | 42.4 |
| Giessen | Apr | 8.8 | 40.8 |
| Giessen | May | 13.4 | 58.7 |
| Giessen | Jun | 16.6 | 61.0 |
| Giessen | Jul | 18.3 | 65.2 |
| Giessen | Aug | 17.5 | 59.4 |
| Giessen | Sep | 13.9 | 49.5 |
| Giessen | Oct | 9.2 | 48.3 |
| Giessen | Nov | 4.6 | 52.7 |
| Giessen | Dec | 1.7 | 56.1 |

## 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