

# Climate Data Visualization - Atmospheric $CO_2$ Concentration / Temperature / Precipitation

Wolfgang Vollmer

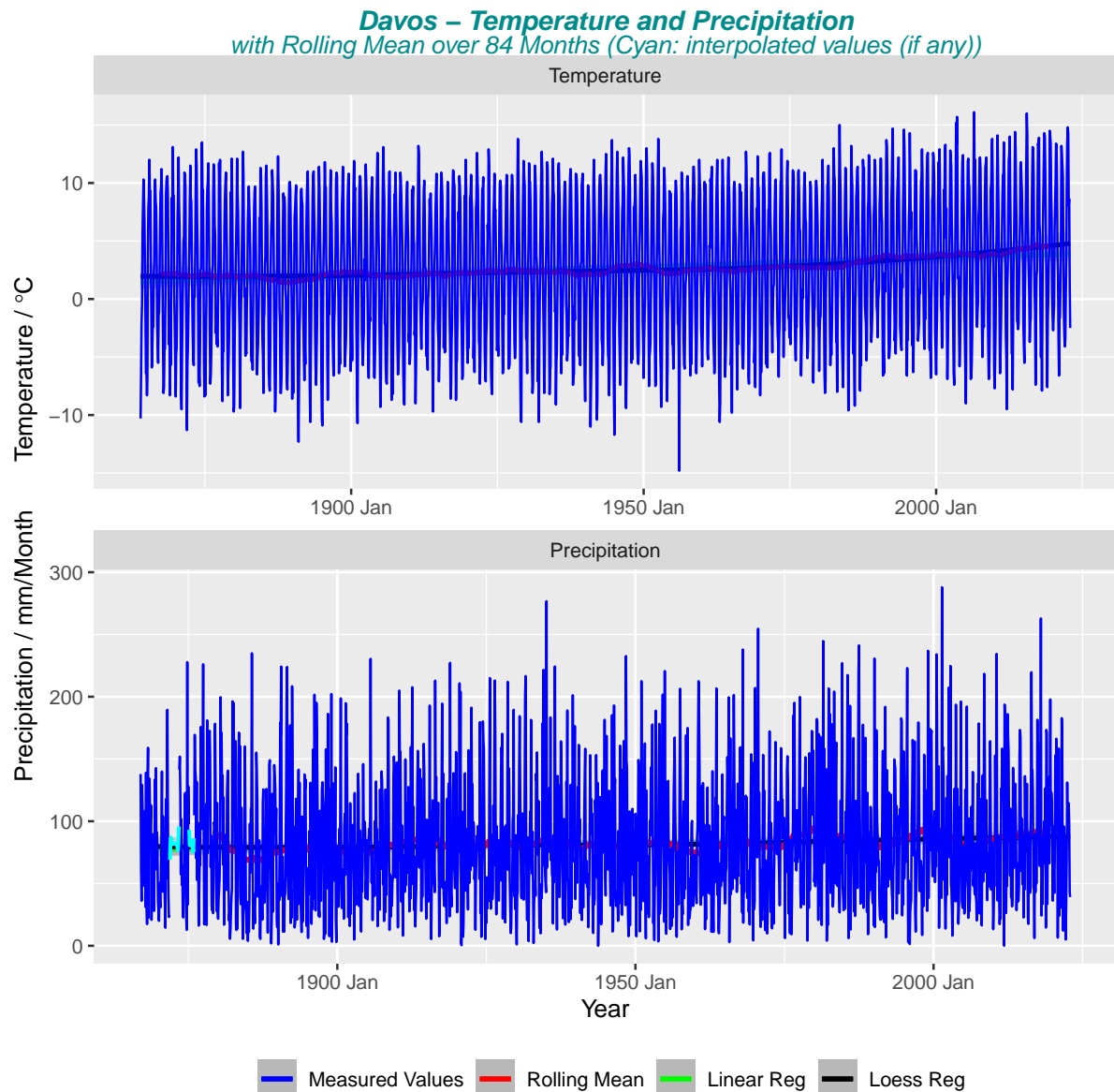
2023-02-18

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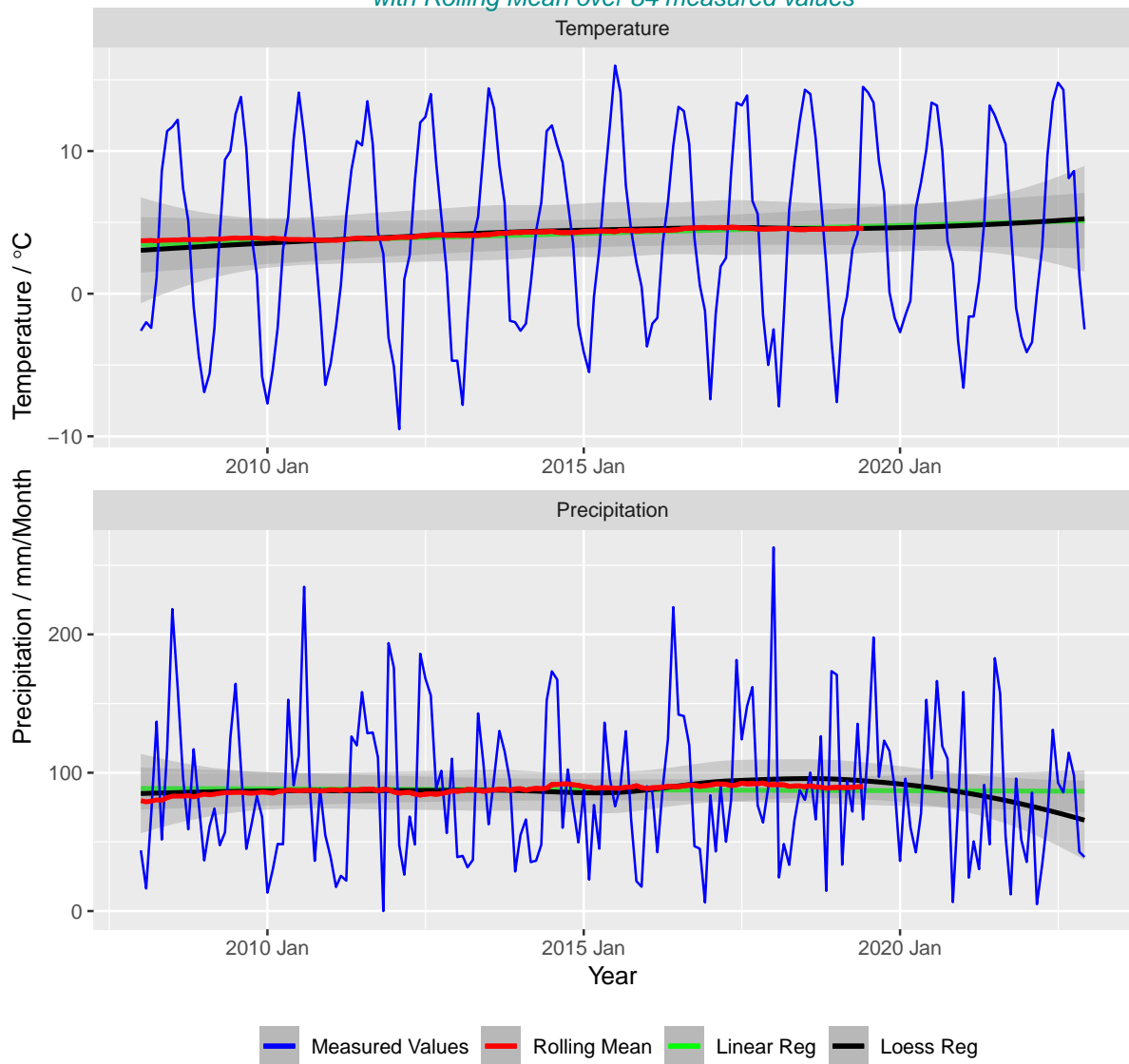
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# 1 Davos - Visualization of Temperature and Precipitation Data 1864 - 2022

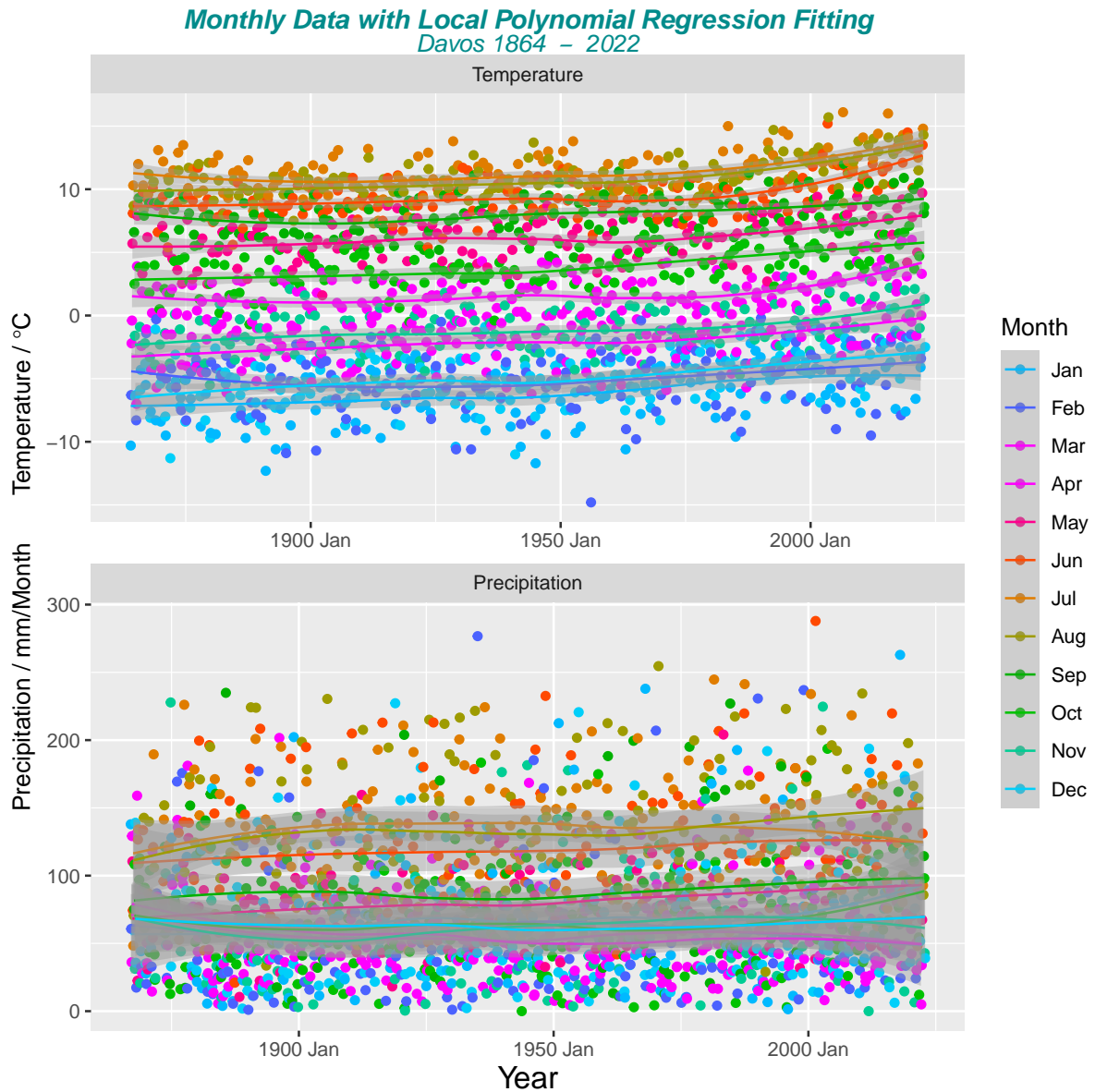
## 1.1 Monthly Time Plots with Rolling Mean



**Davos – Temperature and Precipitation – Past 15 years only**  
*with Rolling Mean over 84 measured values*



## 1.2 Yearly plots with monthly breakdown



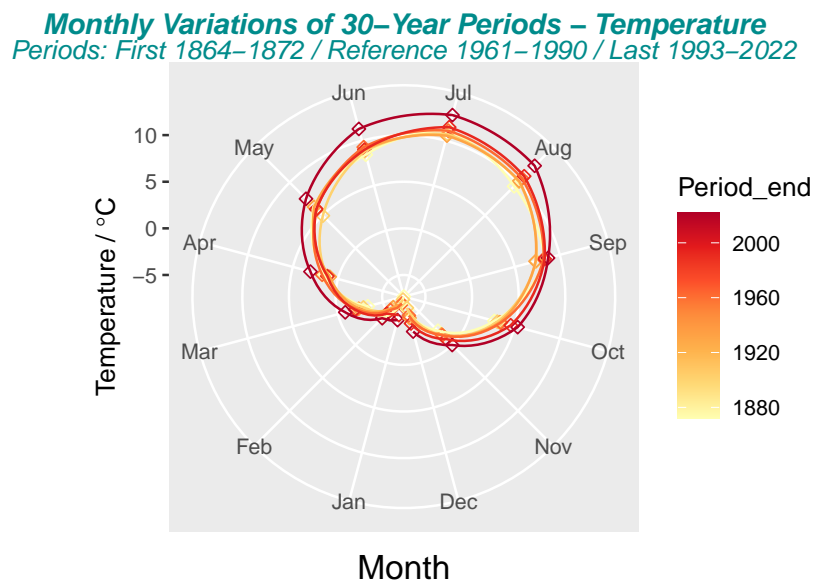
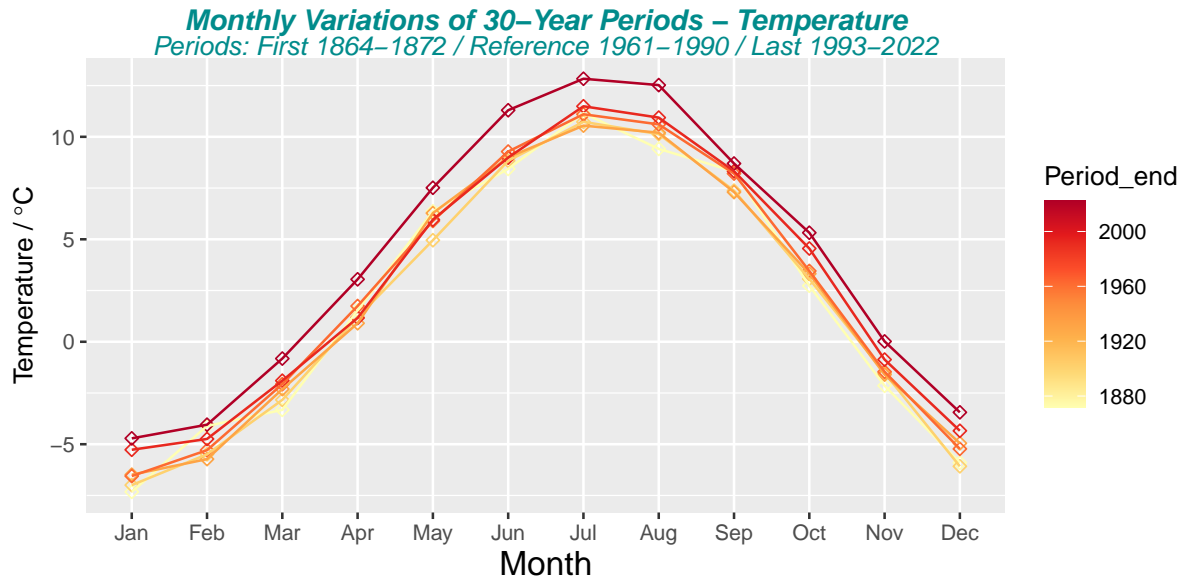
### 1.2.1 30-year period plots with monthly breakdown - Cartesian and Polar Coordinates

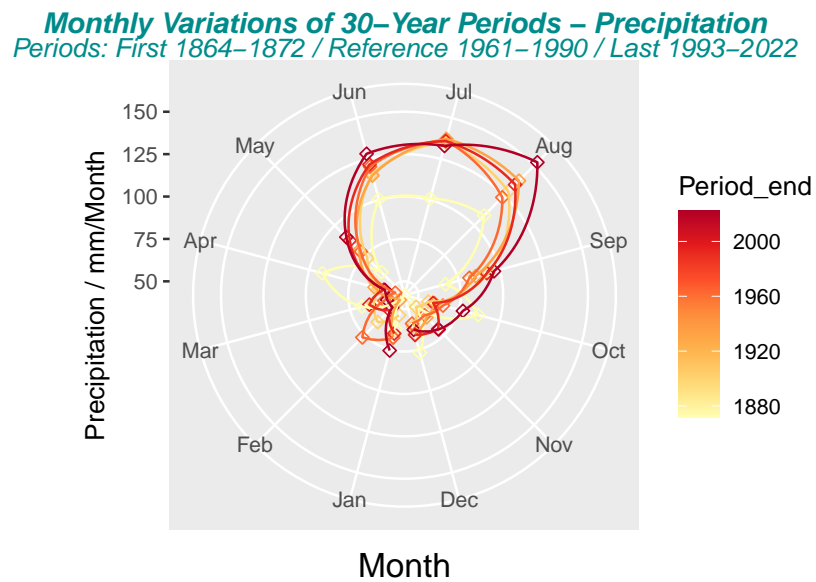
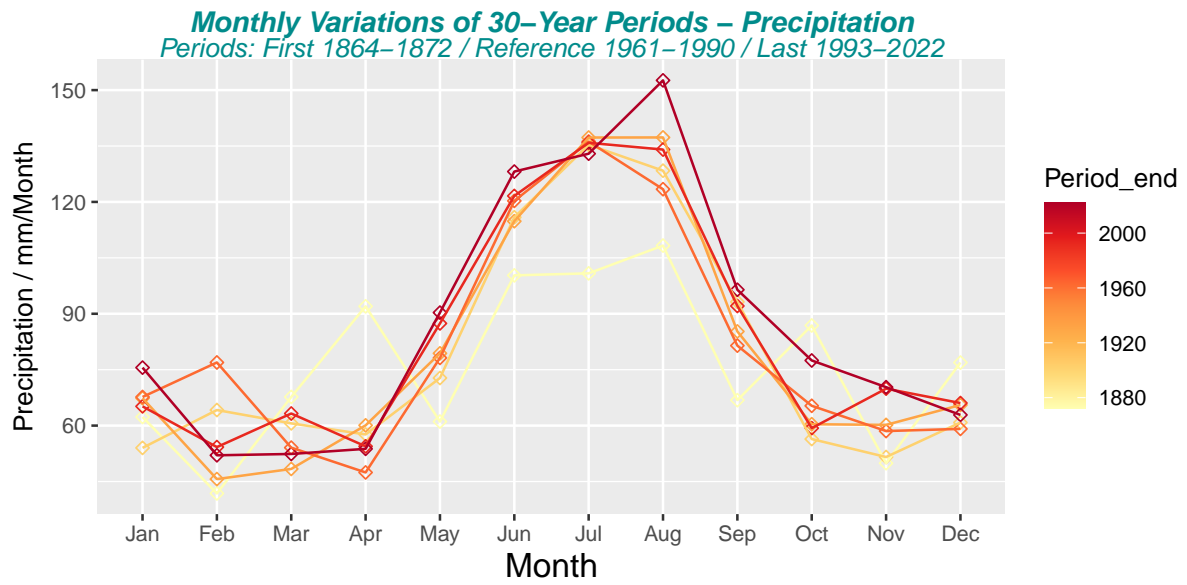
Table 1: 30-years Periods - Average Data (Temperature / degree C and Monthly Precipitation / mm)

| City  | Period    | Temperature | Monthly Precipitation | Annual Precipitation |
|-------|-----------|-------------|-----------------------|----------------------|
| Davos | 1864-1872 | 2.1         | 76.2                  | 914.8                |
| Davos | 1873-1902 | 1.9         | 79.2                  | 950.8                |
| Davos | 1903-1932 | 2.2         | 80.1                  | 961.6                |
| Davos | 1933-1962 | 2.5         | 80.7                  | 968.6                |
| Davos | 1963-1992 | 2.9         | 83.6                  | 1003.4               |
| Davos | 1993-2022 | 4.0         | 87.1                  | 1044.8               |

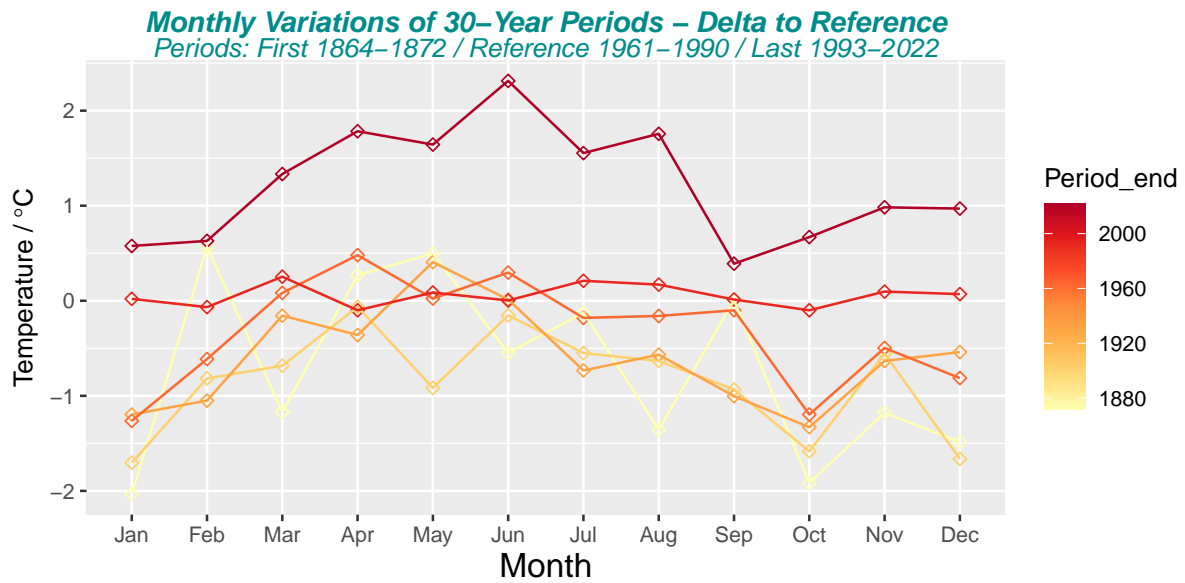
| City  | Ref_Period | Temperature | Monthly Precipitation | Annual Precipitation |
|-------|------------|-------------|-----------------------|----------------------|
| Davos | 1961-1990  | 2.8         | 83.2                  | 998.7                |

Note: First Period shorter in general (starts with first data year = 1864)

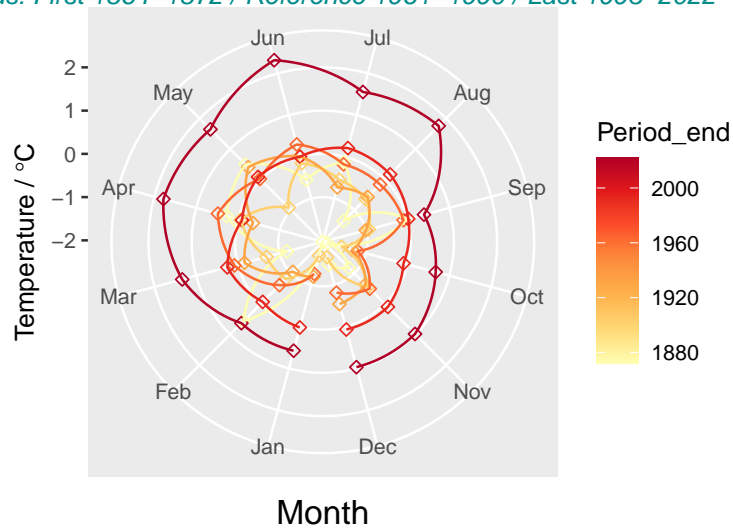


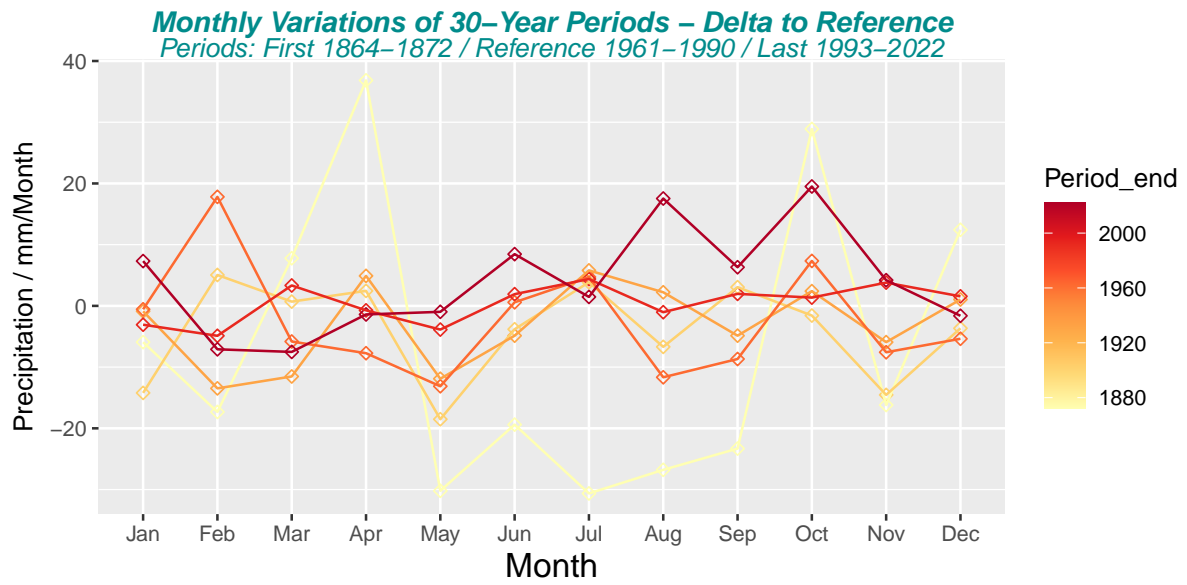


### 1.2.2 Plot Monthly Delta to Reference Period - Cartesian and Polar Coordinates

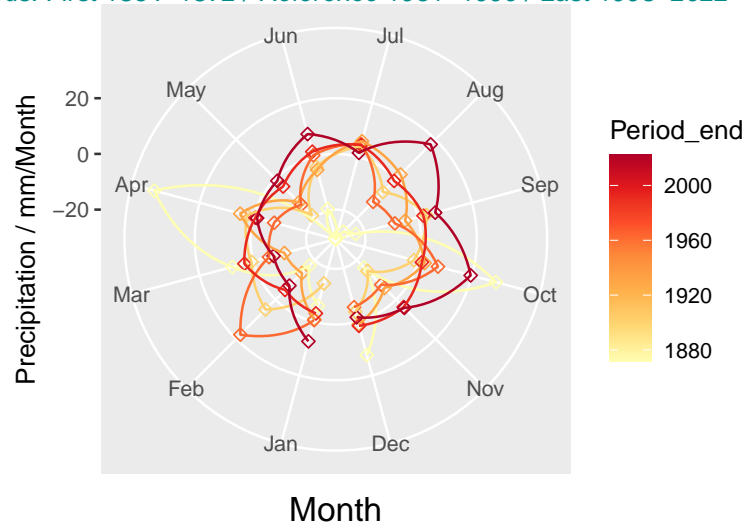


**Monthly Variations of 30-Year Periods – Delta to Reference**  
*Periods: First 1864–1872 / Reference 1961–1990 / Last 1993–2022*



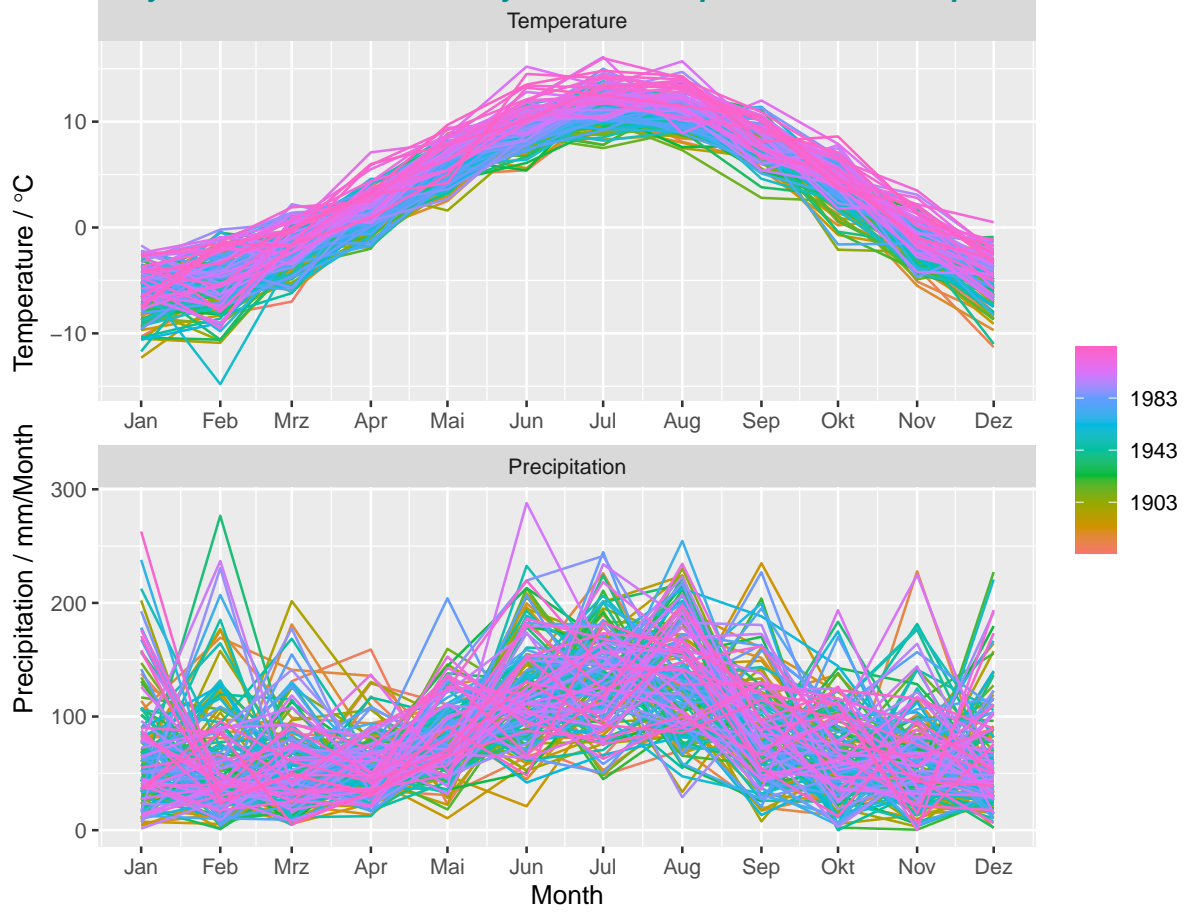


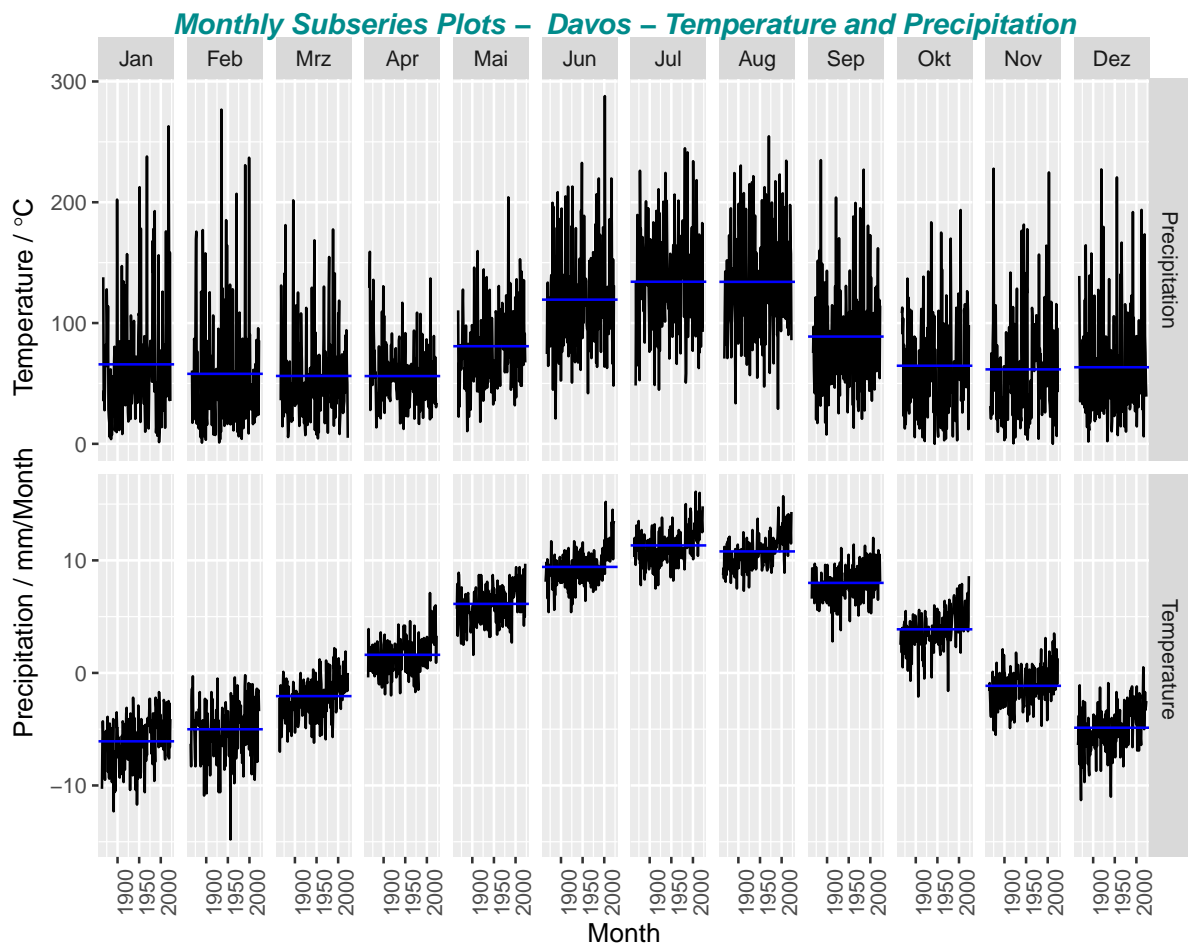
**Monthly Variations of 30-Year Periods – Delta to Reference**  
*Periods: First 1864–1872 / Reference 1961–1990 / Last 1993–2022*





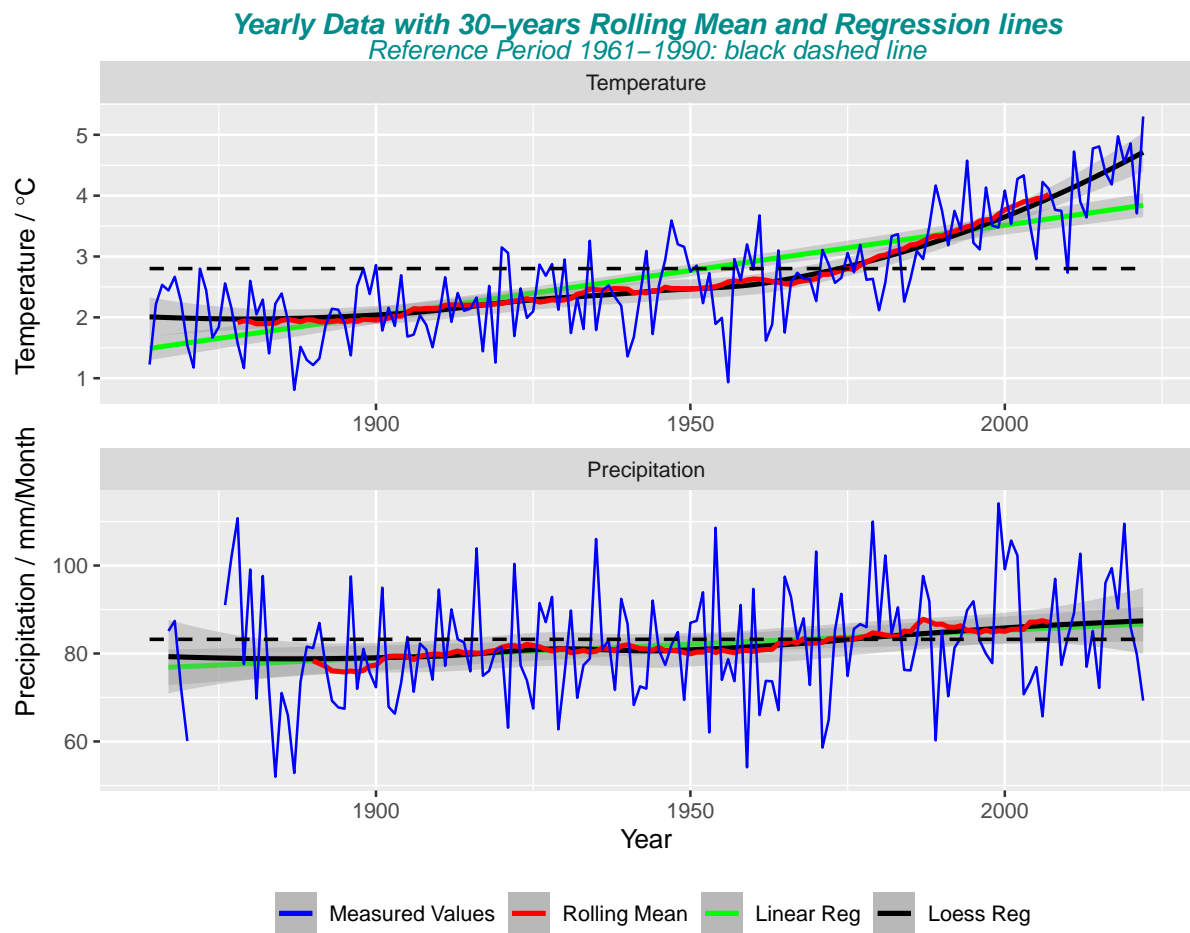
### Yearly Seasonal Plots – Monthly Davos – Temperature and Precipitation



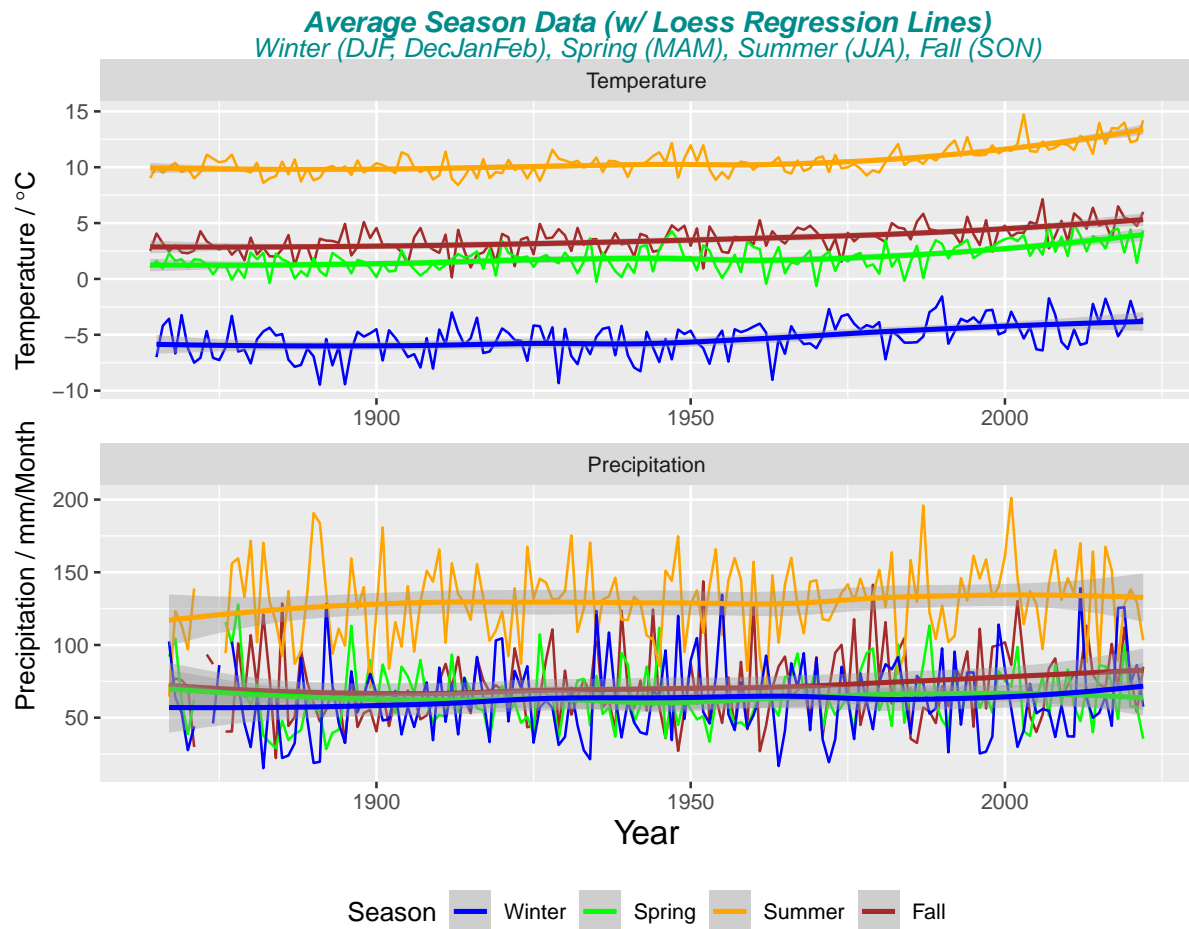


### 1.3 Yearly Davos - Temperature and Precipitation

### 1.3.1 Plot Yearly Temperature and Precipitation



### 1.3.2 Plot Seasonal Yearly Temperature and Precipitation



## 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.

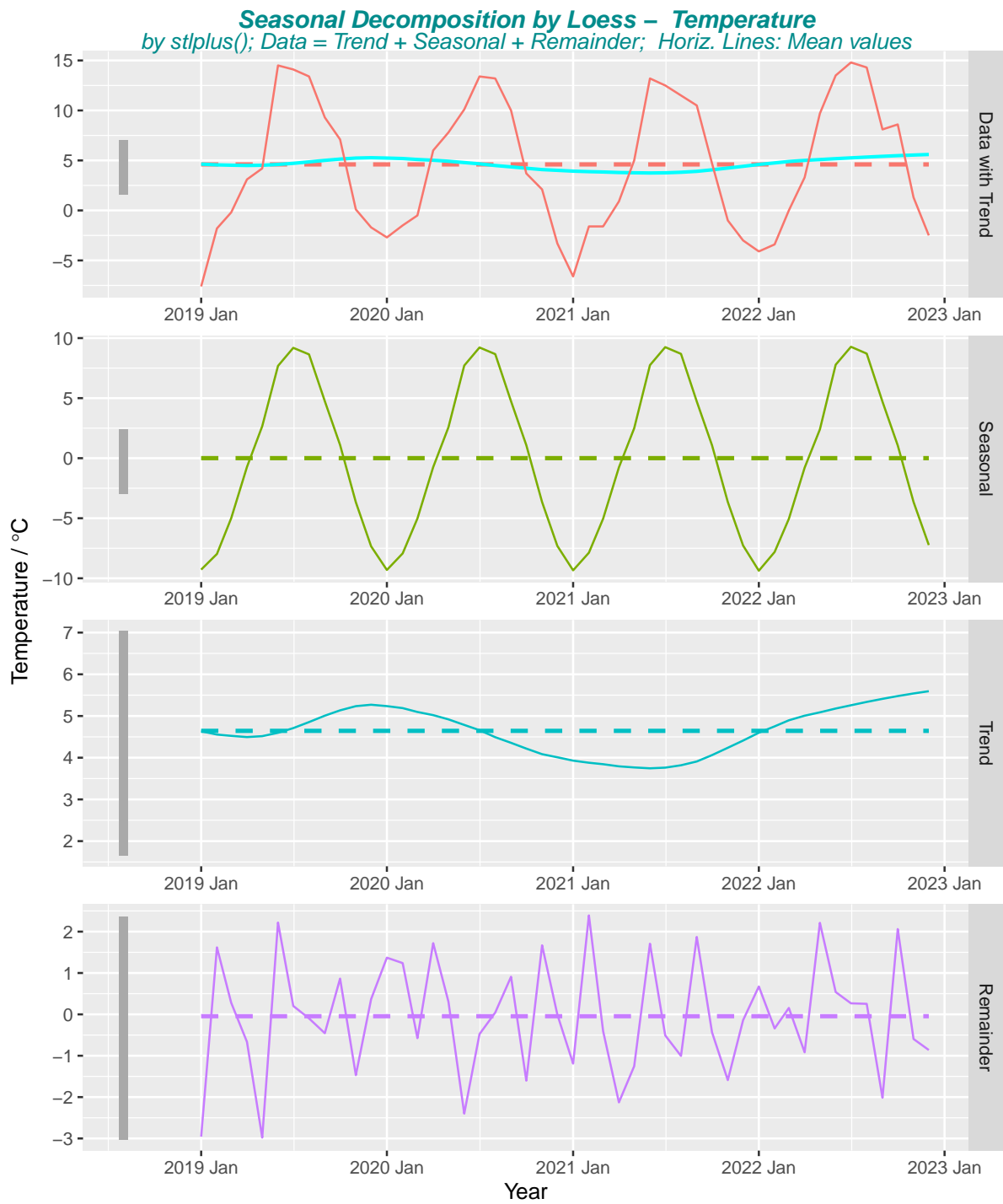
Time series using an

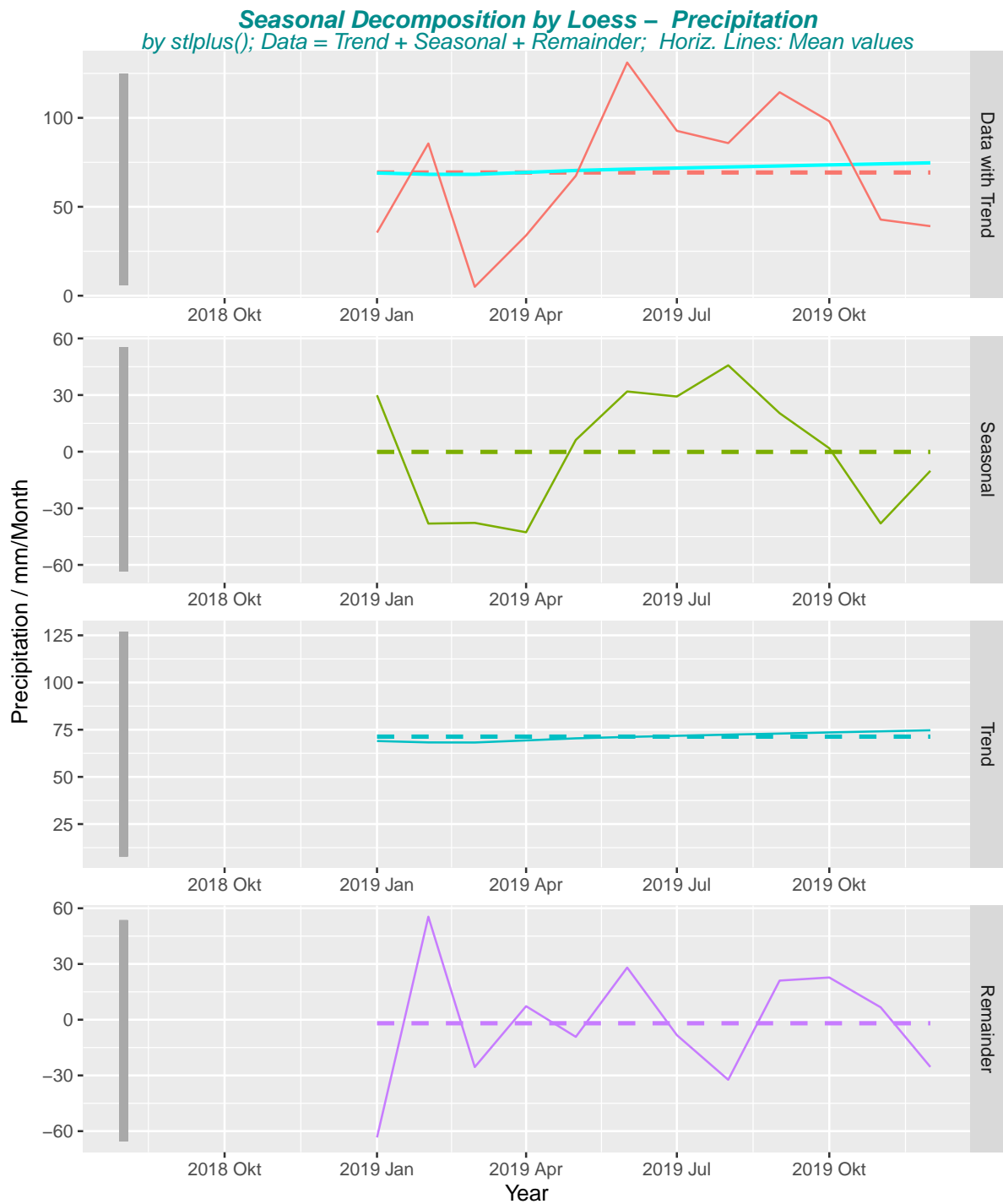
- additive model:  $y_t = T_t + C_t + S_t + \epsilon_t$
- multiplicative model:  $y_t = T_t * C_t * S_t * \epsilon_t$

Trend / Cycle / Seasonal / Noise component

Cyclical components is often grouped into the Trend component

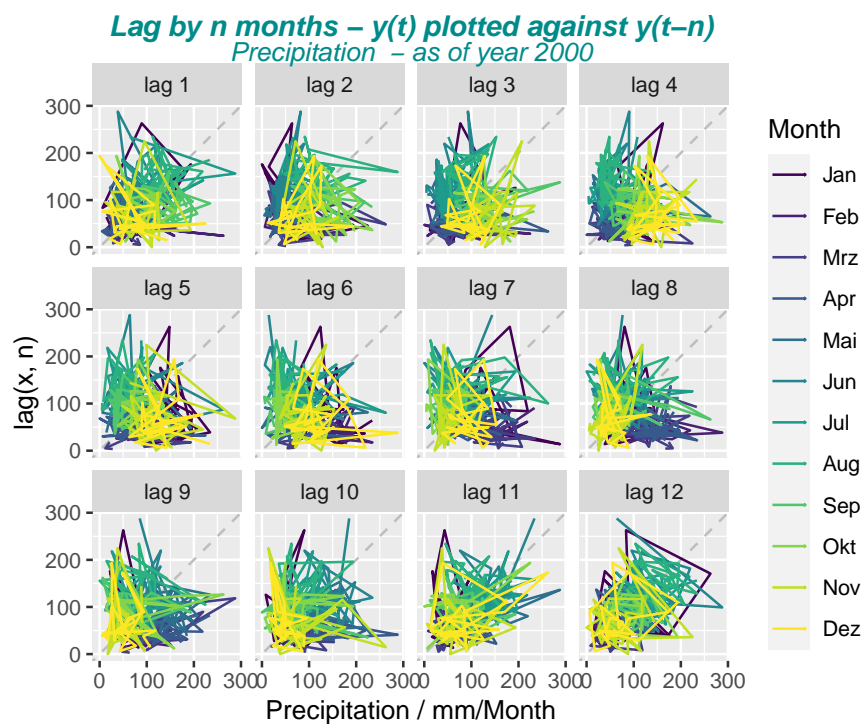
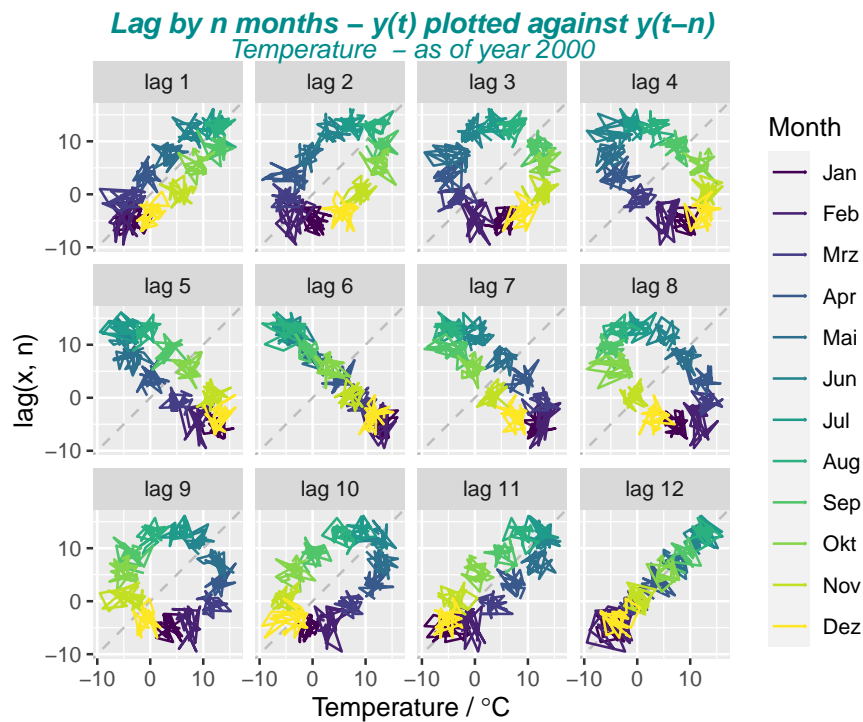
For *Seasonal decomposition of time series by Loess (stlplus)* uses in general an additive error model, it only provides facilities for additive decompositions. It is possible to obtain a multiplicative decomposition by first taking logs of the data.





## 2.2 Periodicities - Season Frequency

### 2.2.1 Lag Plot - Differences



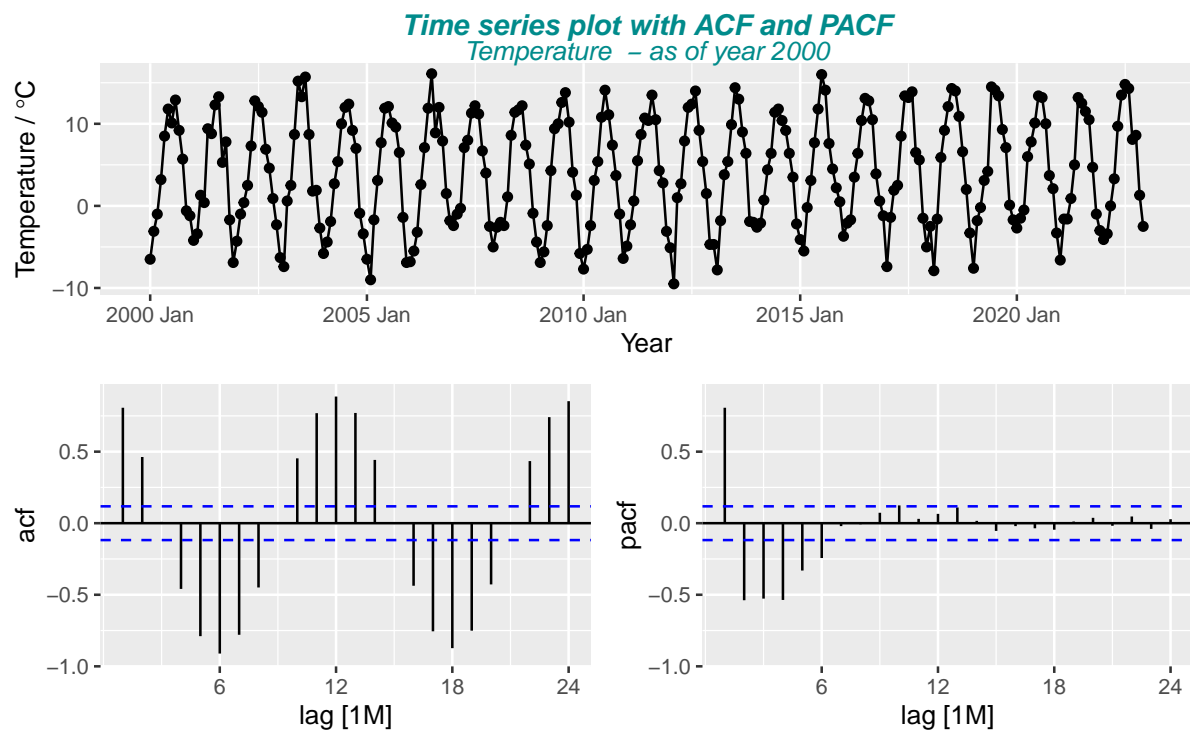
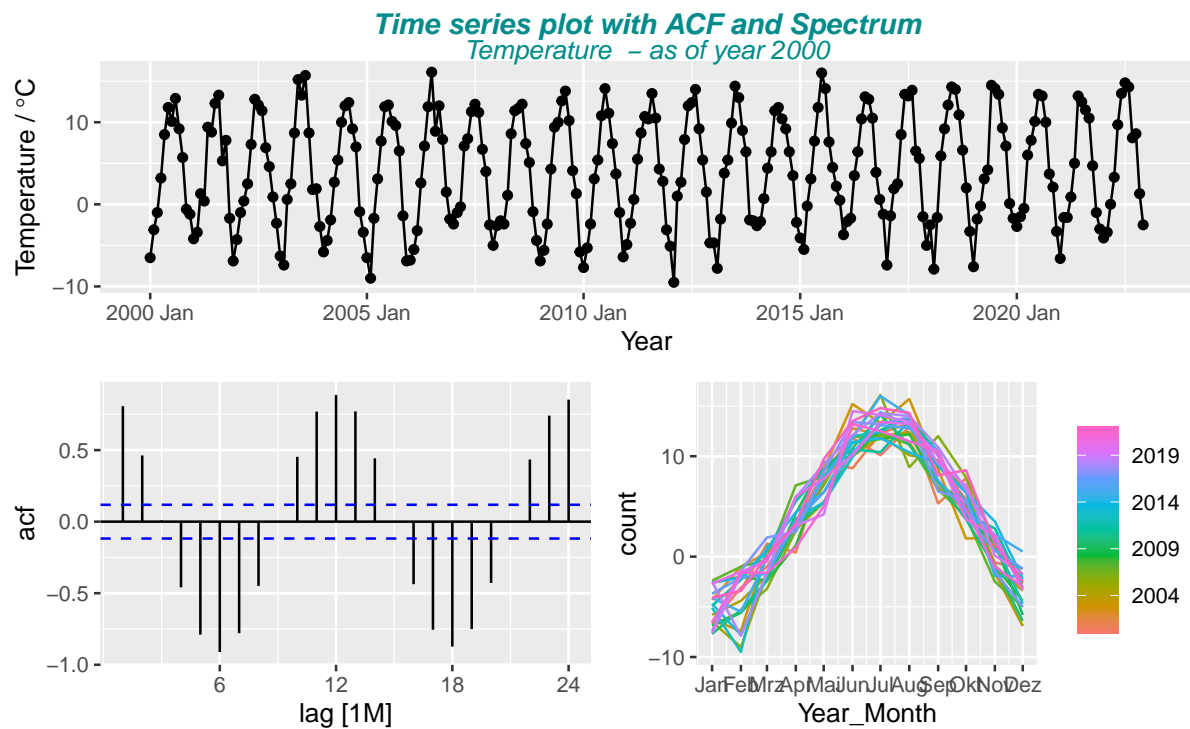
### 2.2.2 ACF / PACF Correlogram

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

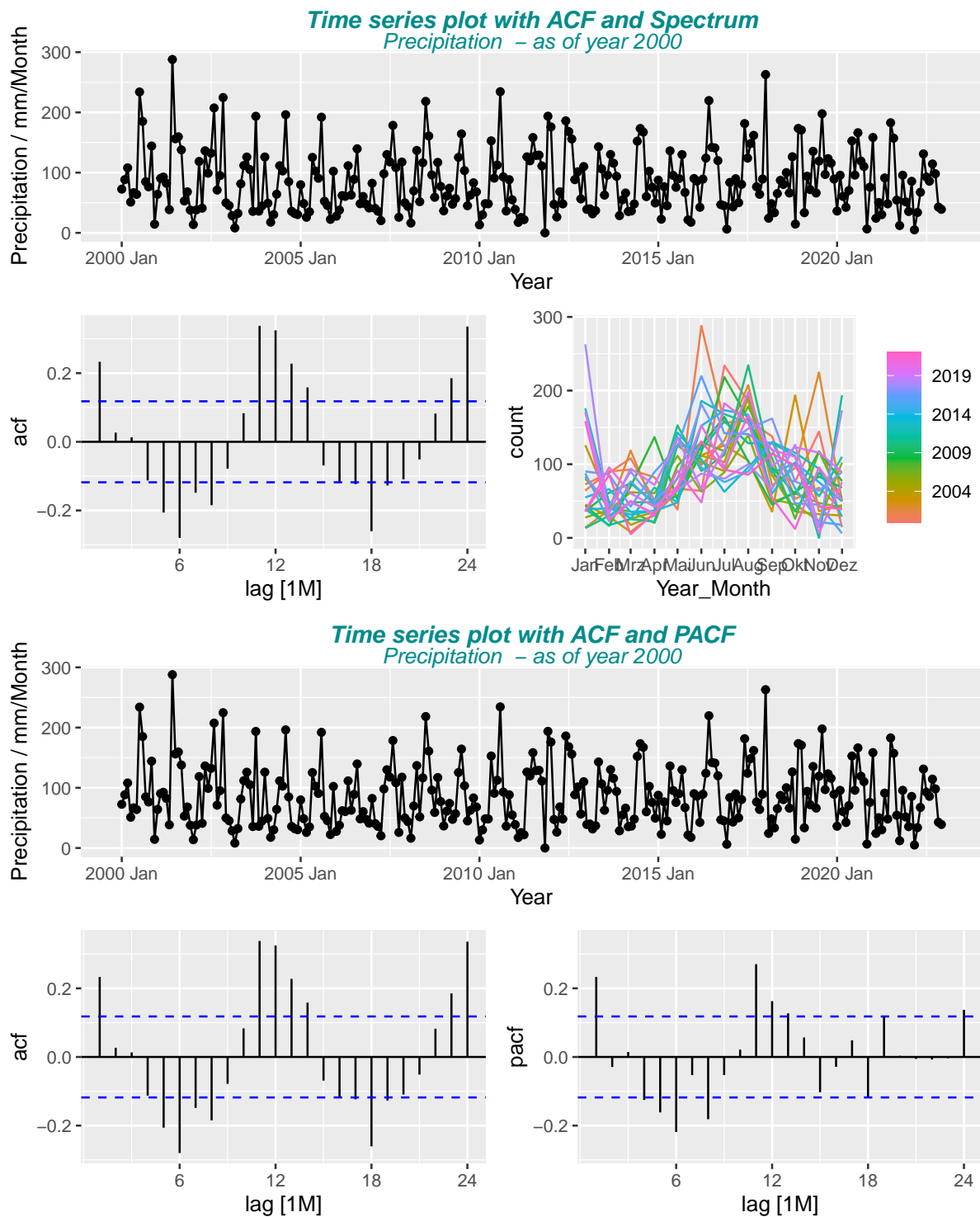
The spectral density characterizes the frequency content of the signal. One purpose of estimating the spectral density is to detect any periodicities in the data, by observing peaks at the frequencies corresponding to these periodicities.

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.





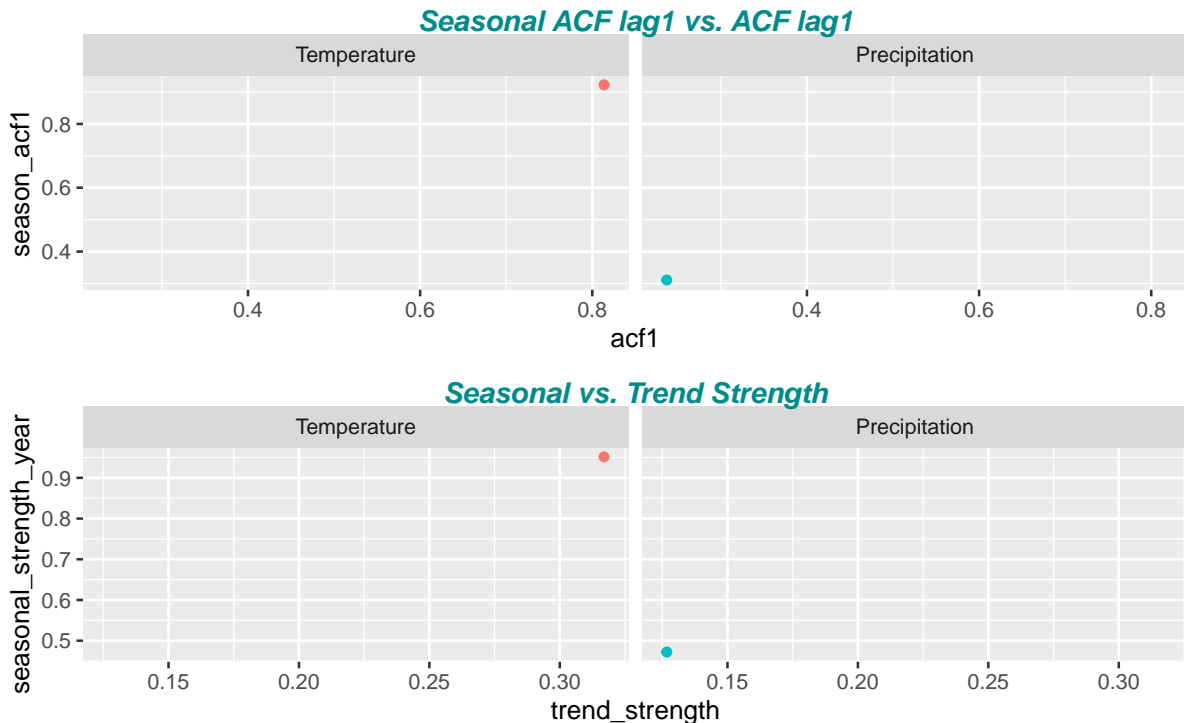


## 2.2.4 Seasonal vs non Seasonal ACF / Strength (Seasonal/Trend)

- 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: 2 x 8
#>   Measure      acf1 acf10 diff1_acf1 diff1_acf10 diff2_acf1 diff2_acf1 season_acf1
#>   <fct>      <dbl> <dbl>      <dbl>      <dbl>      <dbl>      <dbl>      <dbl>
#> 1 Temperature 0.814 3.52      0.421      1.70      -0.416      0.298      0.922
#> 2 Precipitation 0.237 0.213     -0.403      0.175     -0.645      0.450      0.311
#> # ... 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 season~2 season~3 season~4 spiki~5 line~6 curva~7 stl_e~8
#>   <fct>      <dbl>      <dbl>      <dbl>      <dbl>      <dbl>      <dbl>      <dbl>      <dbl>
#> 1 Temperature 0.317      0.952          7          1 2.78e-6      29.9      12.4 -0.0286
#> 2 Precipitation 0.127      0.472          8          1 1.57e+0     112.      42.2 -0.146
#> # ... 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      0.196
#> 2 Precipitation     0.926
```

## 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 Davos - 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 |
|-------|-------------|------|------------|------------|------------|----------|----------|
| Davos | Temperature | 1864 | NA         | 1.0        | 9.0        | 2.5      | 1.2      |
| Davos | Temperature | 1865 | -7.0       | 1.6        | 10.0       | 4.1      | 2.2      |
| Davos | Temperature | 1866 | -4.2       | 0.9        | 9.5        | 3.2      | 2.5      |
| Davos | Temperature | 1867 | -3.6       | 2.3        | 10.0       | 2.5      | 2.4      |
| Davos | Temperature | 1868 | -6.7       | 1.6        | 10.4       | 3.0      | 2.7      |
| Davos | Temperature | 1869 | -3.2       | 1.8        | 9.6        | 2.4      | 2.3      |
| Davos | Temperature | 1870 | -6.2       | 1.0        | 9.9        | 2.3      | 1.5      |
| Davos | Temperature | 1871 | -7.5       | 1.8        | 9.0        | 2.5      | 1.2      |
| Davos | Temperature | 1872 | -7.1       | 1.7        | 9.6        | 4.3      | 2.8      |
| Davos | Temperature | 1873 | -4.7       | 1.3        | 11.1       | 3.4      | 2.4      |
| Davos | Temperature | 2013 | -5.7       | 2.5        | 12.4       | 4.5      | 3.6      |
| Davos | Temperature | 2014 | -2.2       | 3.8        | 11.2       | 6.4      | 4.8      |
| Davos | Temperature | 2015 | -3.9       | 3.5        | 14.0       | 4.8      | 4.8      |
| Davos | Temperature | 2016 | -1.8       | 2.7        | 12.1       | 5.0      | 4.4      |
| Davos | Temperature | 2017 | -3.3       | 4.3        | 13.5       | 3.5      | 4.2      |
| Davos | Temperature | 2018 | -5.1       | 4.5        | 13.5       | 6.5      | 5.0      |
| Davos | Temperature | 2019 | -4.2       | 2.4        | 14.0       | 5.5      | 4.5      |
| Davos | Temperature | 2020 | -2.0       | 4.4        | 12.2       | 5.3      | 4.9      |
| Davos | Temperature | 2021 | -3.8       | 1.4        | 12.4       | 4.7      | 3.7      |
| Davos | Temperature | 2022 | -3.5       | 4.3        | 14.2       | 6.0      | 5.3      |

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

| City  | Measure       | Year | Winter_avg | Spring_avg | Summer_avg | Fall_avg | Year_avg |
|-------|---------------|------|------------|------------|------------|----------|----------|
| Davos | Precipitation | 1864 | NA         | NA         | NA         | NA       | NA       |
| Davos | Precipitation | 1865 | NA         | NA         | NA         | NA       | NA       |
| Davos | Precipitation | 1866 | NA         | NA         | NA         | NA       | NA       |
| Davos | Precipitation | 1867 | 102.5      | 91.9       | 64.4       | 71.6     | 85.1     |
| Davos | Precipitation | 1868 | 64.0       | 104.2      | 123.1      | 76.8     | 87.4     |
| Davos | Precipitation | 1869 | 53.5       | 61.5       | 113.6      | 75.9     | 72.1     |
| Davos | Precipitation | 1870 | 27.7       | 38.8       | 97.1       | 71.1     | 60.1     |

| City  | Measure       | Year | Winter_avg | Spring_avg | Summer_avg | Fall_avg | Year_avg |
|-------|---------------|------|------------|------------|------------|----------|----------|
| Davos | Precipitation | 1871 | 44.1       | 62.1       | 138.9      | 29.8     | NA       |
| Davos | Precipitation | 1872 | NA         | NA         | NA         | NA       | NA       |
| Davos | Precipitation | 1873 | NA         | NA         | NA         | 93.4     | NA       |
| Davos | Precipitation | 2013 | 63.0       | 70.5       | 88.4       | 113.2    | 77.0     |
| Davos | Precipitation | 2014 | 49.9       | 39.9       | 164.3      | 79.4     | 85.1     |
| Davos | Precipitation | 2015 | 53.3       | 86.0       | 87.1       | 72.9     | 72.2     |
| Davos | Precipitation | 2016 | 64.6       | 85.3       | 167.6      | 70.7     | 96.1     |
| Davos | Precipitation | 2017 | 44.3       | 73.5       | 151.3      | 100.8    | 99.4     |
| Davos | Precipitation | 2018 | 125.5      | 49.1       | 89.3       | 69.1     | 90.2     |
| Davos | Precipitation | 2019 | 125.9      | 100.5      | 127.7      | 112.0    | 109.5    |
| Davos | Precipitation | 2020 | 73.7       | 57.8       | 138.3      | 78.6     | 86.0     |
| Davos | Precipitation | 2021 | 86.1       | 57.3       | 129.4      | 54.1     | 79.7     |
| Davos | Precipitation | 2022 | 57.6       | 35.4       | 103.2      | 85.1     | 69.3     |

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

| City  | Month | Temperature | Precipitation |
|-------|-------|-------------|---------------|
| Davos | Jan   | -6.1        | 65.8          |
| Davos | Feb   | -5.0        | 58.0          |
| Davos | Mar   | -2.1        | 56.2          |
| Davos | Apr   | 1.6         | 56.1          |
| Davos | May   | 6.1         | 80.8          |
| Davos | Jun   | 9.4         | 119.4         |
| Davos | Jul   | 11.3        | 134.2         |
| Davos | Aug   | 10.8        | 134.1         |
| Davos | Sep   | 8.0         | 88.8          |
| Davos | Oct   | 3.9         | 64.7          |
| Davos | Nov   | -1.1        | 61.6          |
| Davos | Dec   | -4.9        | 63.4          |

## 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>