

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

Wolfgang Vollmer

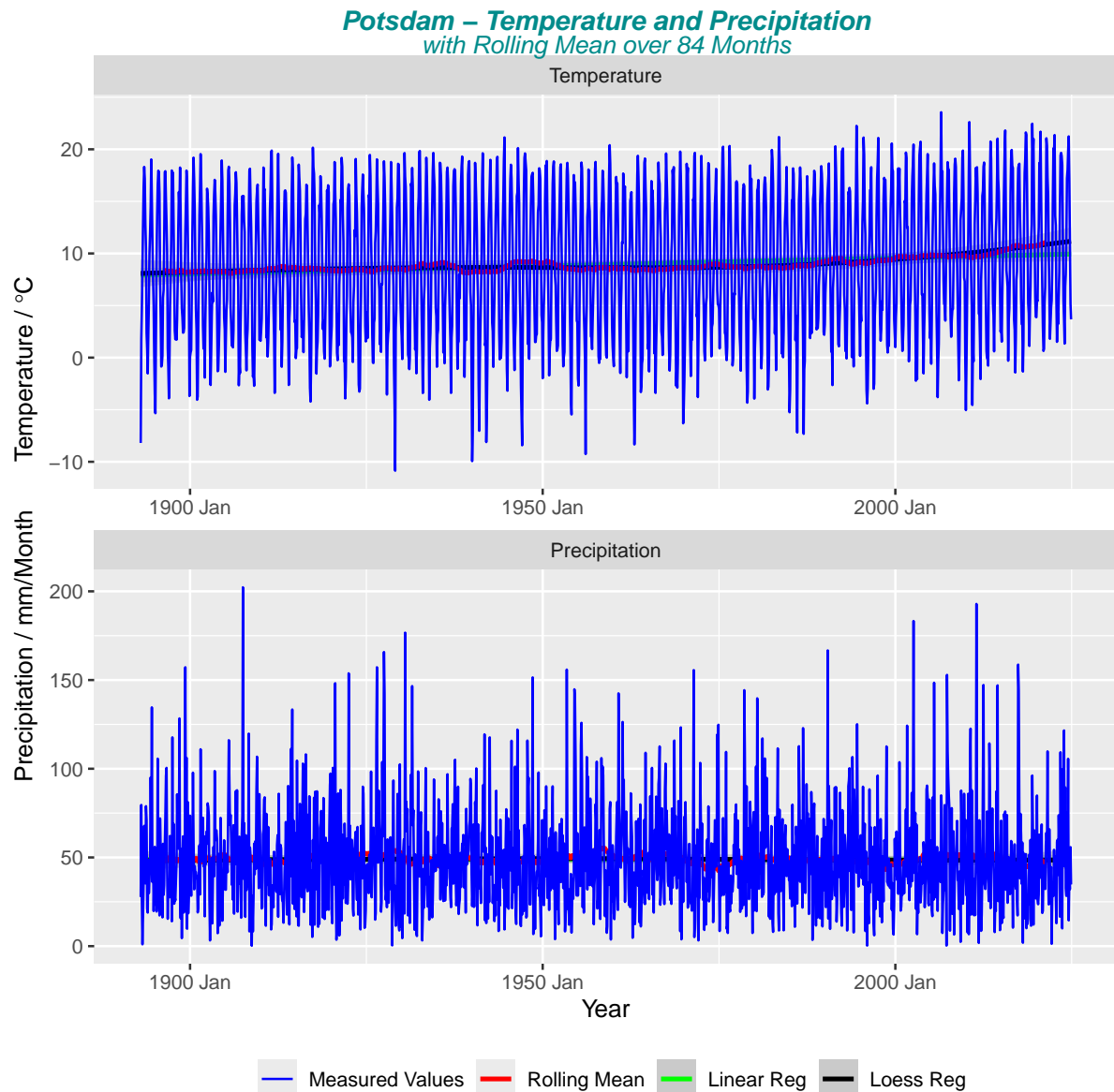
2025-01-03

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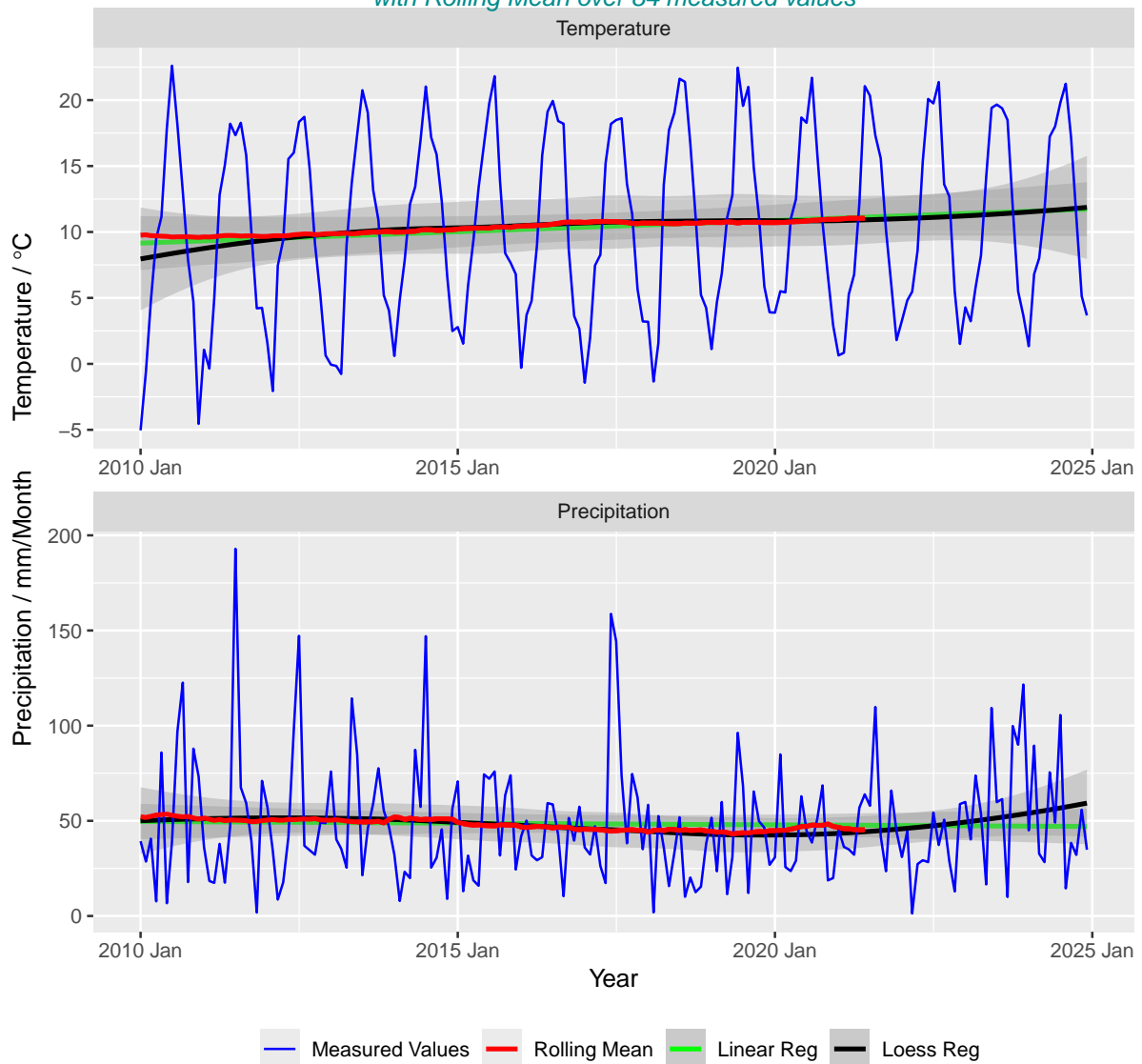
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# 1 Potsdam - Visualization of Temperature and Precipitation Data 1893 - 2024

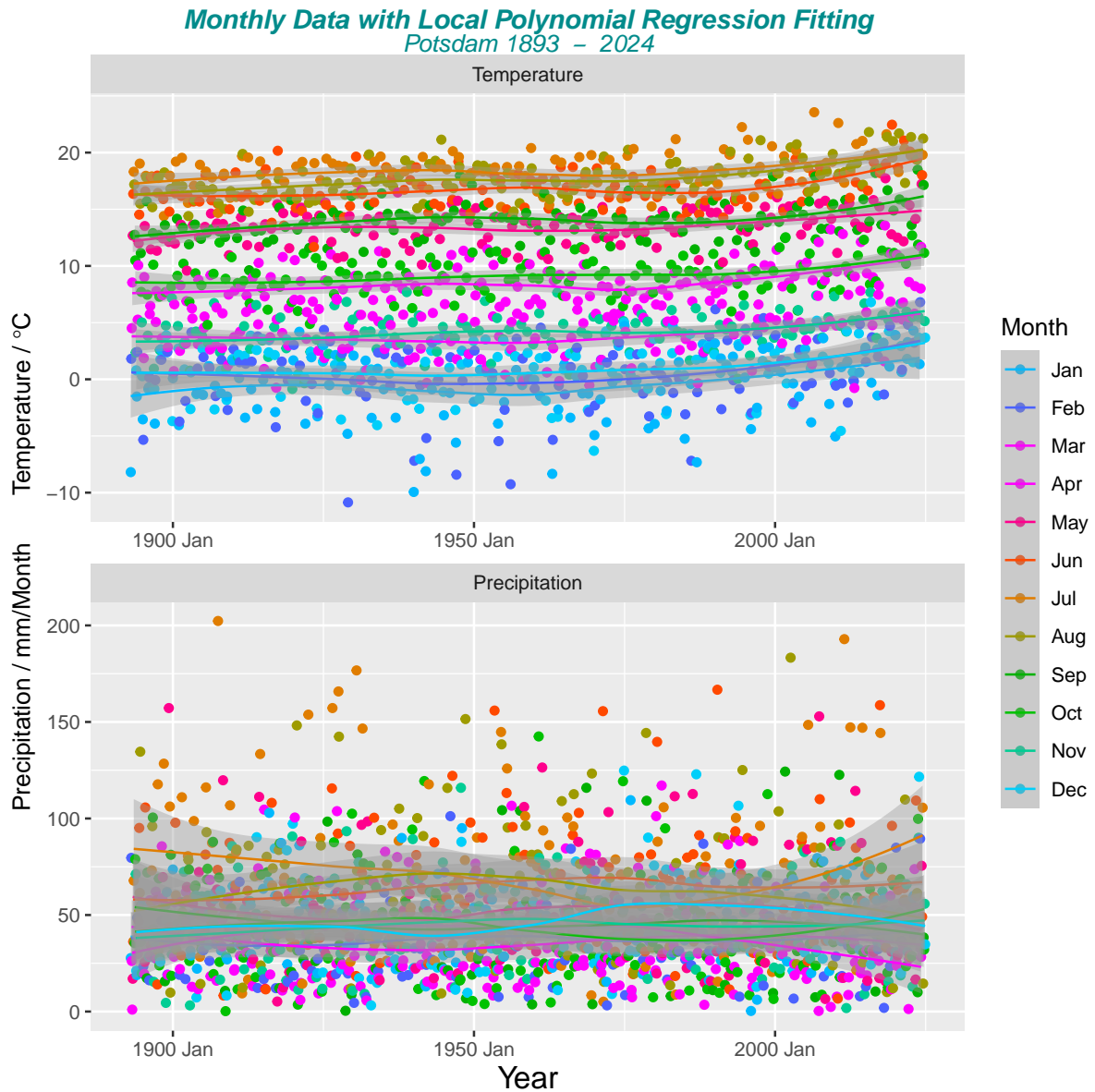
## 1.1 Monthly Time Plots with Rolling Mean



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



## 1.2 Yearly plots with monthly breakdown



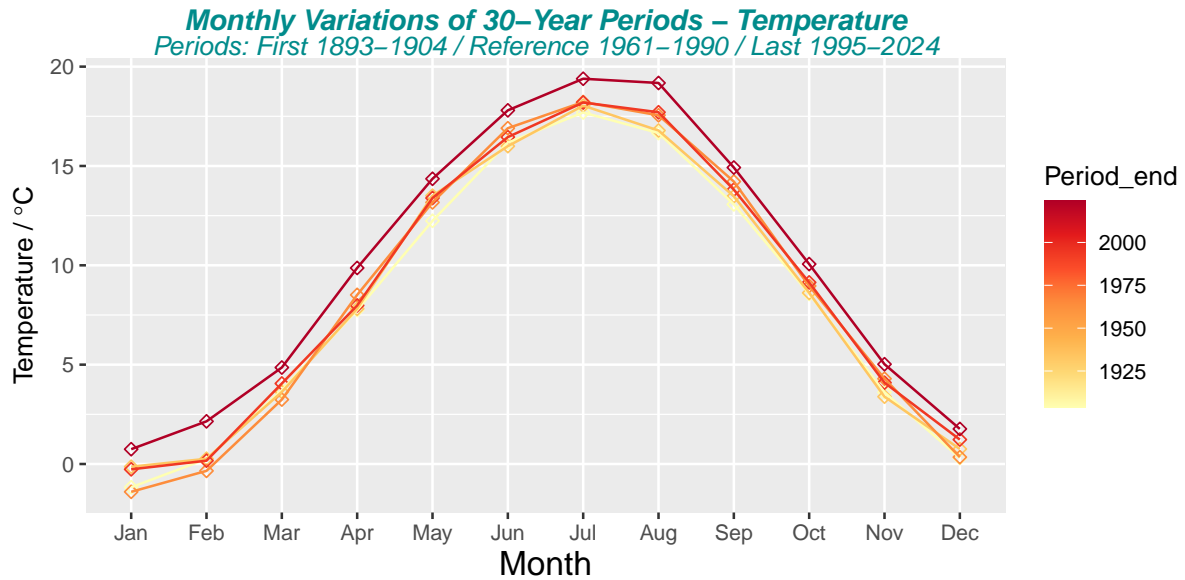
### 1.2.1 30-year period plots with monthly breakdown - Cartesian and Polar Coordinates

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

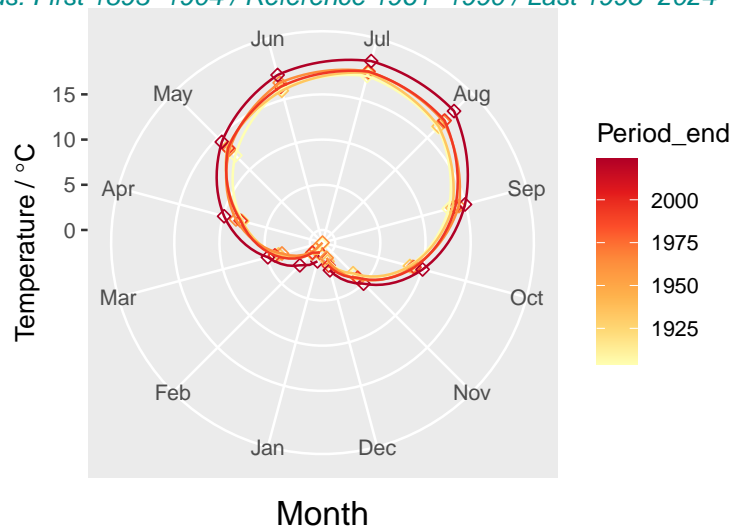
City	Period	Temperature	Monthly Precipitation	Annual Precipitation
Potsdam	1893-1904	8.2	47.5	570.6
Potsdam	1905-1934	8.5	49.2	591.0
Potsdam	1935-1964	8.6	49.1	589.4
Potsdam	1965-1994	8.8	49.4	592.8
Potsdam	1995-2024	10.0	48.0	575.6

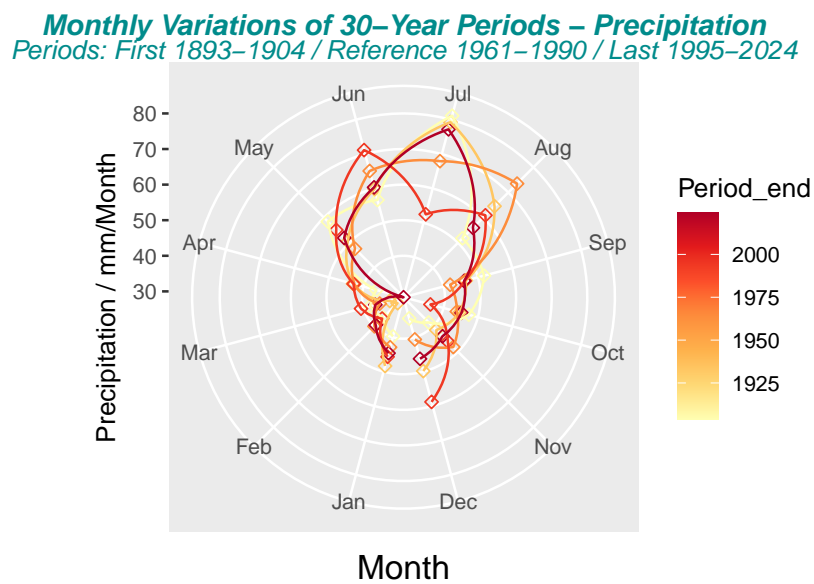
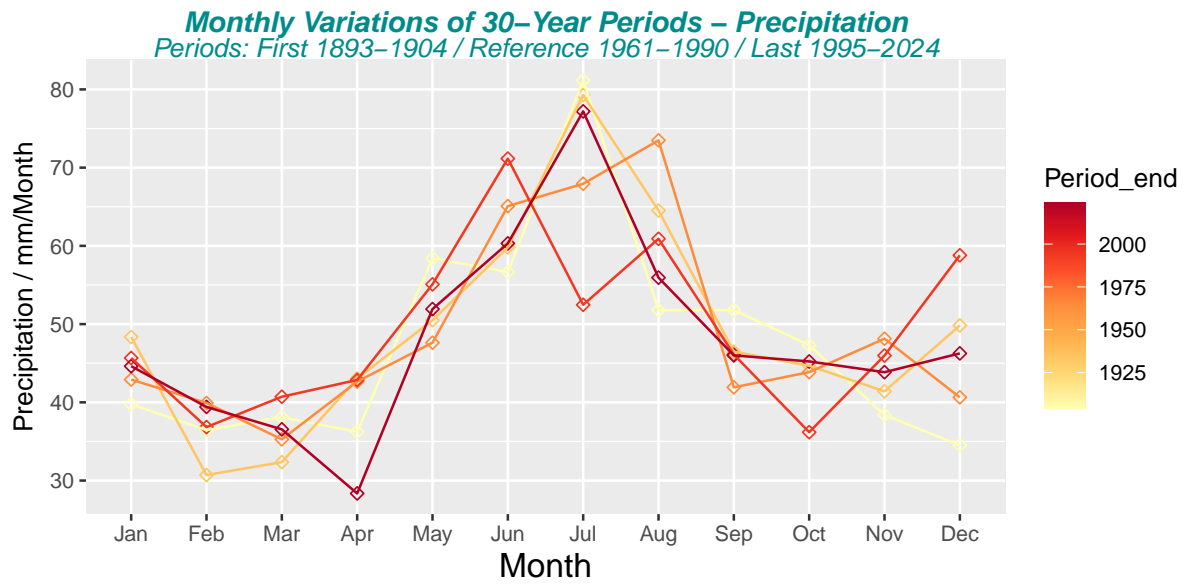
City	Ref_Period	Temperature	Monthly Precipitation	Annual Precipitation
Potsdam	1961-1990	8.7	48.8	585.1

Note: First Period shorter in general (starts with first data year = 1893)

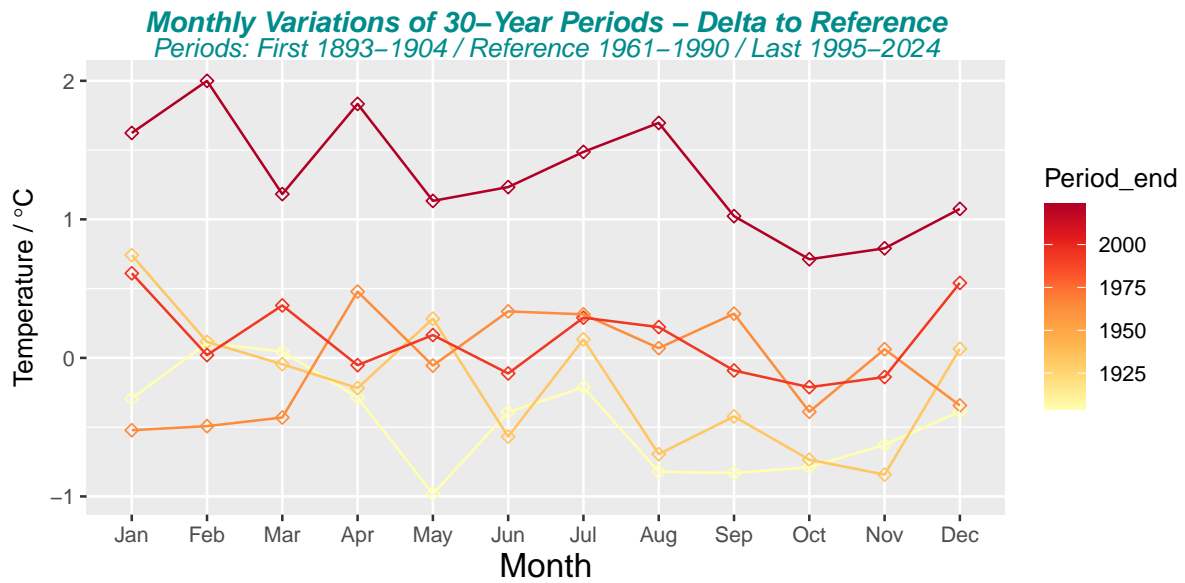


**Monthly Variations of 30-Year Periods – Temperature**  
*Periods: First 1893–1904 / Reference 1961–1990 / Last 1995–2024*

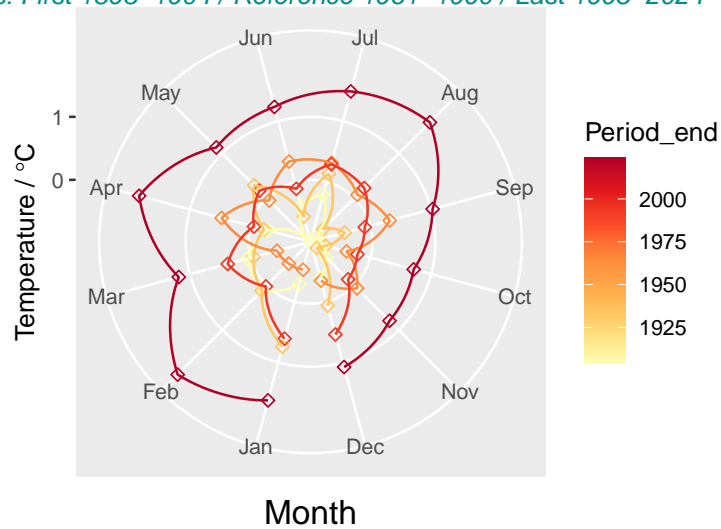


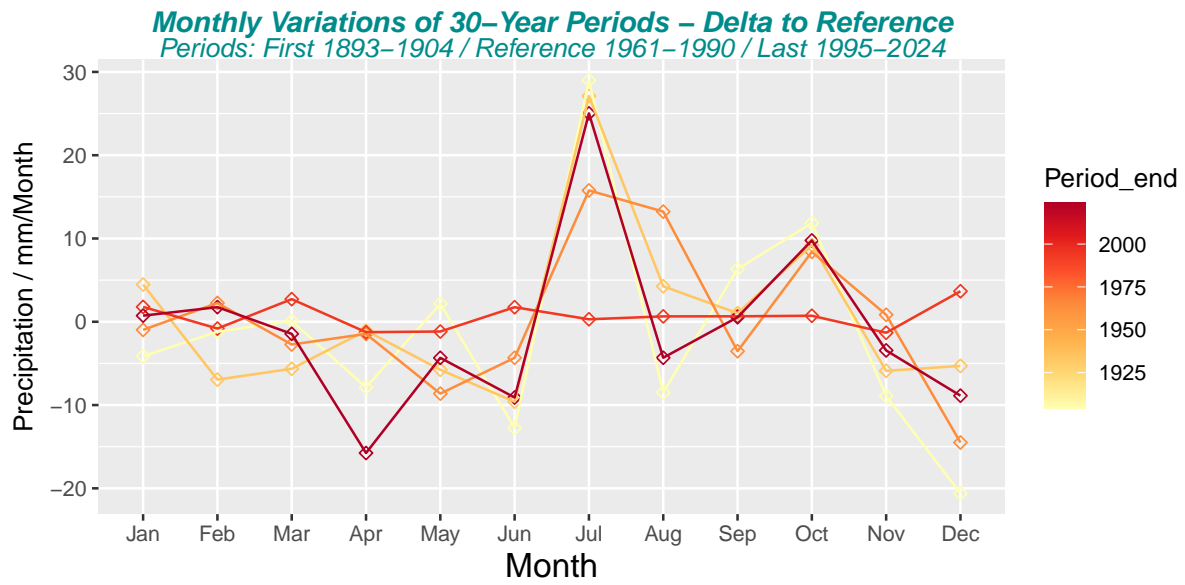


### 1.2.2 Plot Monthly Delta to Reference Period - Cartesian and Polar Coordinates

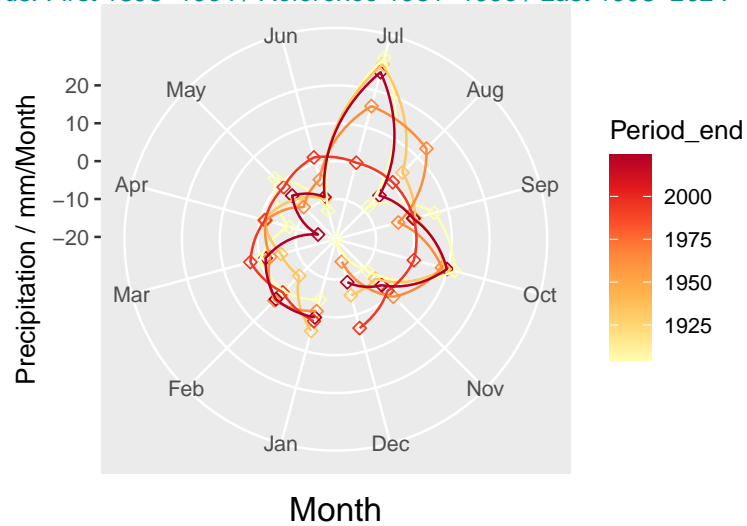


**Monthly Variations of 30-Year Periods – Delta to Reference**  
*Periods: First 1893–1904 / Reference 1961–1990 / Last 1995–2024*



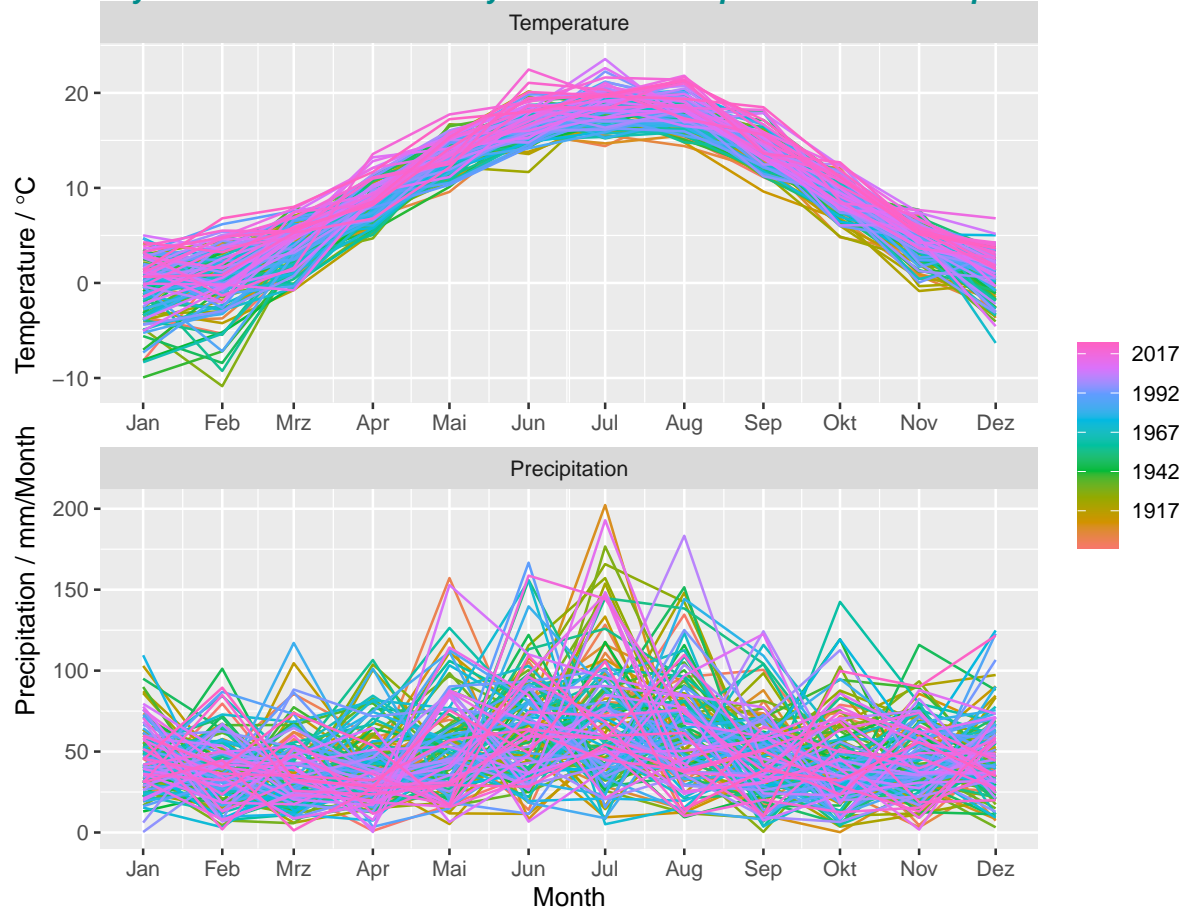


**Monthly Variations of 30-Year Periods – Delta to Reference**  
*Periods: First 1893–1904 / Reference 1961–1990 / Last 1995–2024*

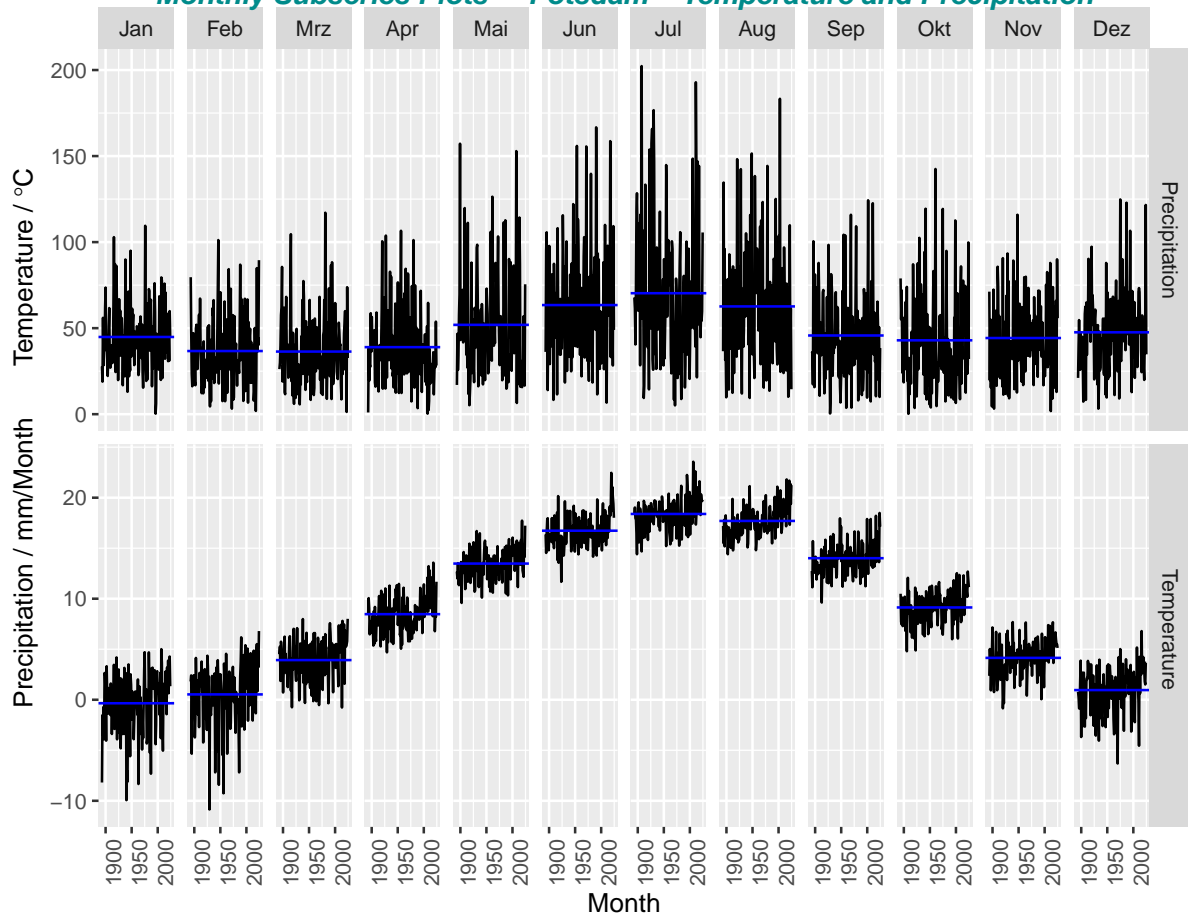




## Yearly Seasonal Plots – Monthly Potsdam – Temperature and Precipitation

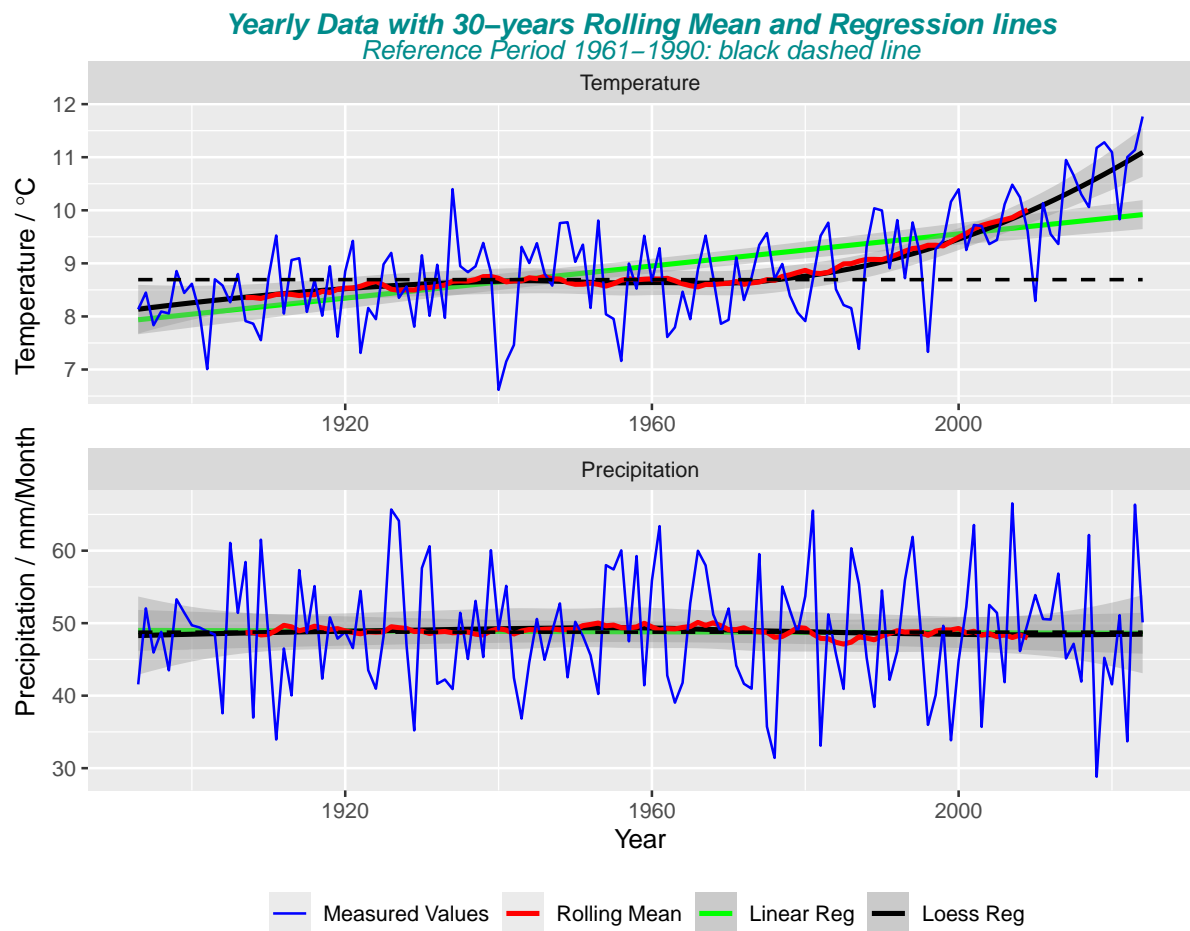


### Monthly Subseries Plots – Potsdam – Temperature and Precipitation

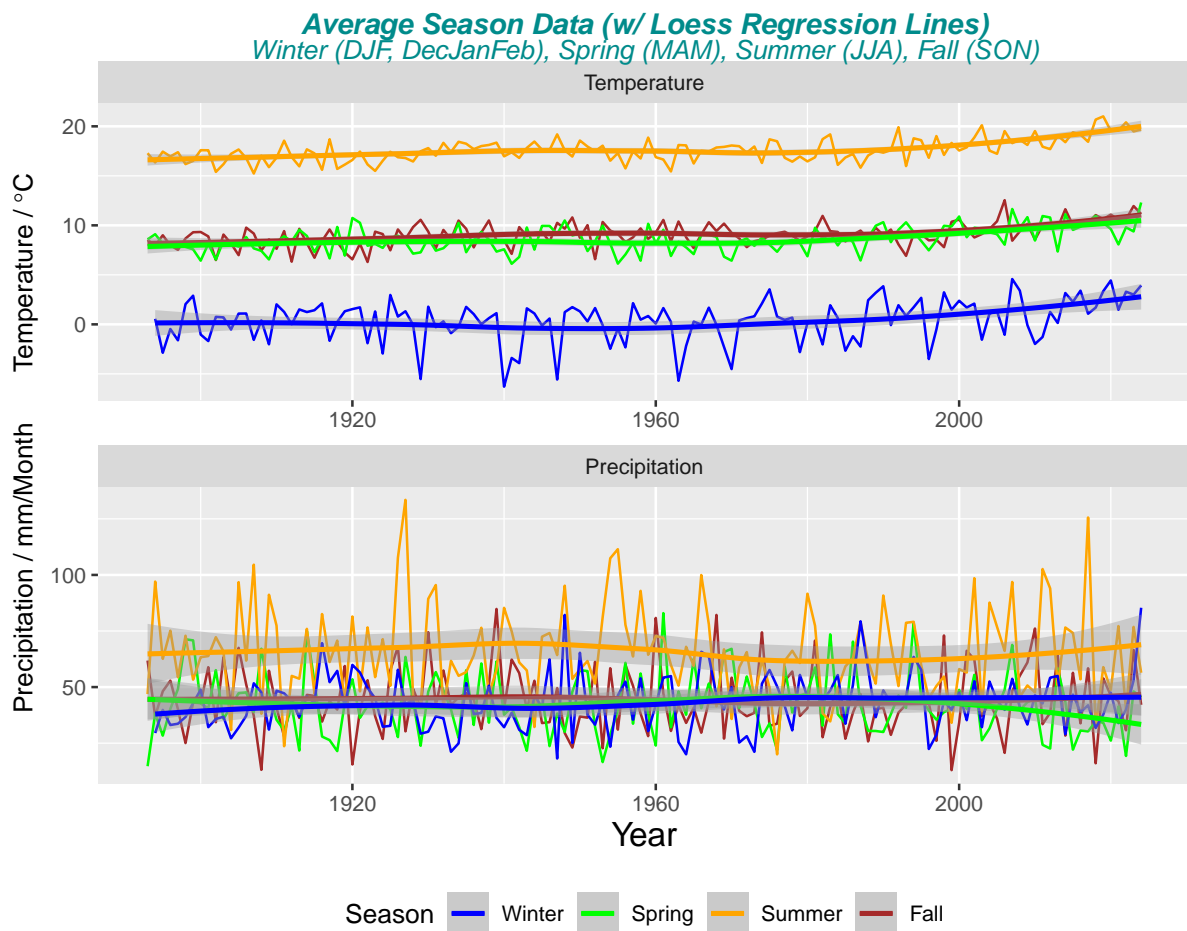


## 1.3 Yearly Potsdam - Temperature and Precipitation

### 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.

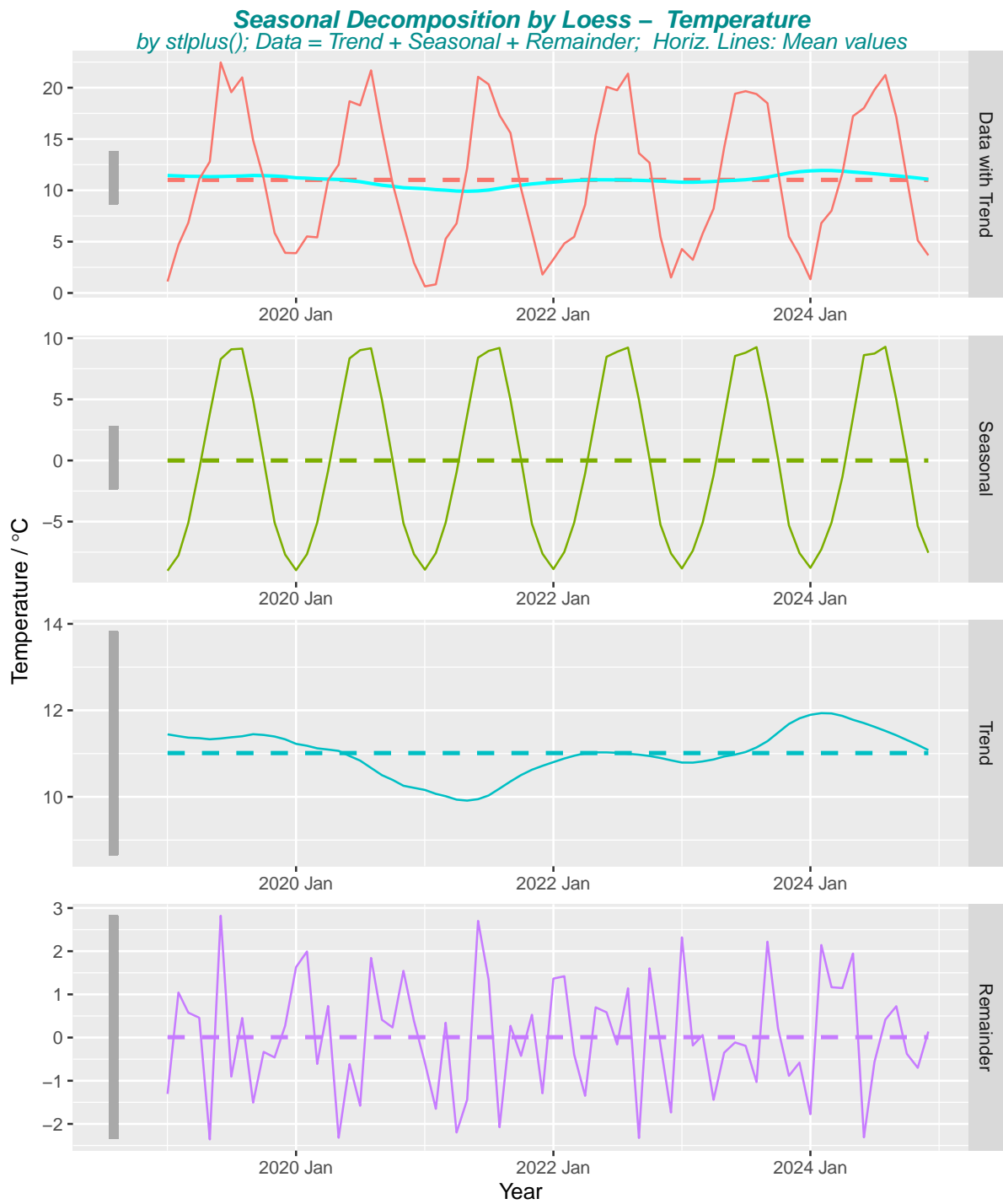
Time series using an

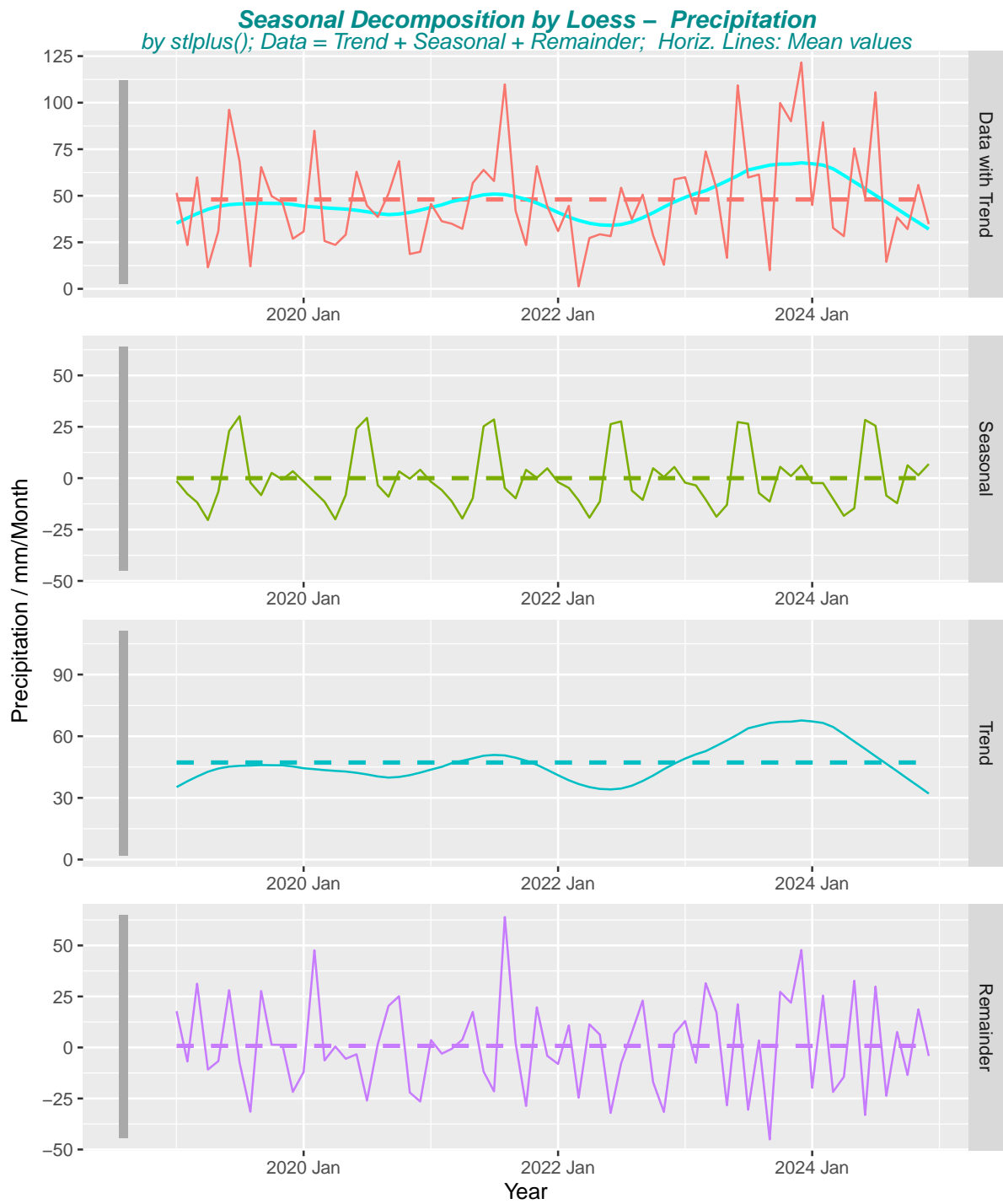
- additive model:  $y_t = T_t + C_t + S_t + \epsilon_t$
- multiplicative model:  $y_t = T_t * C_t * S_t * \epsilon_t$

Trend / Cycle / Seasonal / Noise component

Cyclical components is often grouped into the Trend component

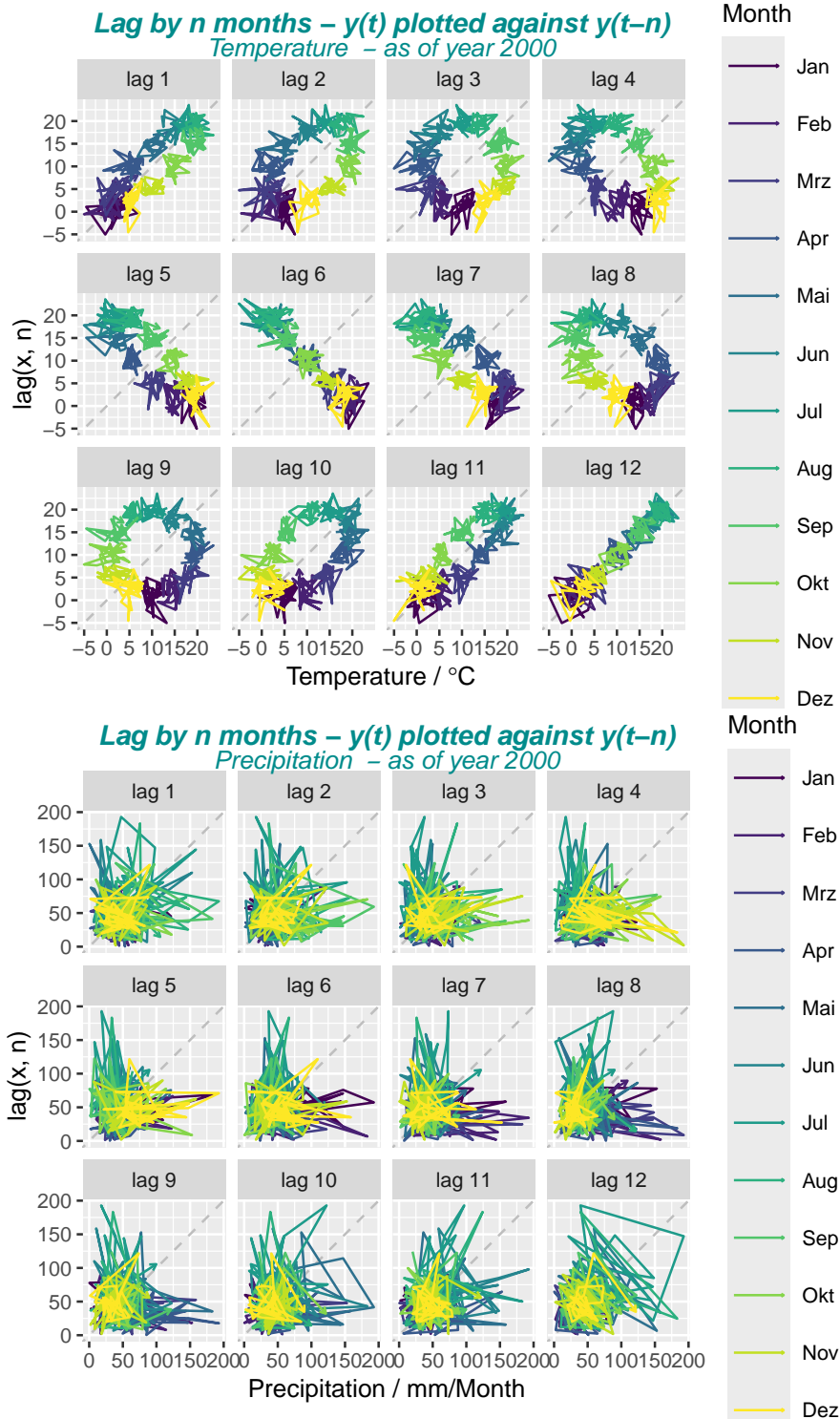
For *Seasonal decomposition of time series by Loess (stlplus)* uses in general an additive error model, it only provides facilities for additive decompositions. It is possible to obtain a multiplicative decomposition by first taking logs of the data.





## 2.2 Periodicities - Season Frequency

### 2.2.1 Lag Plot - Differences



### 2.2.2 ACF / PACF Correlogram

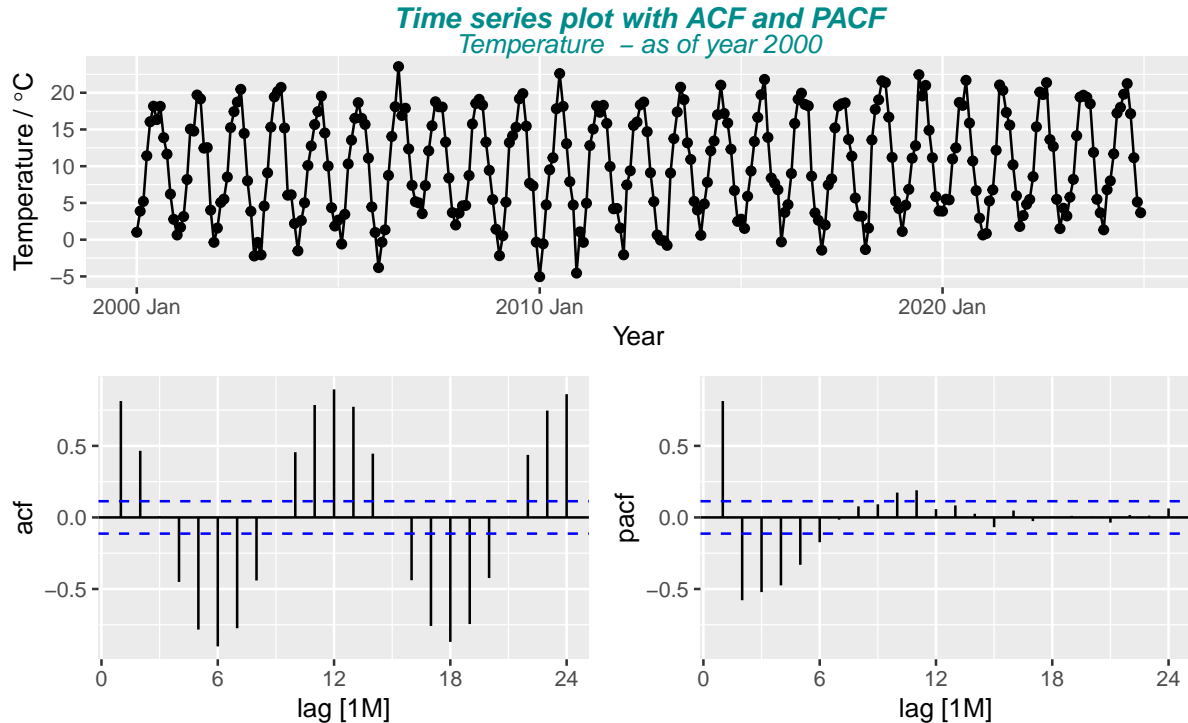
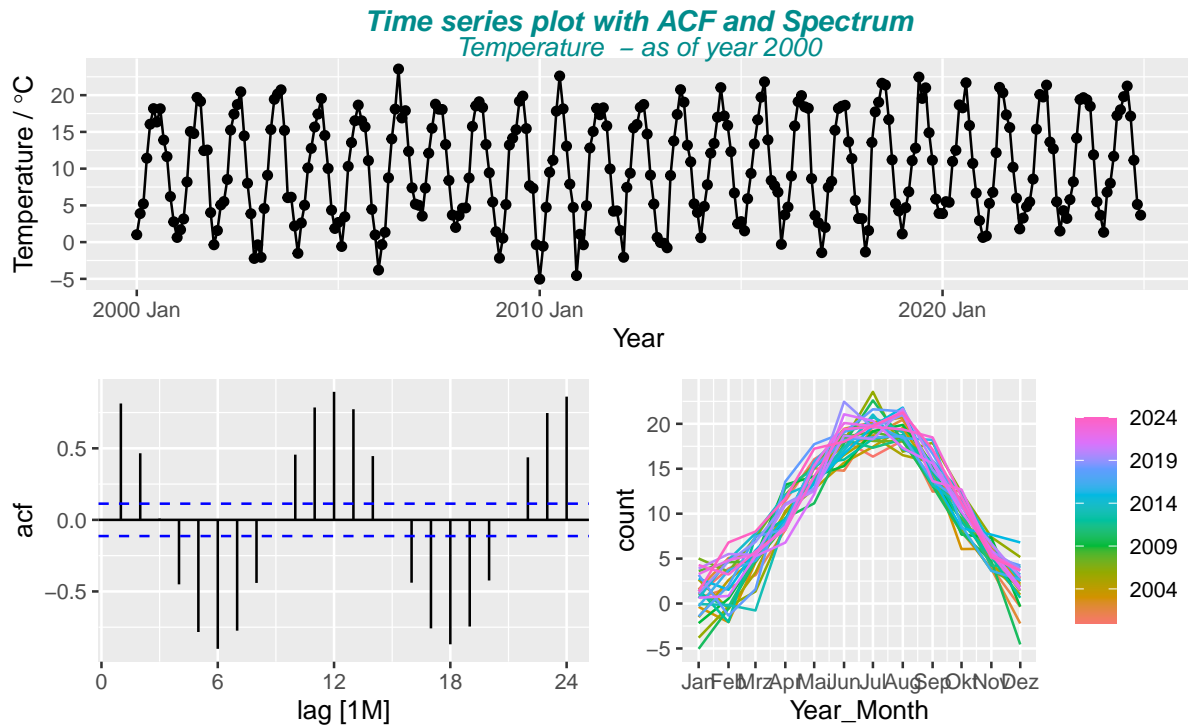
### 2.2.3 Periodogram - Spectral Density Estimation of a Time Series

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 corre-

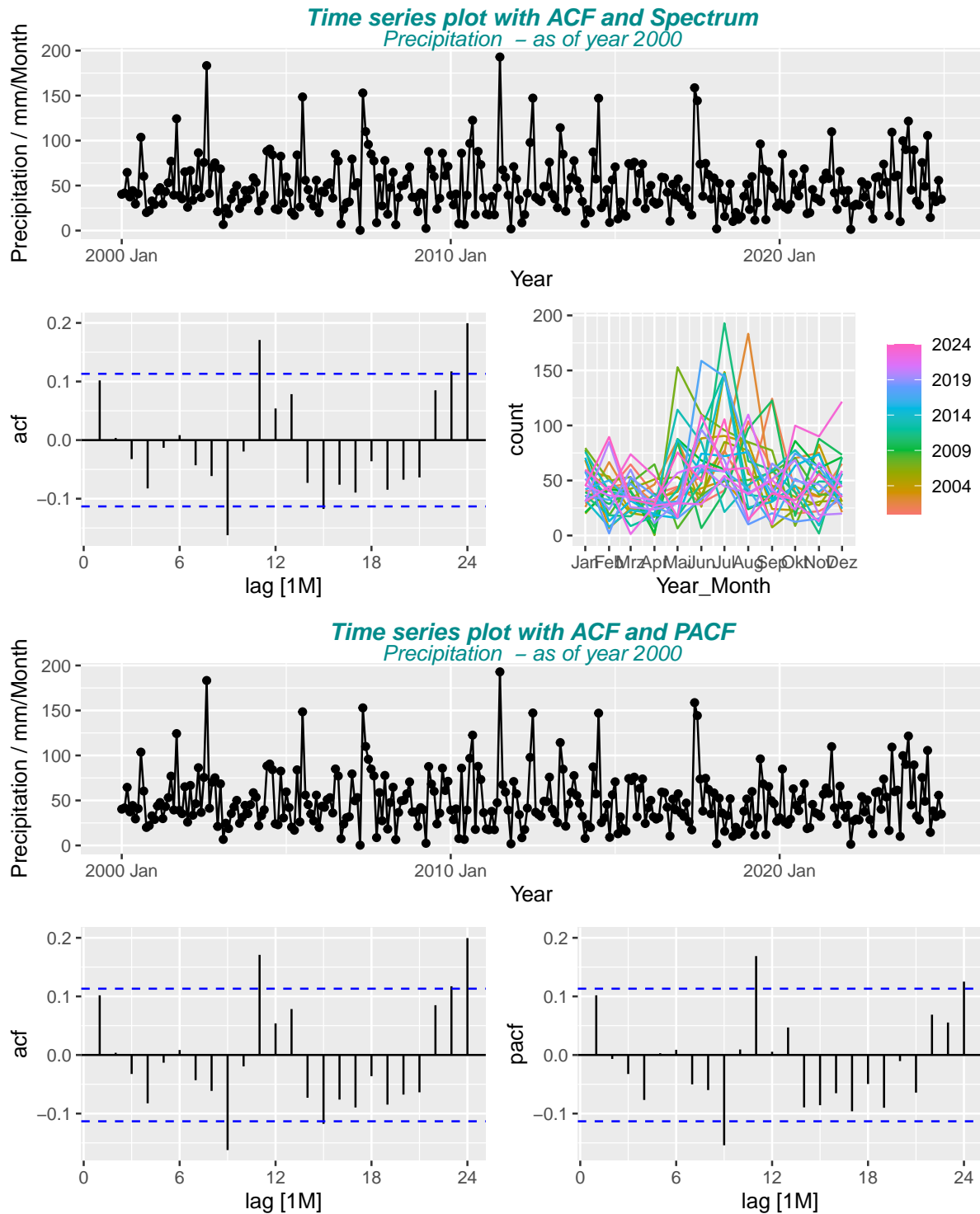
sponding to these periodicities.

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.





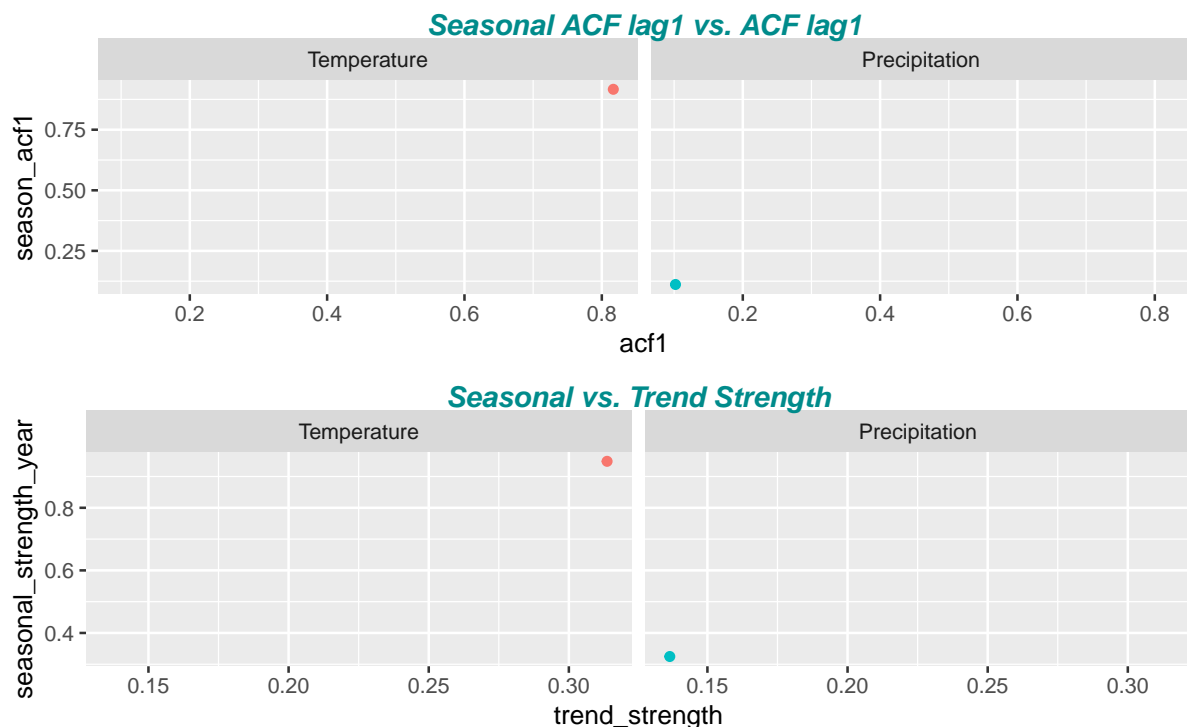


## 2.2.4 Seasonal vs non Seasonal ACF / Strength (Seasonal/Trend)

- 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_acf10 season_acf1
#>   <fct>   <dbl> <dbl>      <dbl>      <dbl>      <dbl>      <dbl>      <dbl>
#> 1 Temper~ 0.817 3.52      0.454      1.77      -0.373      0.255      0.917
#> 2 Precip~ 0.102 0.0288   -0.456      0.217     -0.657      0.472      0.111
#> [1] "Check Trend & Seasonal Strength close to 0 / 1 : weak / strong and compare them"
#> # A tibble: 2 x 10
#>   Measure      trend_strength seasonal_strength_year seasonal_peak_year
#>   <fct>          <dbl>          <dbl>          <dbl>
#> 1 Temperature      0.314          0.949             7
#> 2 Precipitation     0.137          0.325             7
#> # i 6 more variables: seasonal_trough_year <dbl>, spikiness <dbl>,
#> #   linearity <dbl>, curvature <dbl>, stl_e_acf1 <dbl>, stl_e_acf10 <dbl>
```



### 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    0.181
#> 2 Precipitation   0.985
```

## 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 Potsdam - 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
Potsdam	Temperature	1893	NA	8.6	17.3	8.5	8.1
Potsdam	Temperature	1894	0.6	9.1	16.4	8.0	8.4
Potsdam	Temperature	1895	-2.9	8.1	17.4	9.0	7.8
Potsdam	Temperature	1896	-0.5	7.9	17.0	8.0	8.1
Potsdam	Temperature	1897	-1.6	8.1	17.4	7.5	8.1
Potsdam	Temperature	1898	2.0	7.8	16.2	8.7	8.9
Potsdam	Temperature	1899	2.9	7.6	16.5	9.3	8.4
Potsdam	Temperature	1900	-1.0	6.4	17.6	9.3	8.6
Potsdam	Temperature	1901	-1.7	8.1	17.6	8.9	8.1
Potsdam	Temperature	1902	0.8	6.5	15.4	6.5	7.0
Potsdam	Temperature	2015	2.3	9.5	19.4	10.0	10.7
Potsdam	Temperature	2016	3.4	9.9	19.2	10.2	10.3
Potsdam	Temperature	2017	1.1	10.3	18.4	10.2	10.1
Potsdam	Temperature	2018	1.7	11.0	20.7	11.0	11.2
Potsdam	Temperature	2019	3.4	10.2	21.0	10.6	11.3
Potsdam	Temperature	2020	4.4	9.6	19.6	11.1	11.1
Potsdam	Temperature	2021	1.5	8.1	19.6	10.6	9.8
Potsdam	Temperature	2022	3.3	9.8	20.4	10.6	11.0
Potsdam	Temperature	2023	3.0	9.4	19.5	12.0	11.1
Potsdam	Temperature	2024	3.9	12.3	19.7	11.1	11.8

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

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Potsdam	Precipitation	1893	NA	14.7	46.9	61.8	41.6
Potsdam	Precipitation	1894	29.5	38.3	97.0	37.0	52.0
Potsdam	Precipitation	1895	39.8	28.4	62.6	48.1	46.0
Potsdam	Precipitation	1896	33.1	40.3	75.2	52.9	48.8
Potsdam	Precipitation	1897	33.7	49.1	54.4	40.2	43.5
Potsdam	Precipitation	1898	36.7	71.3	72.9	25.0	53.3
Potsdam	Precipitation	1899	42.9	70.8	53.3	43.1	51.5
Potsdam	Precipitation	1900	48.9	42.7	63.3	42.8	49.7
Potsdam	Precipitation	1901	32.1	40.5	63.8	58.9	49.4

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Potsdam	Precipitation	1902	35.8	57.6	72.2	34.3	48.9
Potsdam	Precipitation	2015	46.7	22.1	74.1	56.4	47.2
Potsdam	Precipitation	2016	38.8	30.7	53.5	33.8	41.9
Potsdam	Precipitation	2017	41.9	30.2	125.6	58.4	62.2
Potsdam	Precipitation	2018	31.8	34.7	31.7	16.0	28.8
Potsdam	Precipitation	2019	37.7	34.1	58.9	53.9	45.2
Potsdam	Precipitation	2020	47.5	26.1	48.7	46.2	41.6
Potsdam	Precipitation	2021	33.9	41.4	77.2	43.8	51.1
Potsdam	Precipitation	2022	40.0	19.3	40.0	30.7	33.7
Potsdam	Precipitation	2023	53.0	48.1	76.8	66.6	66.3
Potsdam	Precipitation	2024	85.4	45.5	56.4	42.1	50.1

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

City	Month	Temperature	Precipitation
Potsdam	Jan	-0.3	44.9
Potsdam	Feb	0.5	36.7
Potsdam	Mar	3.9	36.4
Potsdam	Apr	8.5	39.0
Potsdam	May	13.5	51.9
Potsdam	Jun	16.7	63.4
Potsdam	Jul	18.4	70.3
Potsdam	Aug	17.7	62.6
Potsdam	Sep	14.0	45.7
Potsdam	Oct	9.1	42.9
Potsdam	Nov	4.1	44.3
Potsdam	Dec	1.0	47.6

## 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>