Climate Data Visualization -

Atmospheric CO_2 Concentration / Temperature / Precipitation

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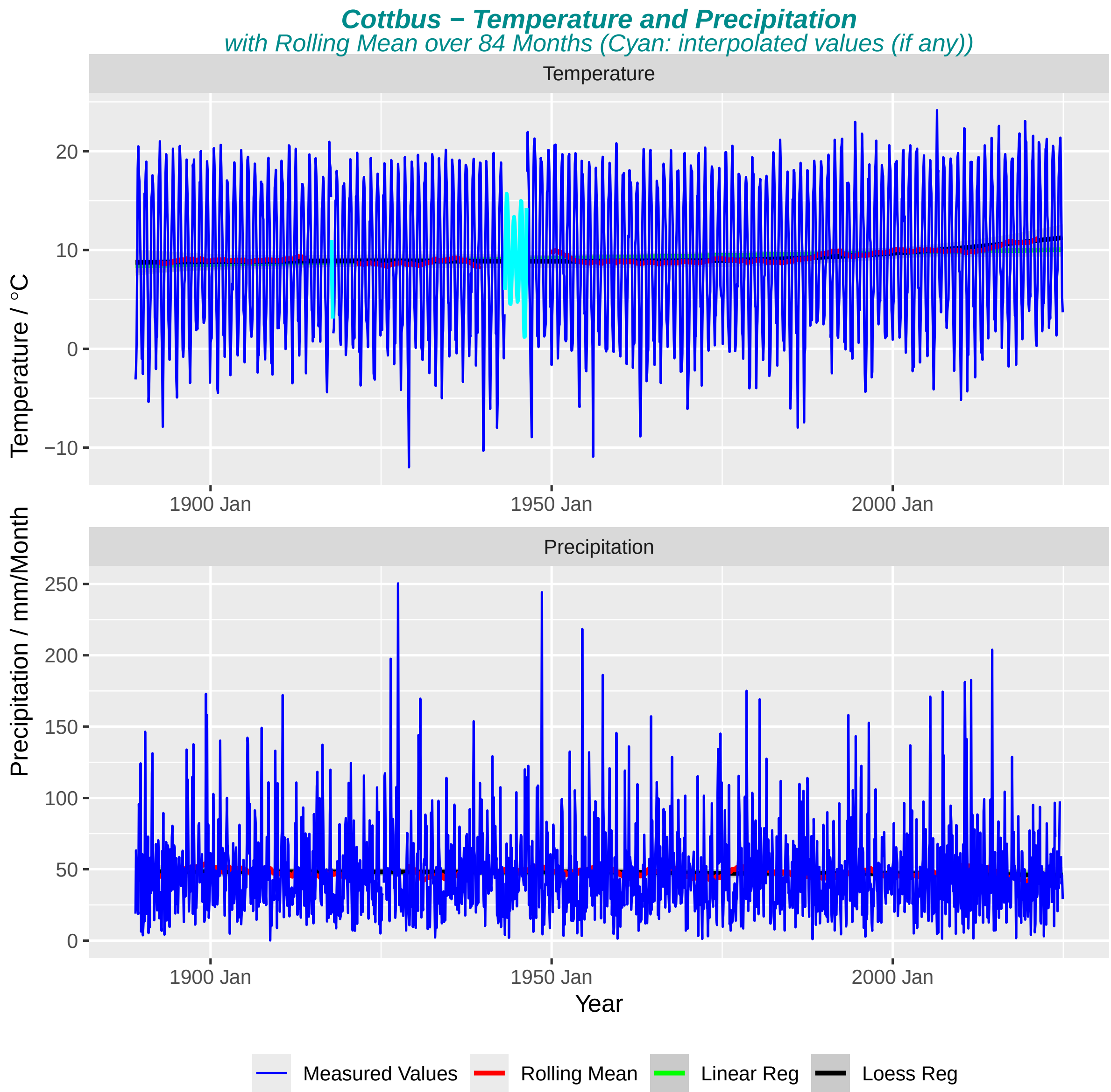
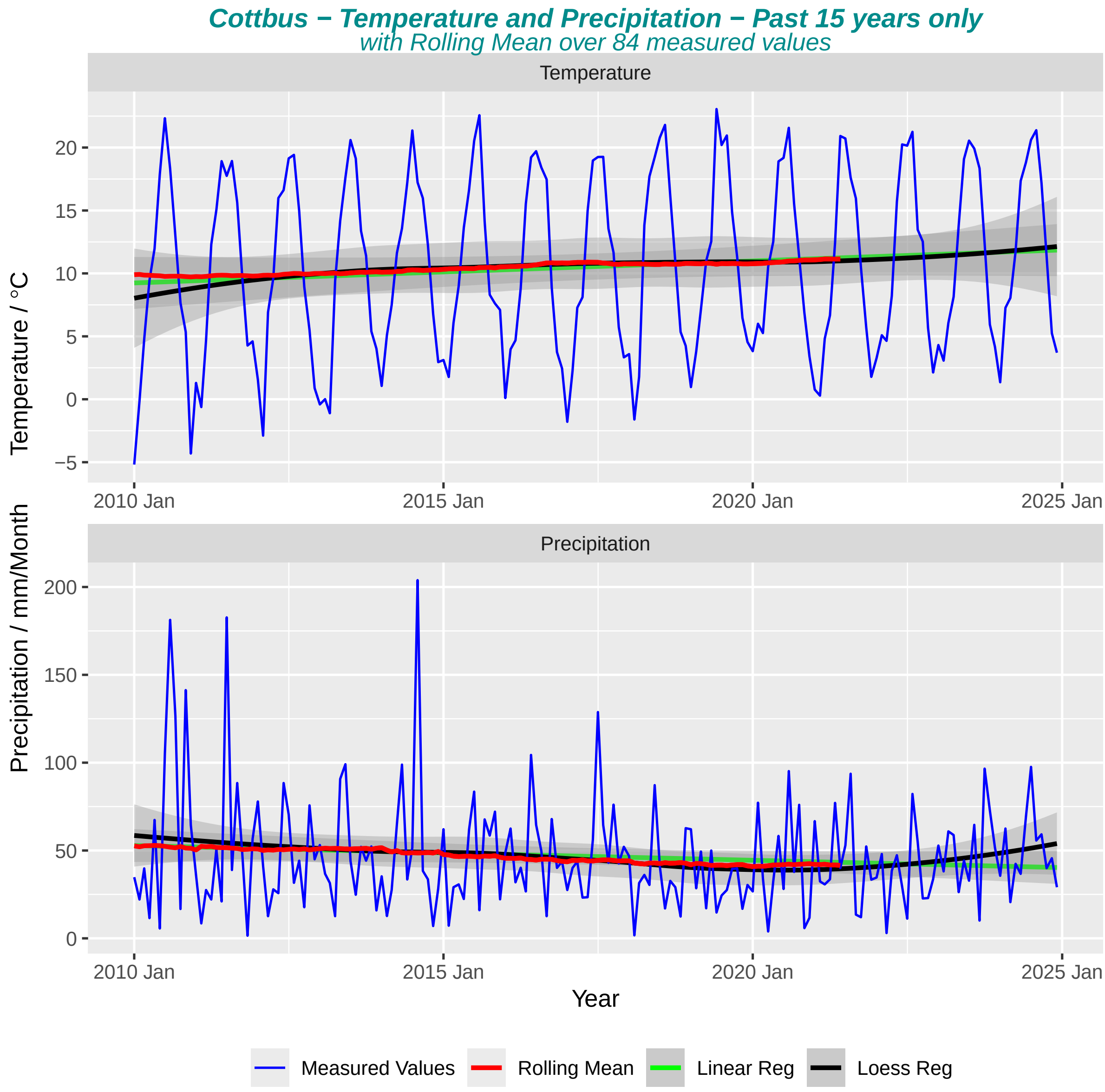
2025-01-03

Contents

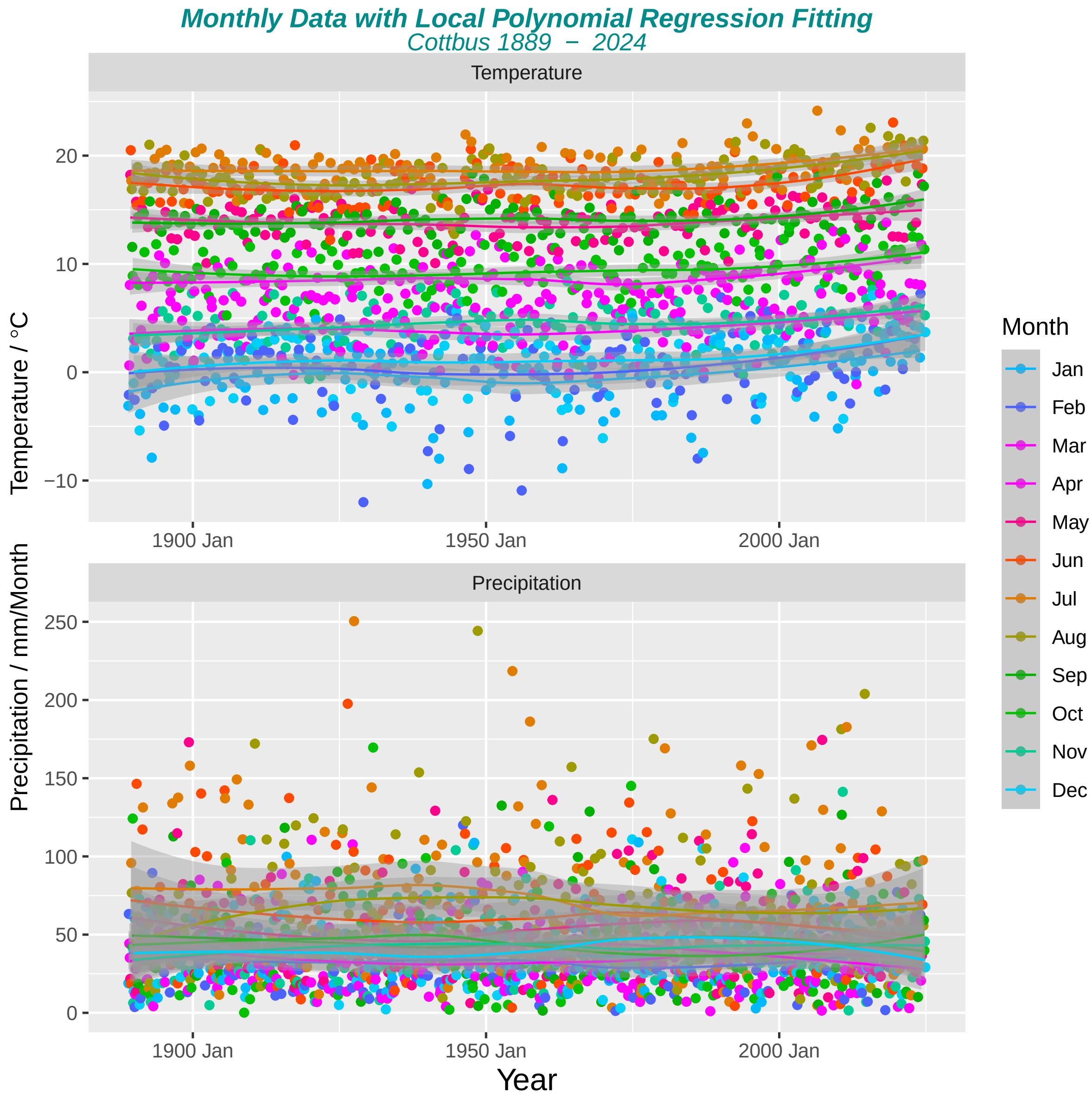
1 Cottbus - Visualization of Temperature and Precipitation Data 1889 - 2024

1.1 Monthly Time Plots with Rolling Mean




Cottbus − Temperature and Precipitation − Past 15 years only
with Rolling Mean over 84 measured values
Temperature
Temperature / °C
20
15
10
5
0
−5
2010 Jan
2015 Jan
2020 Jan
2025 Jan
Precipitation
Precipitation / mm/Month
200
150
100
50
0
Year
Measured Values
Rolling Mean
Linear Reg
Loess Reg

1.2 Yearly plots with monthly breakdown



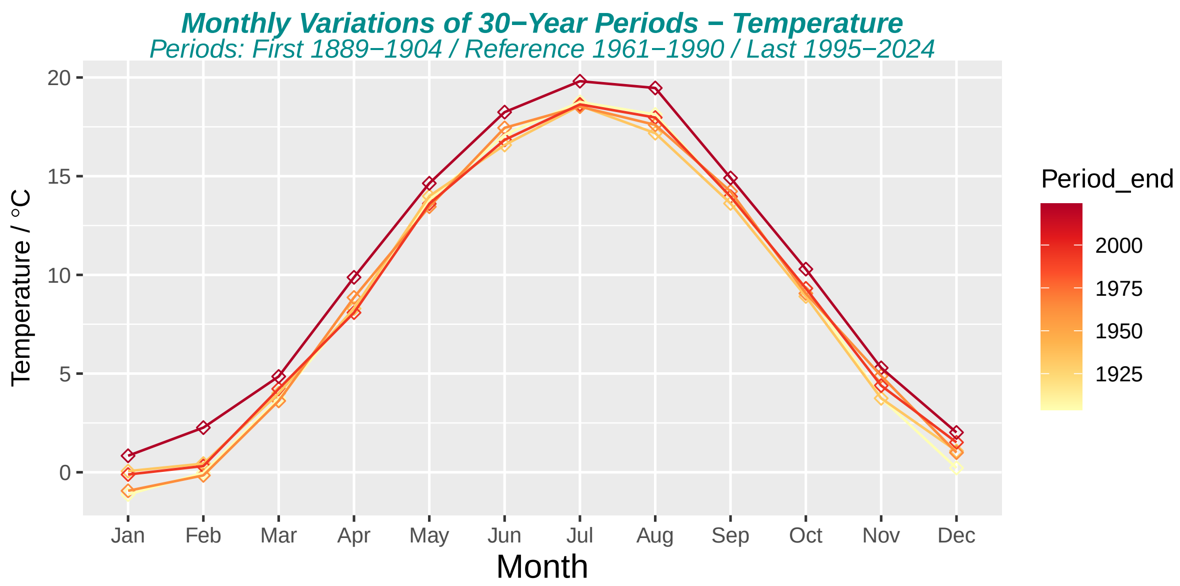
1.2.1 30-year period plots with monthly breakdown - Cartesian and Polar Coordinates

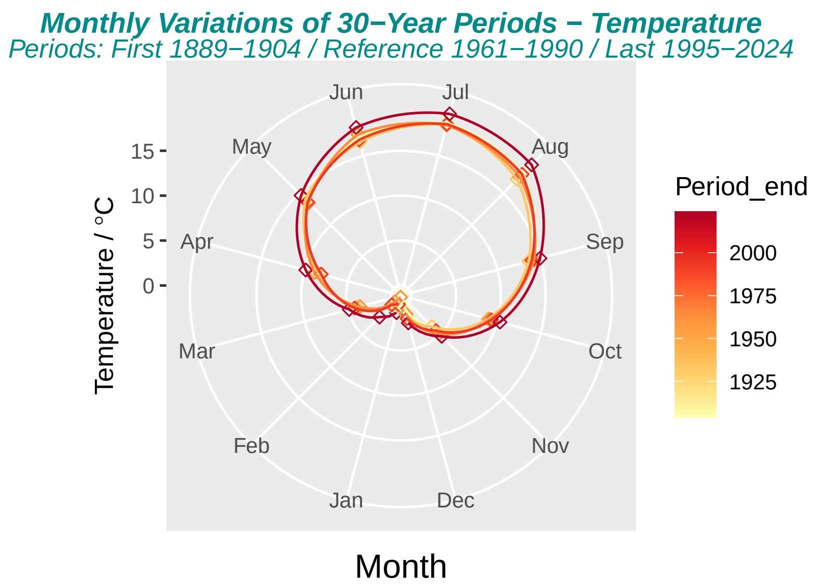
Table 1: 30-years Periods - Average Data (Temperature / degree C and Monthly Precipitation / mm)

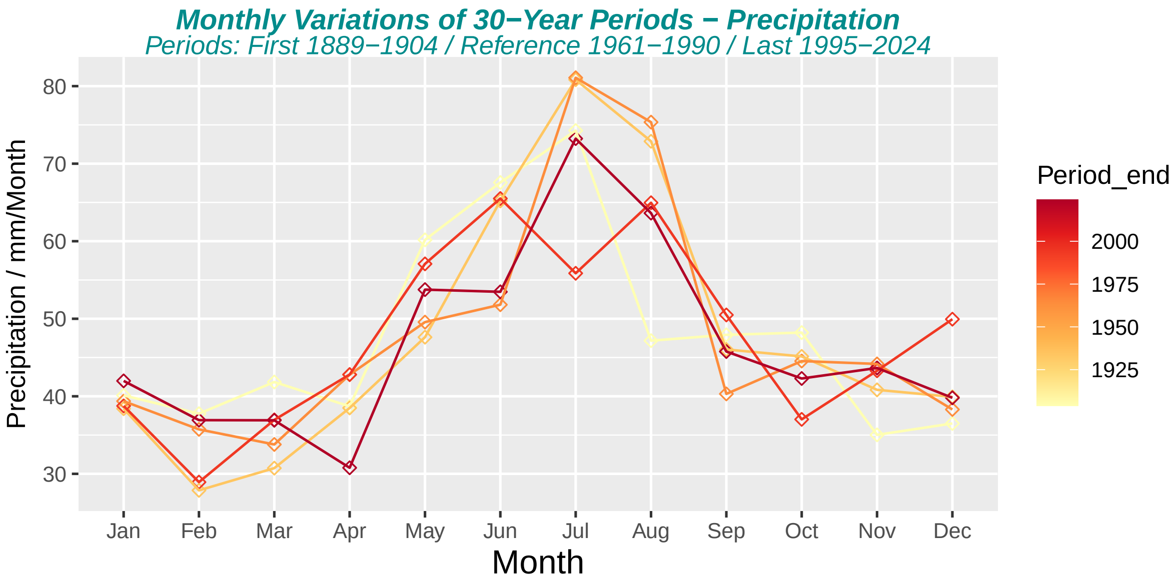
City	Period	Temperature	Monthly Precipitation	Annual Precipitation
Cottbus	1889-1904	8.8	47.9	575.3
Cottbus	1905-1934	8.9	47.8	574.0
Cottbus	1935-1964	9.0	48.1	576.8
Cottbus	1965-1994	9.1	47.6	571.6
Cottbus	1995-2024	10.2	46.9	562.2

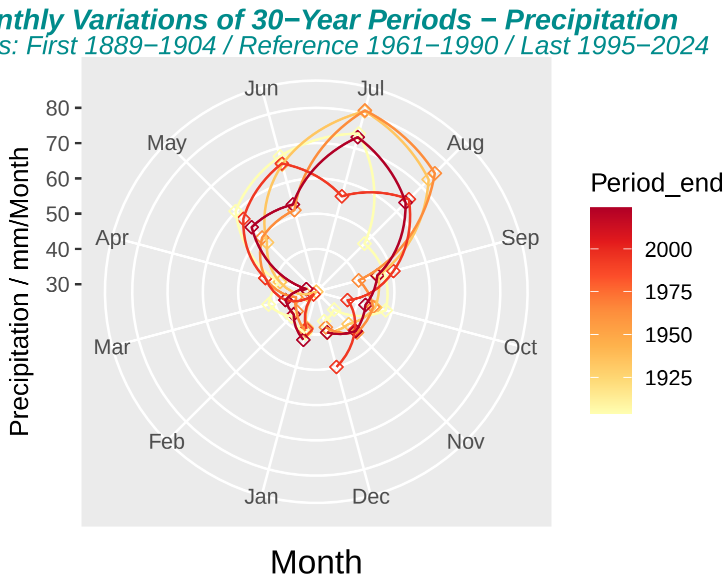
City	Ref_Period	Temperature	Monthly Precipitation	Annual Precipitation
Cottbus	1961-1990	8.9	46.9	562.5

Note: First Period shorter in general (starts with first data year = 1889)

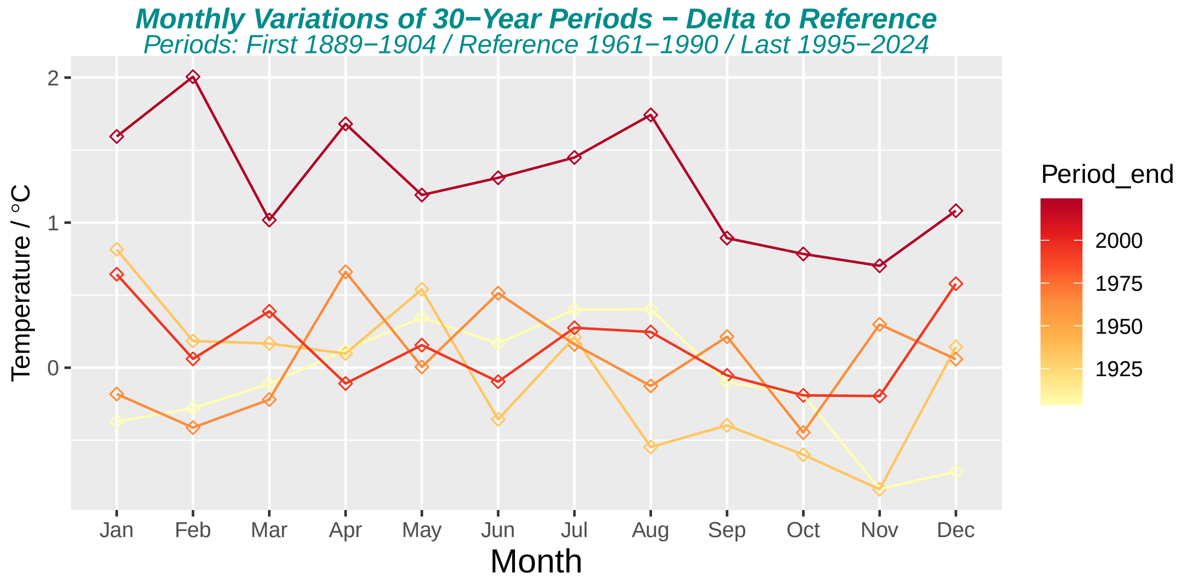


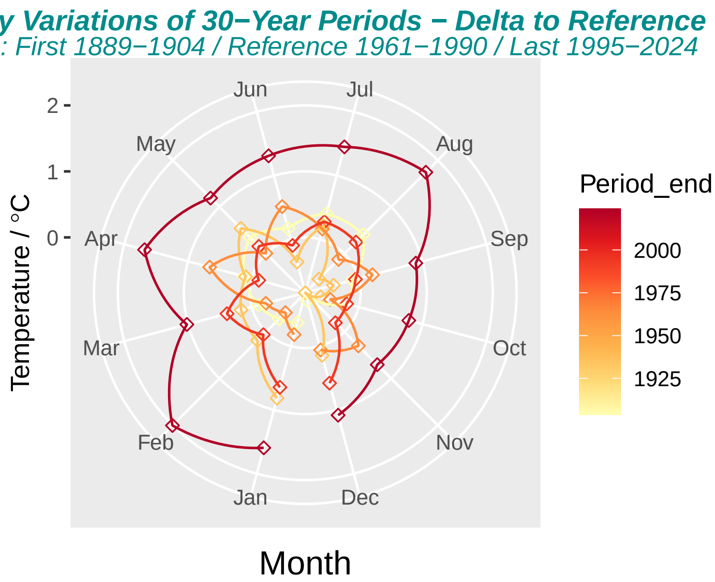


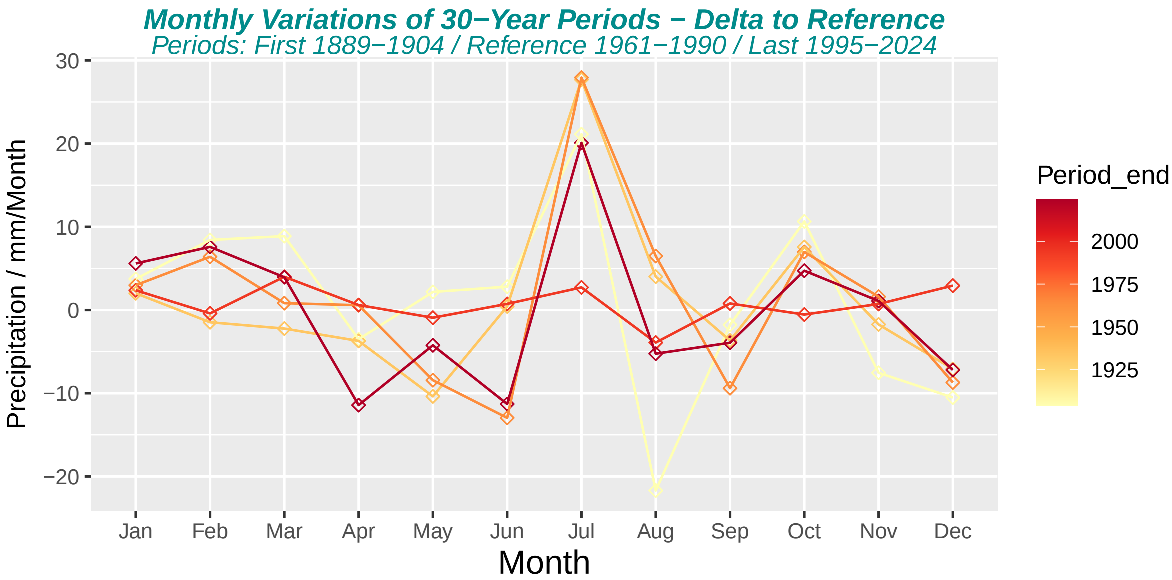

Monthly Variations of 30−Year Periods − Precipitation
Periods: First 1889−1904 / Reference 1961−1990 / Last 1995−2024
Precipitation / mm/Month
80
70
60
50
40
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2000
1975
1950
1925


Monthly Variations of 30−Year Periods − Precipitation
Periods: First 1889−1904 / Reference 1961−1990 / Last 1995−2024
Precipitation / mm/Month
80
70
60
50
40
30
Jun
Jul
May
Aug
Apr
Sep
Mar
Oct
Feb
Nov
Jan
Dec
Month
Period_end
2000
1975
1950
1925

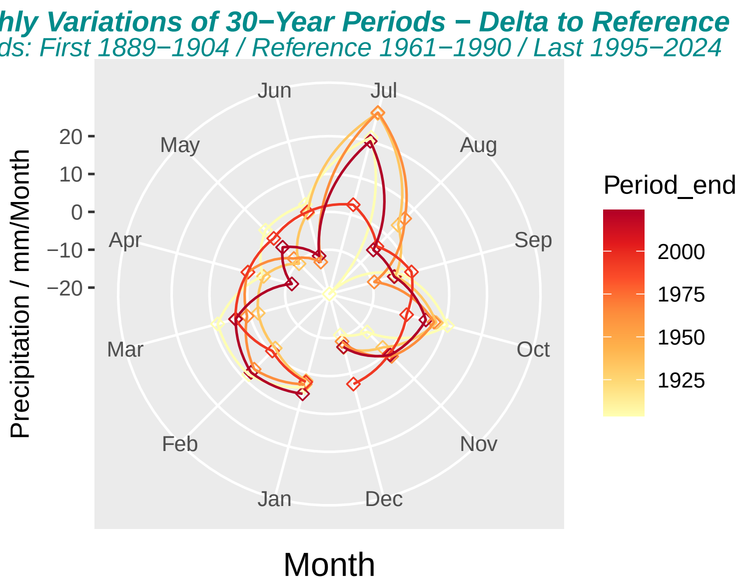
1.2.2 Plot Monthly Delta to Reference Period - Cartesian and Polar Coordinates



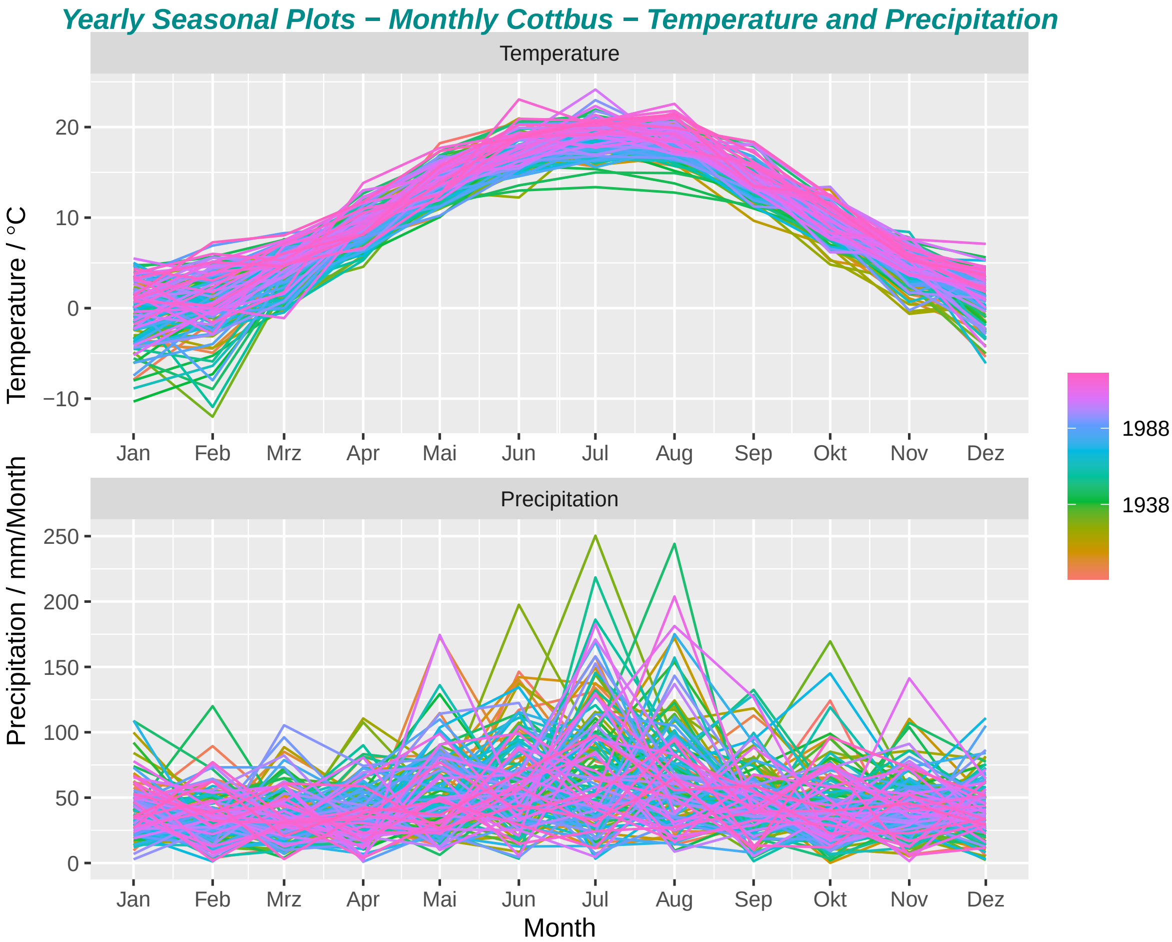


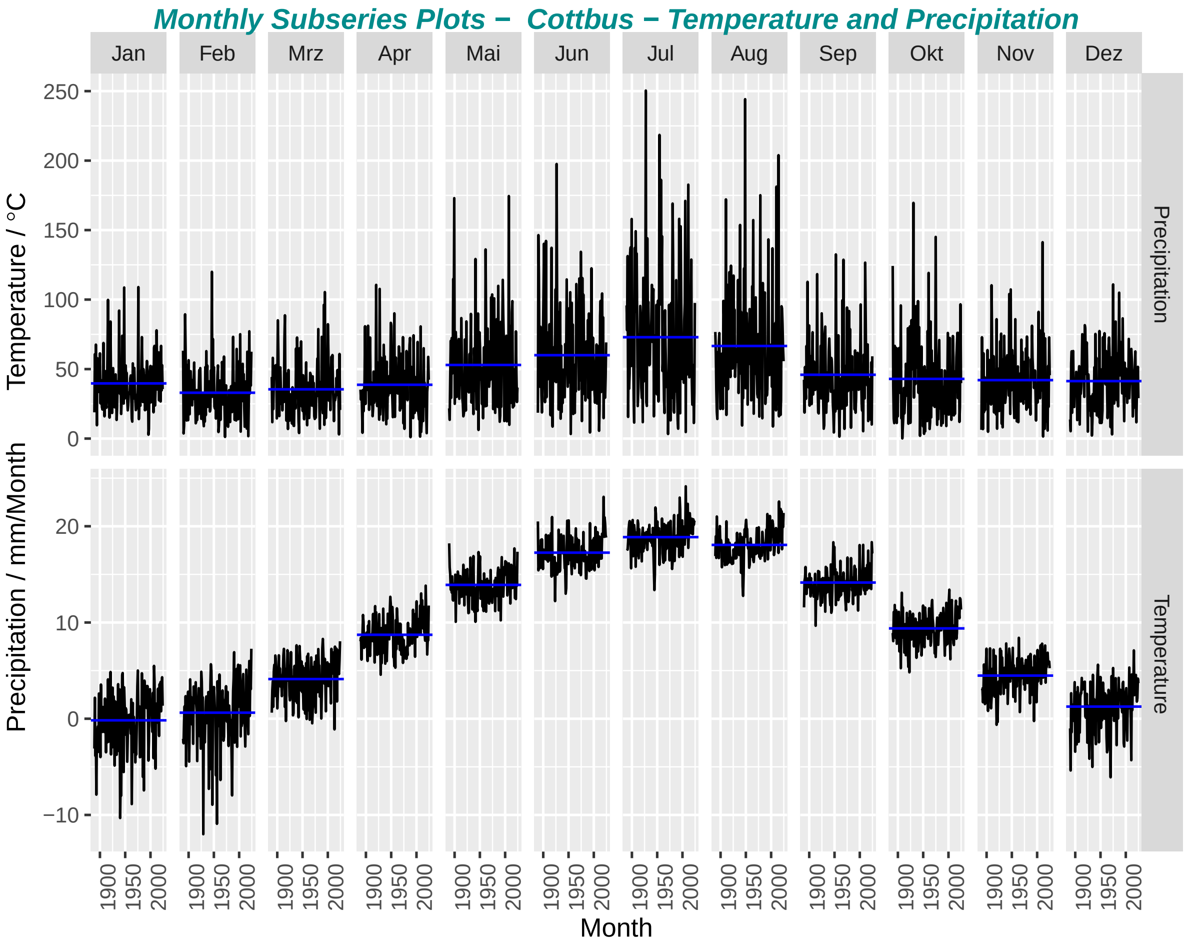


Monthly Variations of 30−Year Periods − Delta to Reference
Periods: First 1889−1904 / Reference 1961−1990 / Last 1995−2024
Precipitation / mm/Month
30
20
10
0
−10
−20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2000
1975
1950
1925



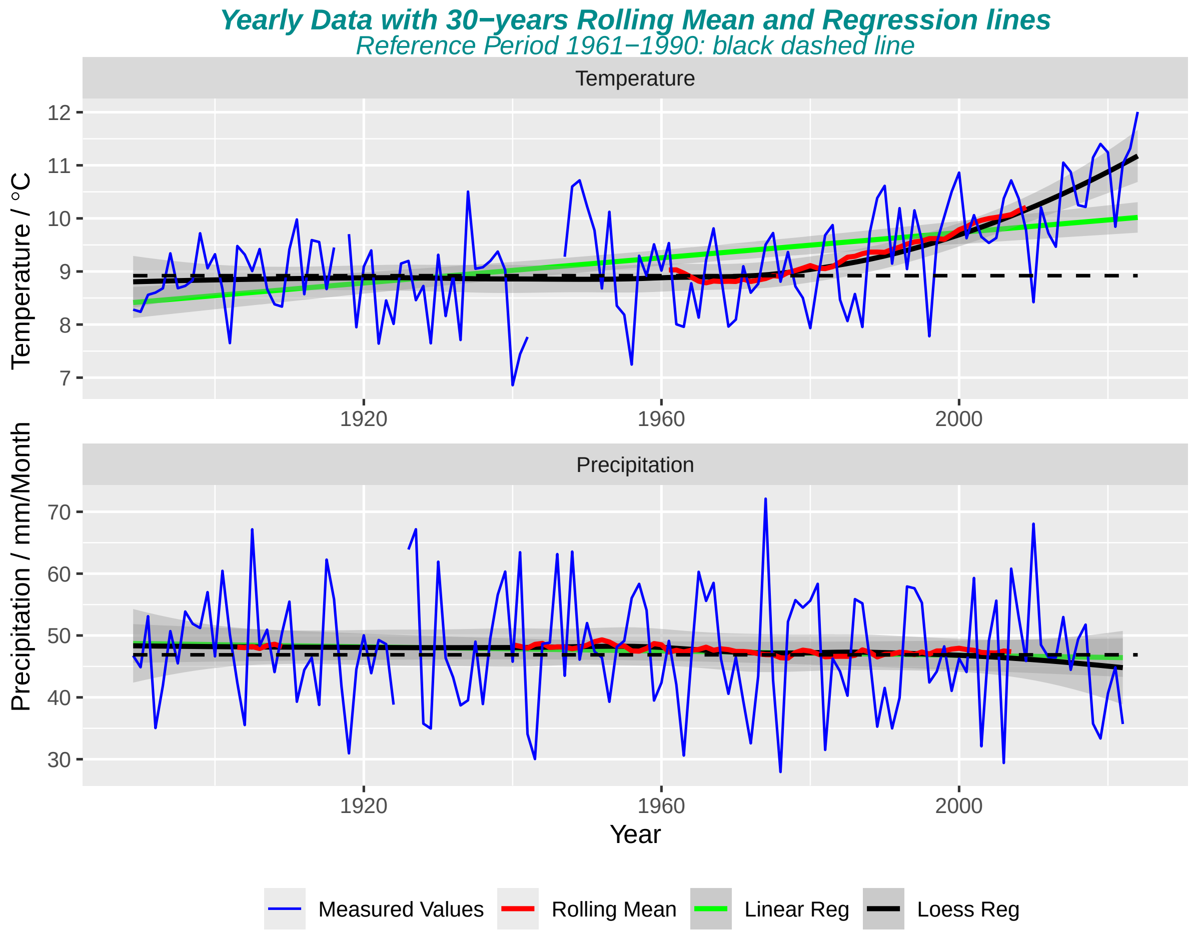
Monthly Variations of 30−Year Periods − Delta to Reference
Periods: First 1889−1904 / Reference 1961−1990 / Last 1995−2024
Precipitation / mm/Month
20
10
0
−10
−20
Jun
Jul
May
Aug
Apr
Sep
Mar
Oct
Feb
Nov
Jan
Dec
Month
Period_end
2000
1975
1950
1925


Yearly Seasonal Plots − Monthly Cottbus − Temperature and Precipitation
Temperature
Temperature / °C
20
10
0
−10
Jan
Feb
Mrz
Apr
Mai
Jun
Jul
Aug
Sep
Okt
Nov
Dez
Precipitation
Precipitation / mm/Month
250
200
150
100
50
0
Month
1988
1938

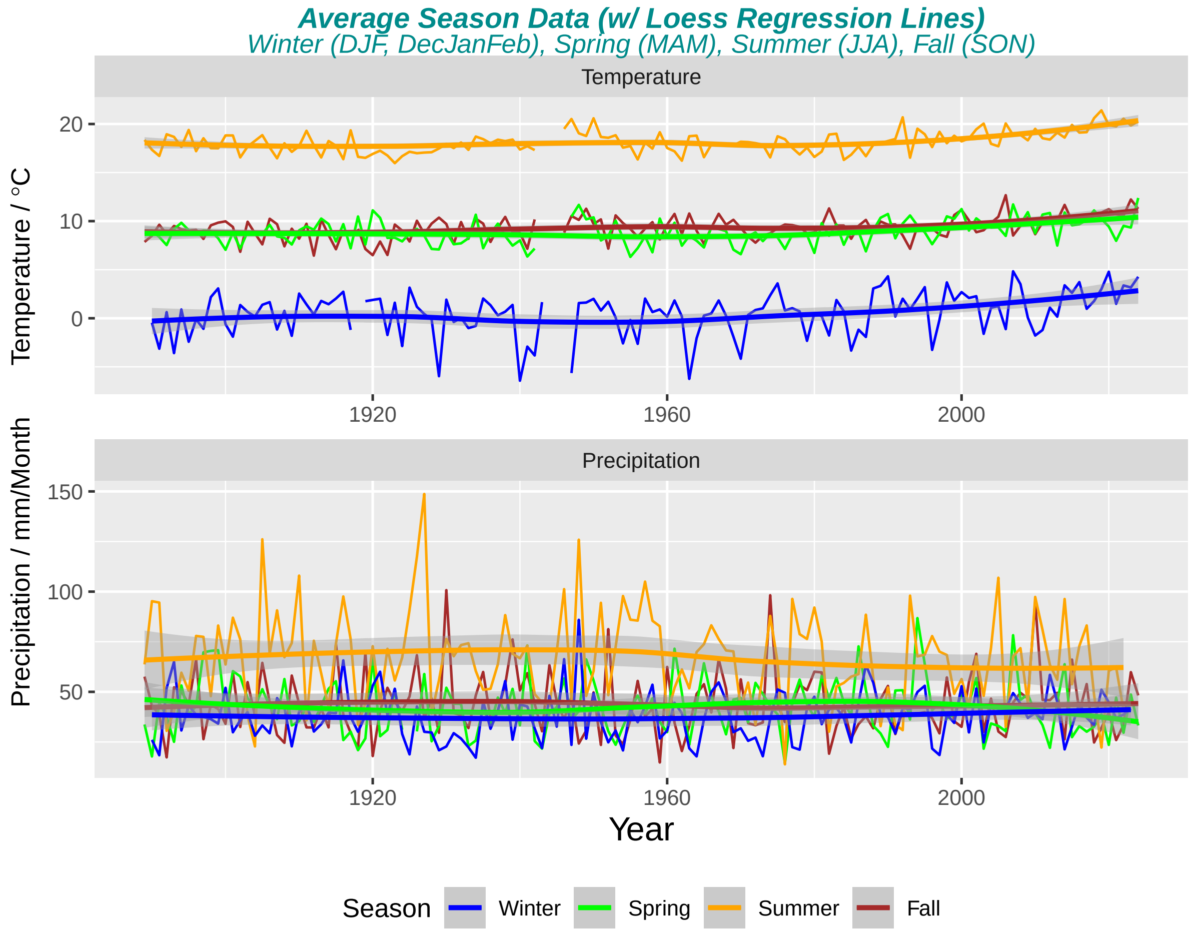

Monthly Subseries Plots – Cottbus – Temperature and Precipitation
Jan
Feb
Mrz
Apr
Mai
Jun
Jul
Aug
Sep
Okt
Nov
Dez
Temperature / °C
Precipitation / mm/Month
Precipitation
Temperature
Month
250
200
150
100
50
0
20
10
0
−10
1900
1950
2000

1.3 Yearly Cottbus - 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

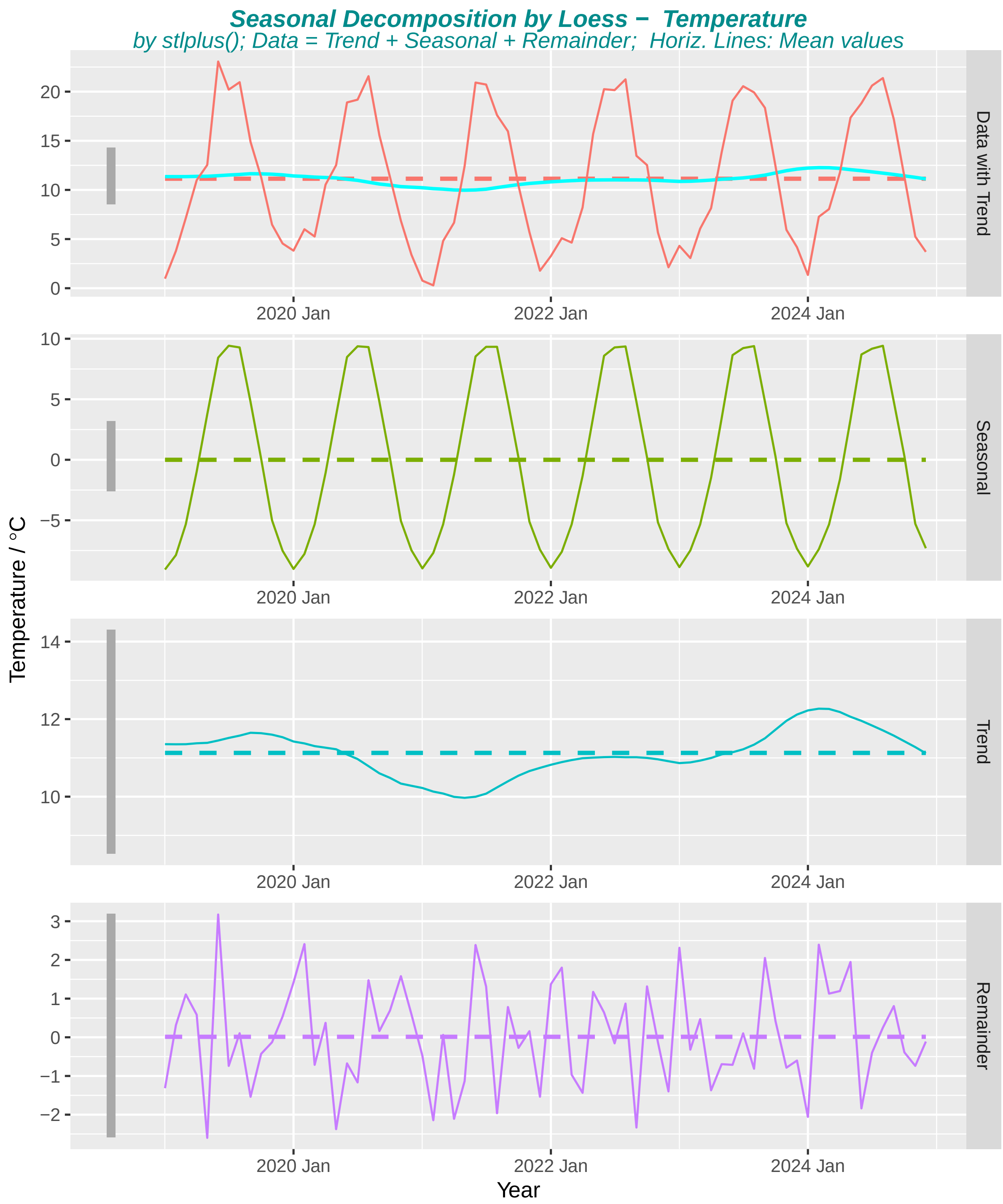
An *additive model* would be used when the variations around the trend do not vary with the level of the time series whereas a *multiplicative model* would be appropriate if the trend is proportional to the level of the time series.

Time series using an

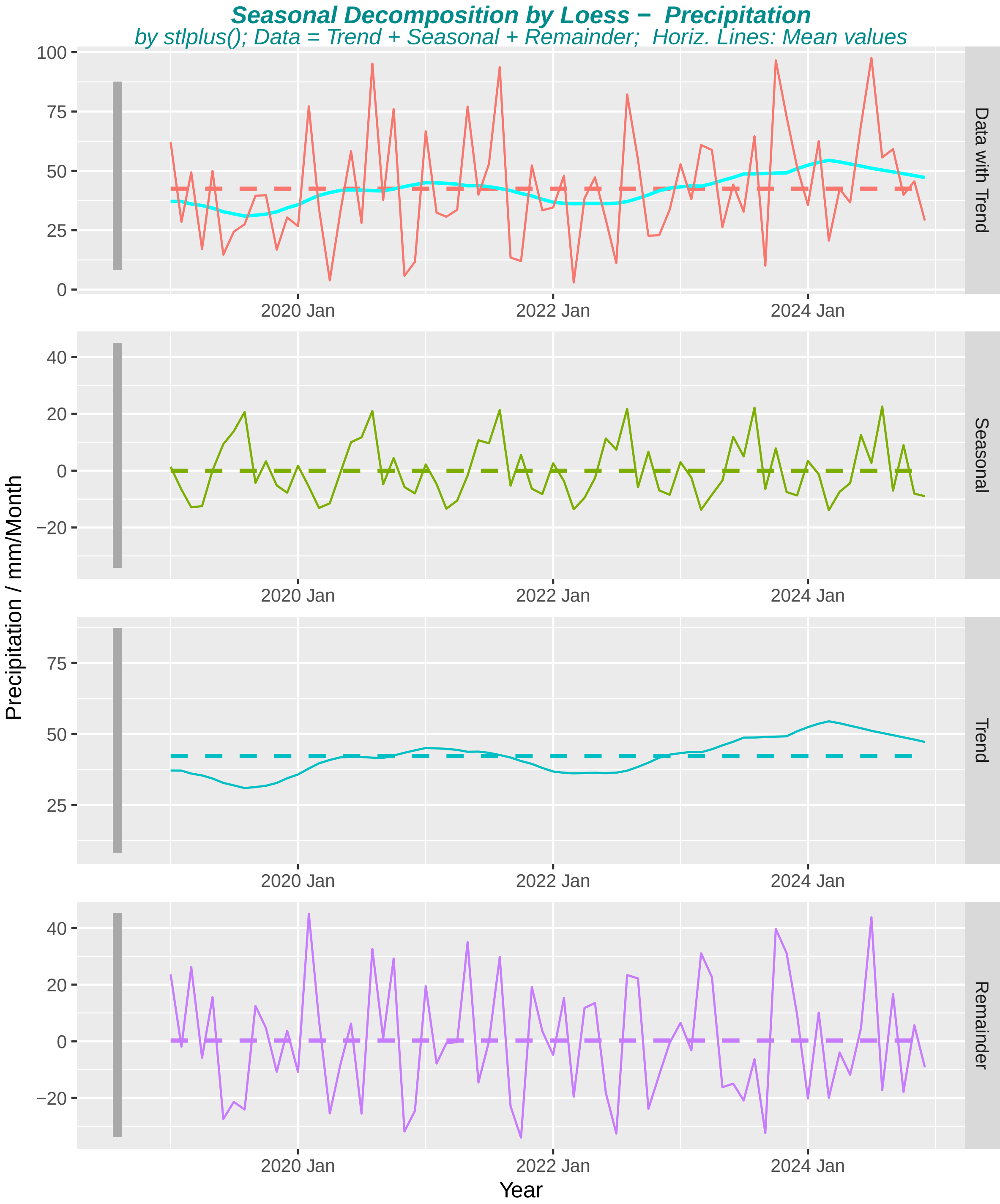
- additive model: $y_t = T_t + C_t + S_t + \epsilon_t$
- multiplicative model: $y_t = T_t * C_t * S_t * \epsilon_t$

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.

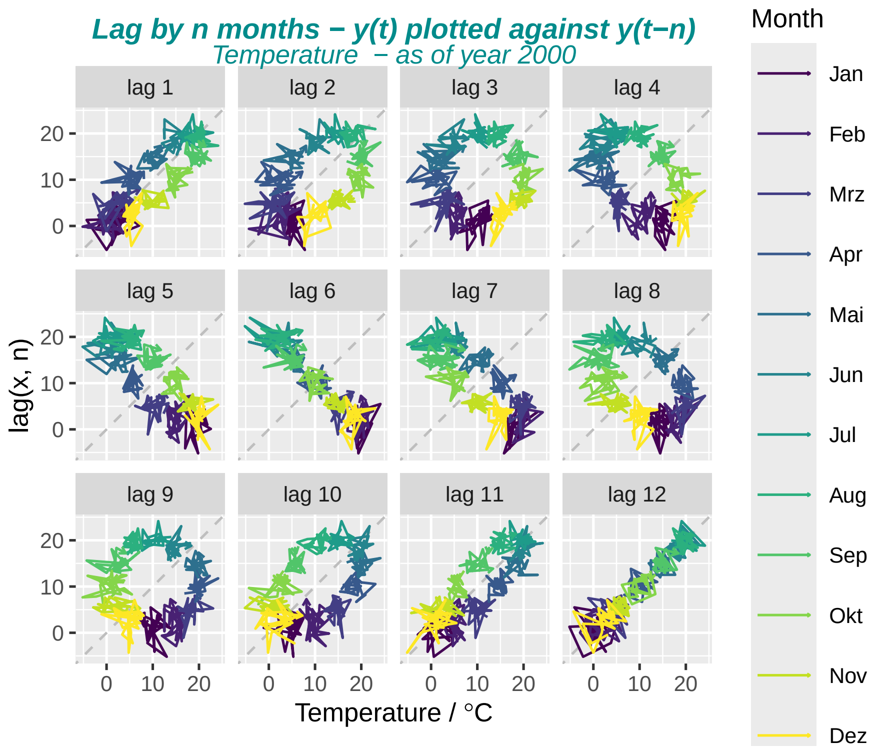


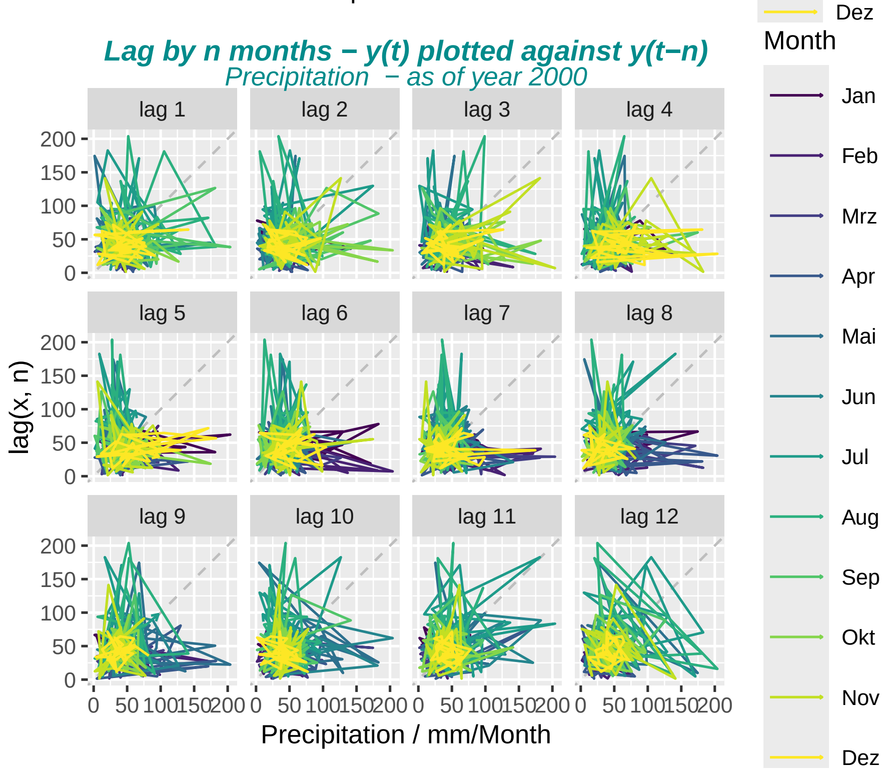
Seasonal Decomposition by Loess − Temperature
by stlplus(); Data = Trend + Seasonal + Remainder; Horiz. Lines: Mean values
Data with Trend
Seasonal
Trend
Remainder
Temperature / °C
Year
2020 Jan
2022 Jan
2024 Jan


Seasonal Decomposition by Loess − Precipitation
by stlplus(); Data = Trend + Seasonal + Remainder; Horiz. Lines: Mean values
Precipitation / mm/Month
Data with Trend
Seasonal
Trend
Remainder
2020 Jan
2022 Jan
2024 Jan
Year

2.2 Periodicities - Season Frequency

2.2.1 Lag Plot - Differences





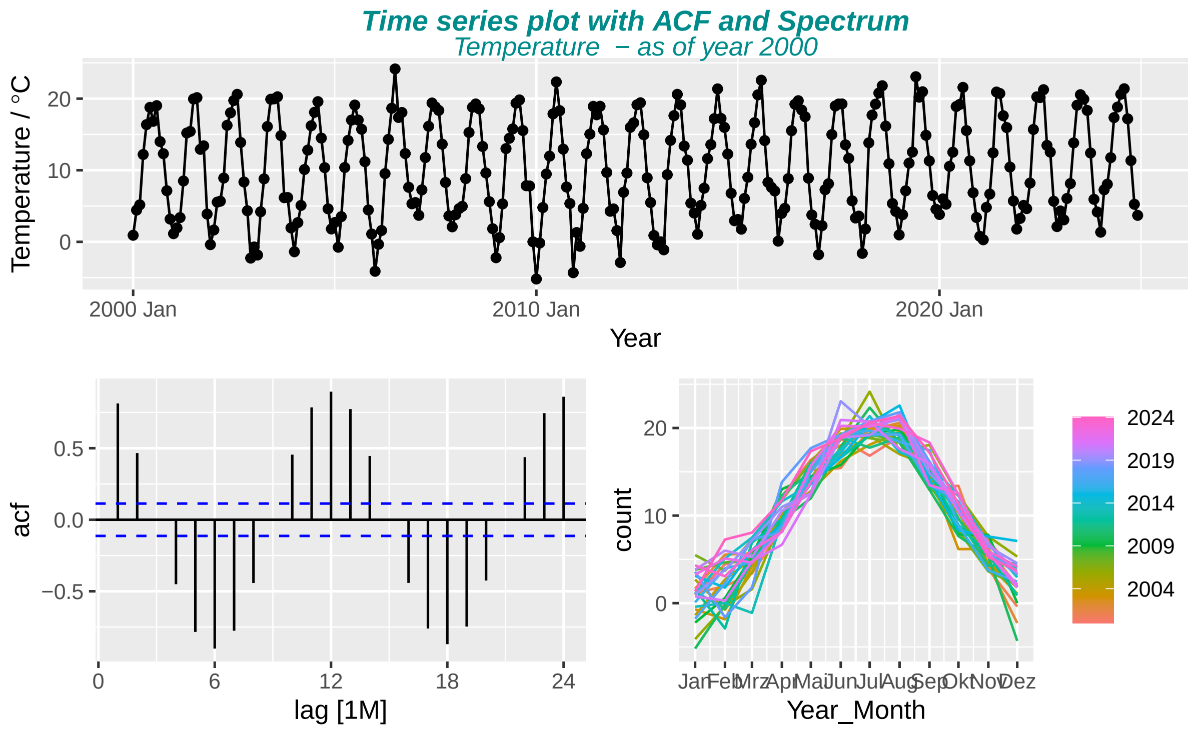
2.2.2 ACF / PACF Correlogram

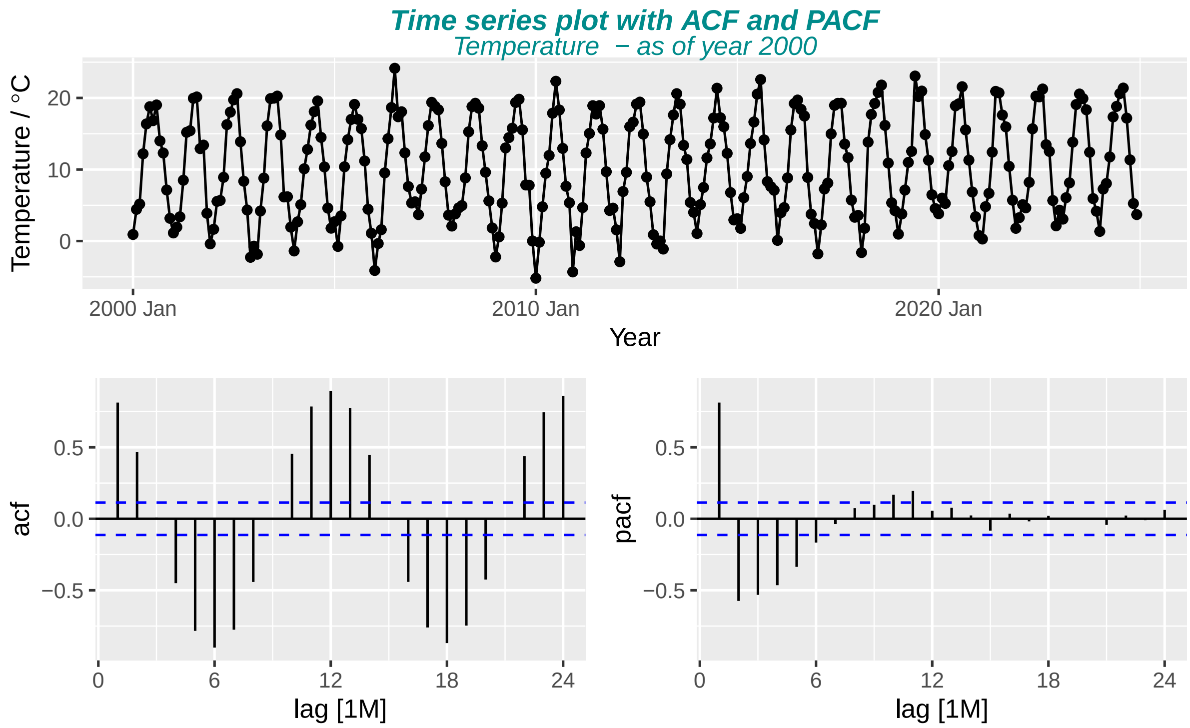
2.2.3 Periodogram - Spectral Density Estimation of a Time Series

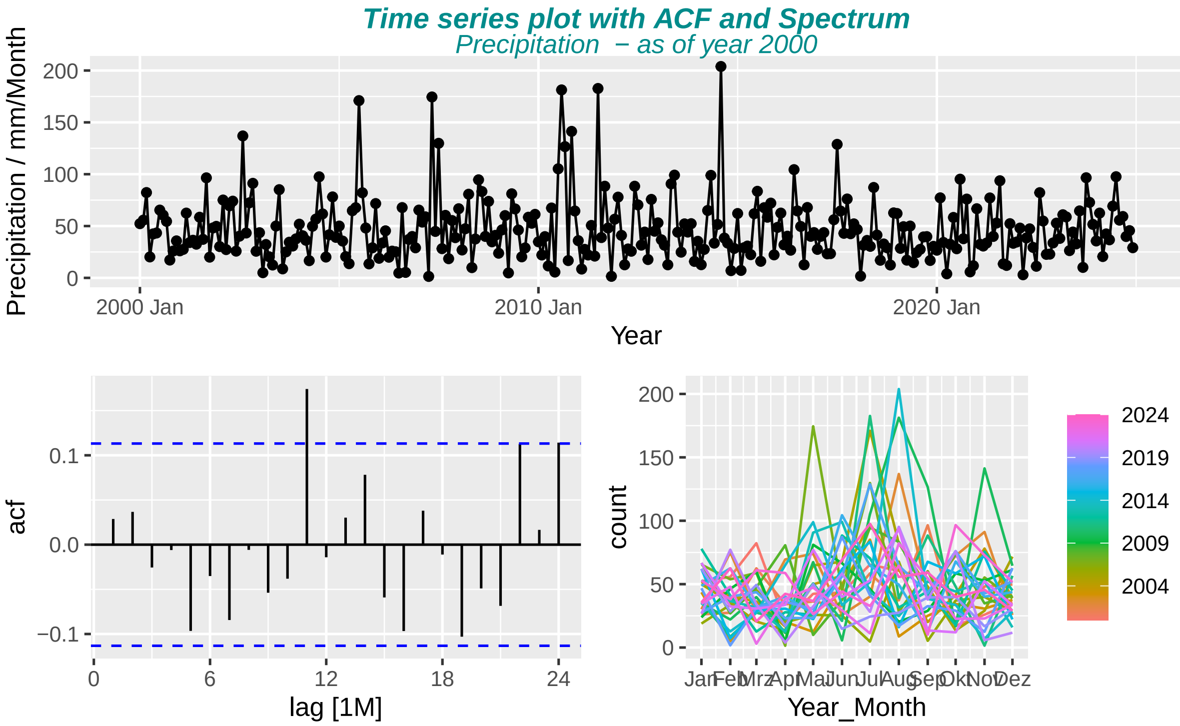
The spectral density characterizes the frequency content of the signal. One purpose of estimating the spectral density is to detect any periodicities in the data, by observing peaks at the frequencies corresponding to these periodicities.

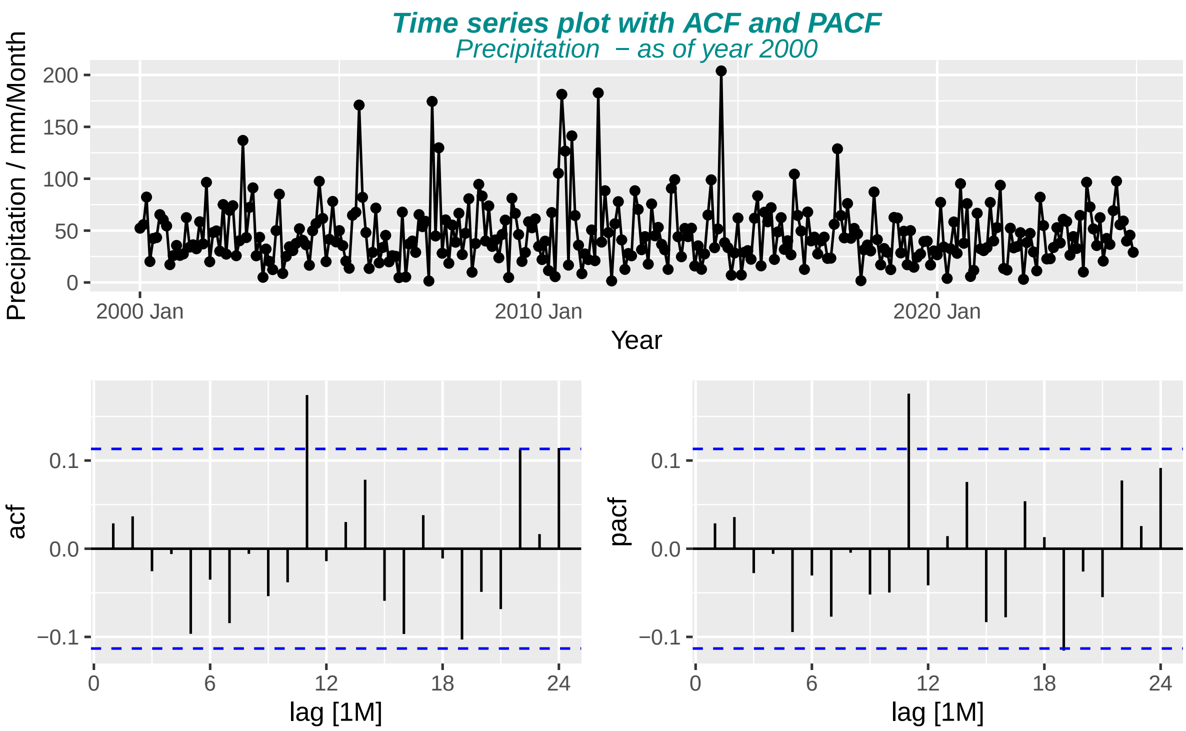
At frequency $\lambda = 1/12$ there is a significant peak => This pattern repeats every full frequency = every 12 months / every year

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







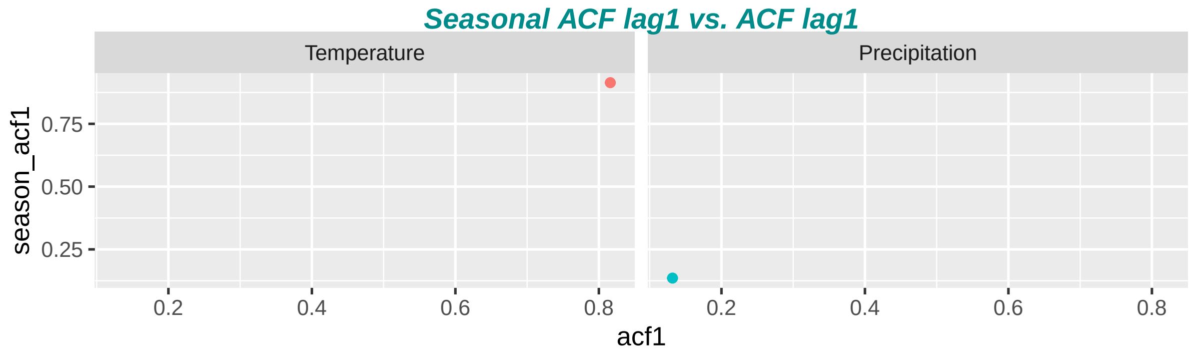


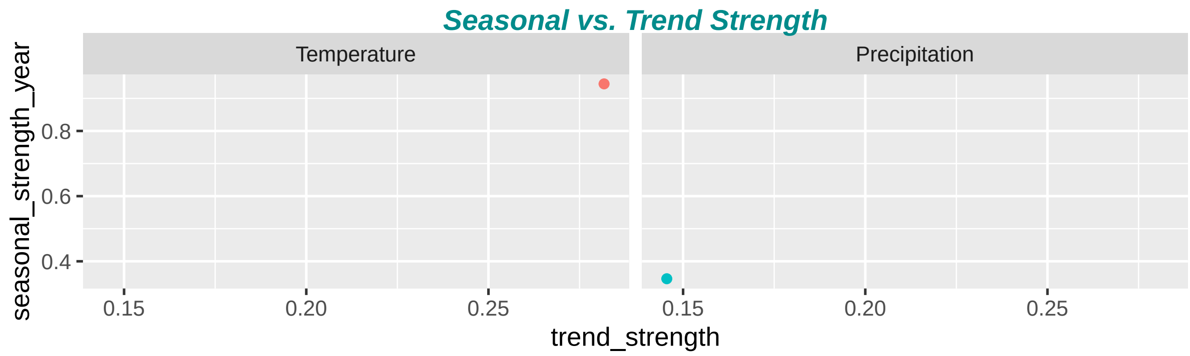
2.2.4 Seasonal vs non Seasonal ACF / Strength (Seasonal/Trend)

- 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_acf10 season_acf1
#>   <fct>   <dbl>  <dbl>      <dbl>       <dbl>      <dbl>       <dbl>       <dbl>
#> 1 Temper~ 0.816 3.52        0.443       1.73      -0.387       0.264       0.914
#> 2 Precip~ 0.132 0.0498     -0.450       0.205     -0.647       0.438       0.136
#> [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            0.282                  0.945                  7
#> 2 Precipitation          0.146                  0.346                  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              0.247
#> 2 Precipitation            0.979
```

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 Cottbus - 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
Cottbus	Temperature	1889	NA	9.0	18.4	7.9	8.3
Cottbus	Temperature	1890	-0.5	9.0	17.3	8.5	8.2
Cottbus	Temperature	1891	-3.1	8.4	16.7	9.6	8.6
Cottbus	Temperature	1892	0.6	7.5	18.9	8.7	8.6
Cottbus	Temperature	1893	-3.6	9.2	18.7	9.5	8.7
Cottbus	Temperature	1894	0.9	9.8	17.6	9.2	9.3
Cottbus	Temperature	1895	-2.4	9.1	19.4	9.0	8.7
Cottbus	Temperature	1896	-0.1	8.8	17.2	9.1	8.7
Cottbus	Temperature	1897	-1.1	9.0	18.5	8.2	8.8
Cottbus	Temperature	1898	2.2	9.0	17.5	9.6	9.7
Cottbus	Temperature	2015	2.6	9.6	19.9	10.0	10.9
Cottbus	Temperature	2016	3.7	9.7	19.1	10.0	10.2
Cottbus	Temperature	2017	1.0	10.1	19.2	10.3	10.2
Cottbus	Temperature	2018	1.8	11.1	20.6	10.8	11.1
Cottbus	Temperature	2019	3.0	10.2	21.4	10.9	11.4
Cottbus	Temperature	2020	4.8	9.4	19.9	11.2	11.2
Cottbus	Temperature	2021	1.5	8.0	19.8	10.7	9.8
Cottbus	Temperature	2022	3.4	9.5	20.6	10.6	11.0
Cottbus	Temperature	2023	3.2	9.3	19.9	12.2	11.3
Cottbus	Temperature	2024	4.3	12.4	20.3	11.3	12.0

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

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Cottbus	Precipitation	1889	NA	33.7	63.7	57.6	46.7
Cottbus	Precipitation	1890	26.0	17.8	95.2	43.2	44.9
Cottbus	Precipitation	1891	18.4	44.7	94.5	38.5	53.1
Cottbus	Precipitation	1892	51.9	37.7	30.5	17.3	35.0
Cottbus	Precipitation	1893	65.0	25.1	40.2	52.2	41.9
Cottbus	Precipitation	1894	30.7	53.2	59.6	50.3	50.7
Cottbus	Precipitation	1895	43.1	38.8	50.5	43.8	45.5
Cottbus	Precipitation	1896	38.6	42.8	77.9	66.1	53.9
Cottbus	Precipitation	1897	37.5	69.7	77.4	26.4	51.9

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Cottbus	Precipitation	1898	36.4	70.4	47.9	43.5	51.2
Cottbus	Precipitation	2015	32.6	27.4	53.8	66.1	44.5
Cottbus	Precipitation	2016	44.5	32.9	72.9	40.2	49.4
Cottbus	Precipitation	2017	37.1	30.1	83.1	53.9	51.8
Cottbus	Precipitation	2018	33.5	32.7	48.5	24.7	35.7
Cottbus	Precipitation	2019	51.1	38.8	22.2	32.0	33.4
Cottbus	Precipitation	2020	44.8	23.5	60.5	39.9	40.6
Cottbus	Precipitation	2021	36.9	47.1	62.2	25.9	44.9
Cottbus	Precipitation	2022	38.7	29.6	40.9	33.5	35.7
Cottbus	Precipitation	2023	41.5	48.7	NA	59.8	NA
Cottbus	Precipitation	2024	NA	33.2	NA	48.2	NA

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

City	Month	Temperature	Precipitation
Cottbus	Jan	-0.2	39.7
Cottbus	Feb	0.6	33.0
Cottbus	Mar	4.1	35.4
Cottbus	Apr	8.7	38.7
Cottbus	May	13.9	53.0
Cottbus	Jun	17.3	60.0
Cottbus	Jul	18.9	72.9
Cottbus	Aug	18.1	66.6
Cottbus	Sep	14.2	45.9
Cottbus	Oct	9.4	43.0
Cottbus	Nov	4.5	42.1
Cottbus	Dec	1.3	41.3

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