Climate Data Visualization -

Atmospheric CO_2 Concentration / Temperature / Precipitation

Wolfgang Vollmer

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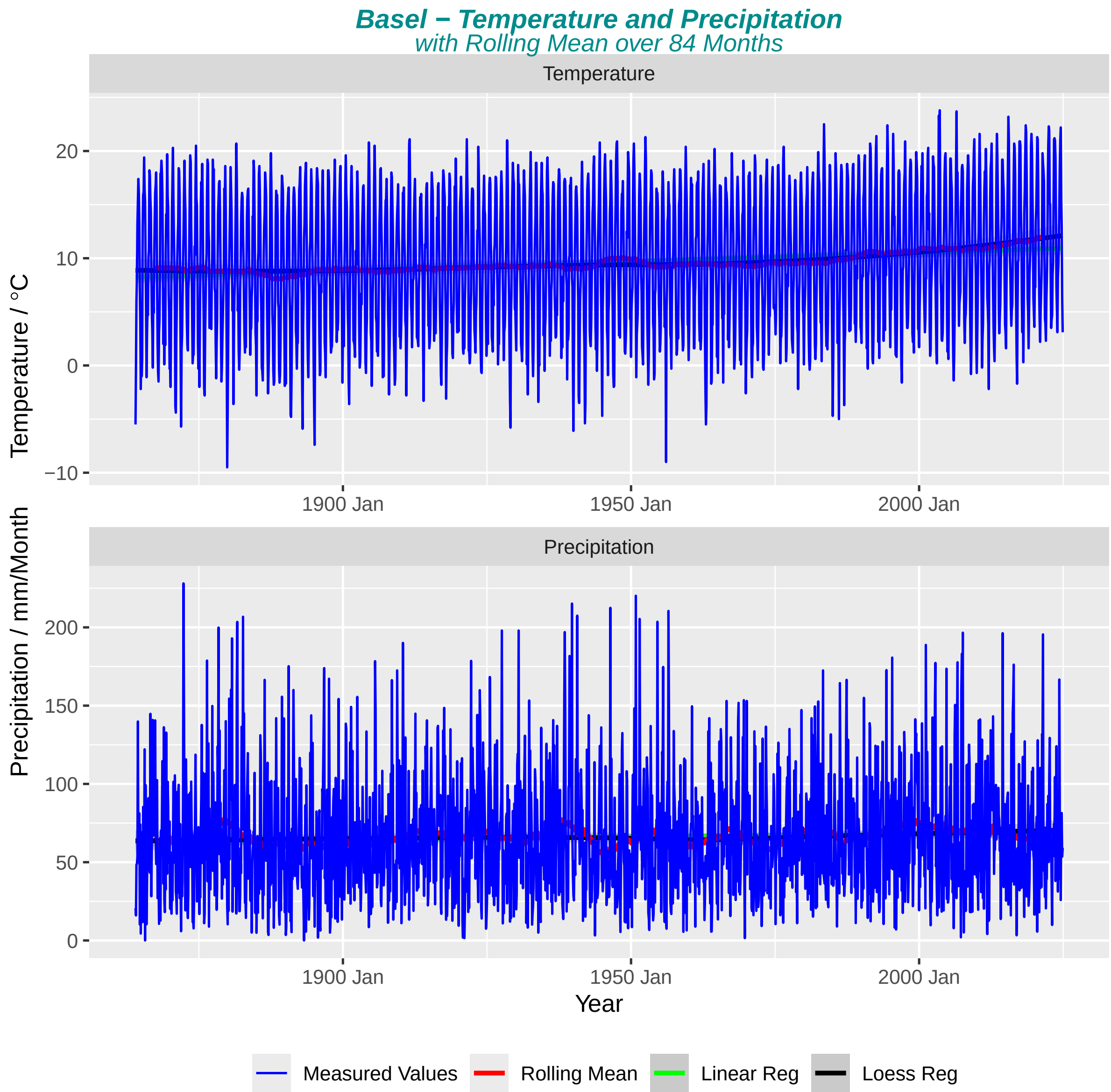
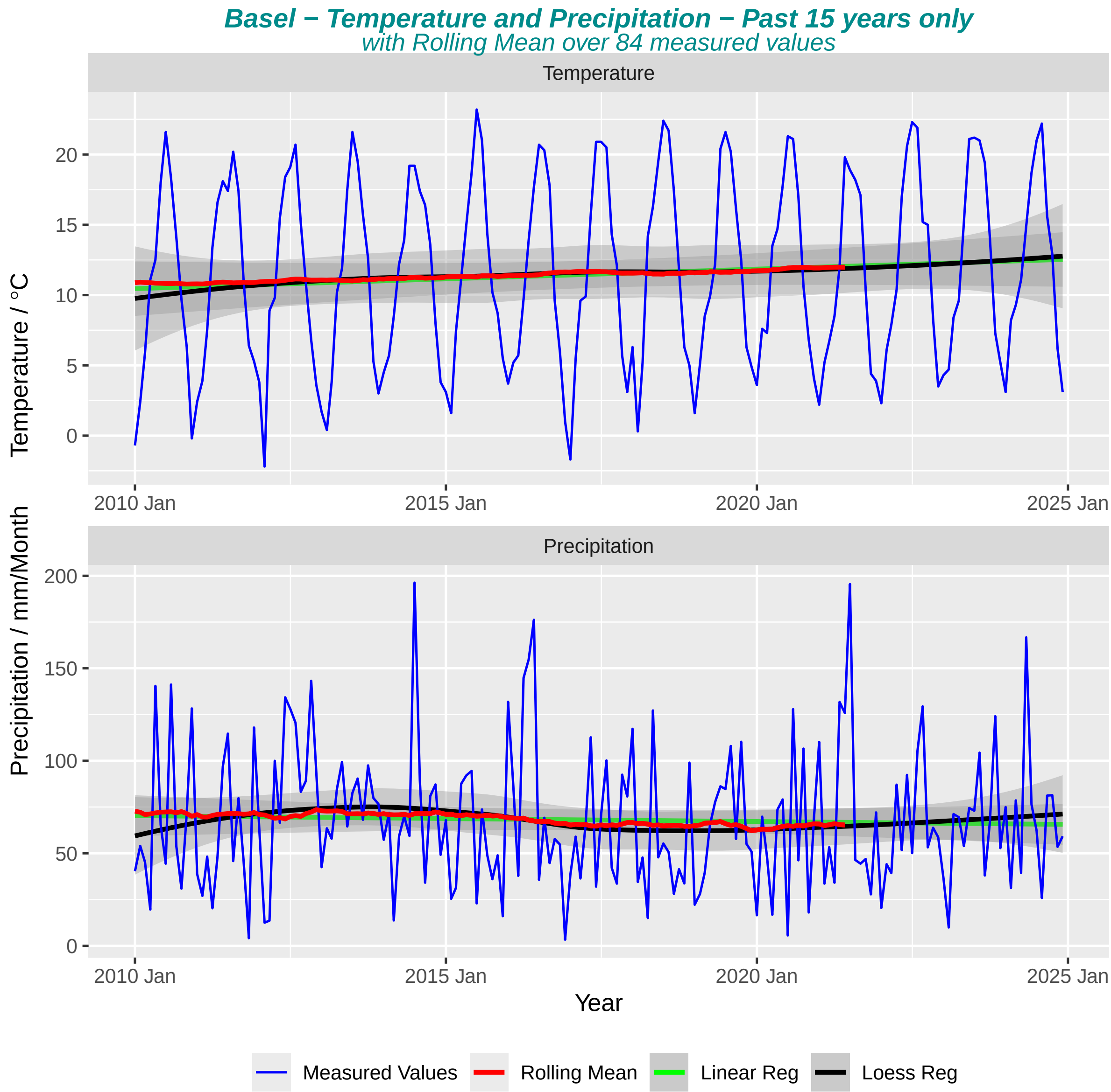
Contents

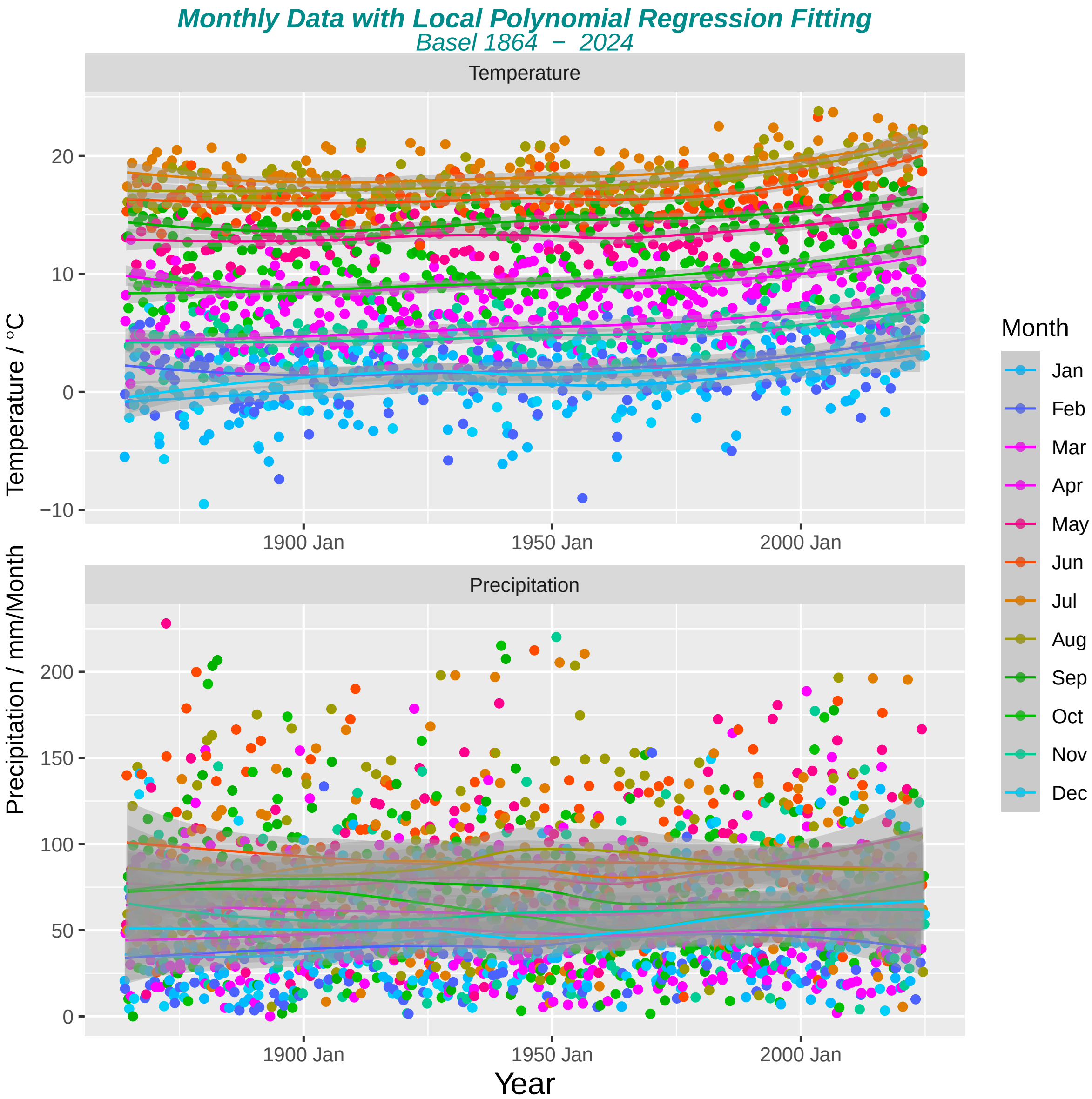
1 Basel - Visualization of Temperature and Precipitation Data 1864 - 2024

1.1 Monthly Time Plots with Rolling Mean




Basel – 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
2025 Jan
Precipitation
Precipitation / mm/Month
200
150
100
50
0
2010 Jan
2015 Jan
2020 Jan
2025 Jan
Year
Measured Values
Rolling Mean
Linear Reg
Loess Reg

1.2 Yearly plots with monthly breakdown



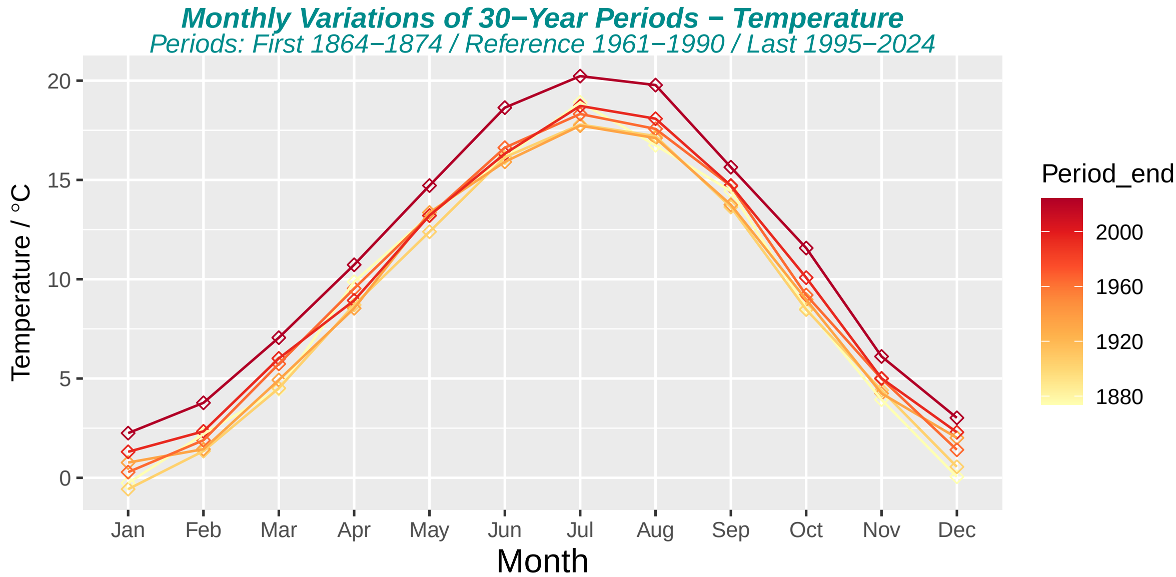
1.2.1 30-year period plots with monthly breakdown - Cartesian and Polar Coordinates

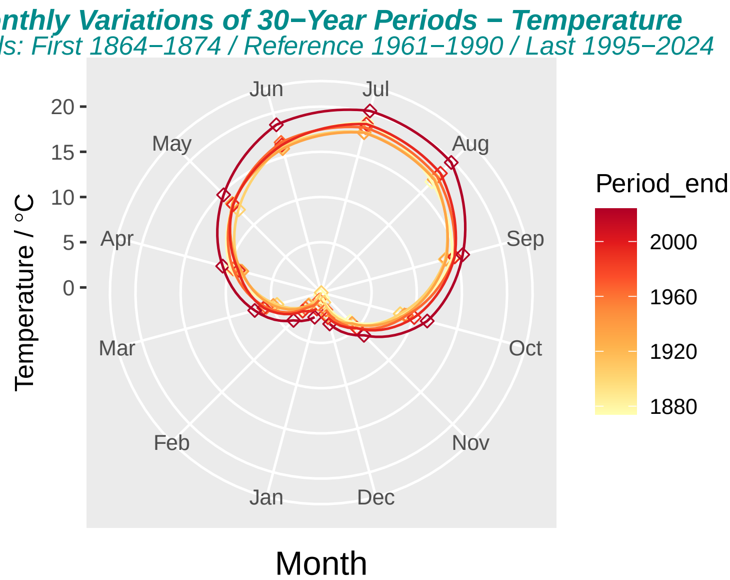
Table 1: 30-years Periods - Average Data (Temperature / degree C and Monthly Precipitation / mm)

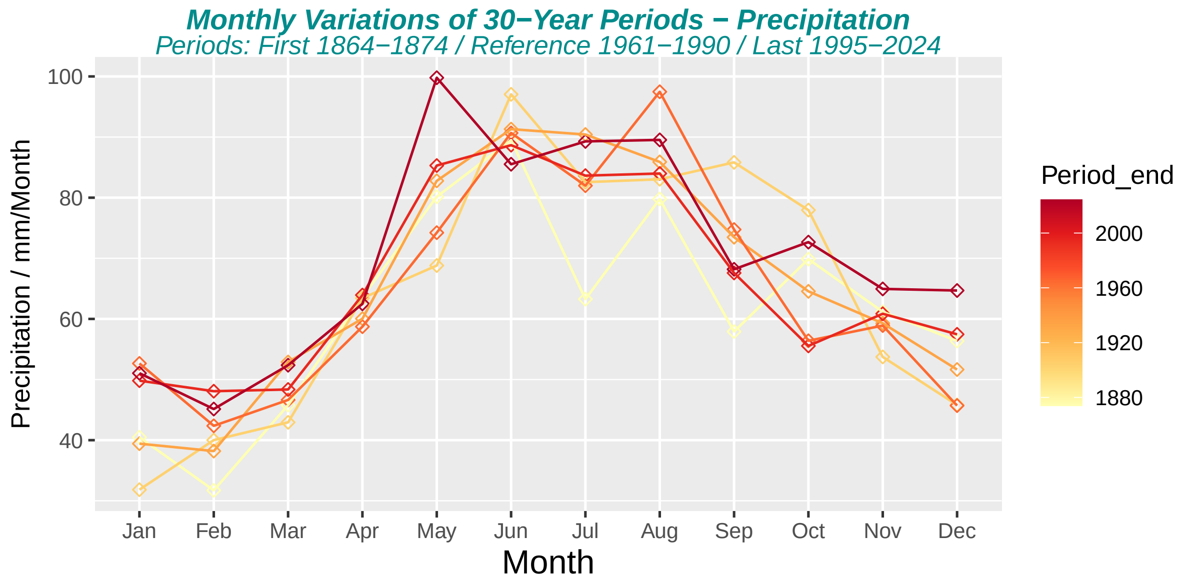
City	Period	Temperature	Monthly Precipitation	Annual Precipitation
Basel	1864-1874	9.0	61.6	739.6
Basel	1875-1904	8.7	64.4	773.0
Basel	1905-1934	9.1	65.8	789.9
Basel	1935-1964	9.5	65.0	780.5
Basel	1965-1994	9.8	66.1	793.2
Basel	1995-2024	11.1	70.5	845.6

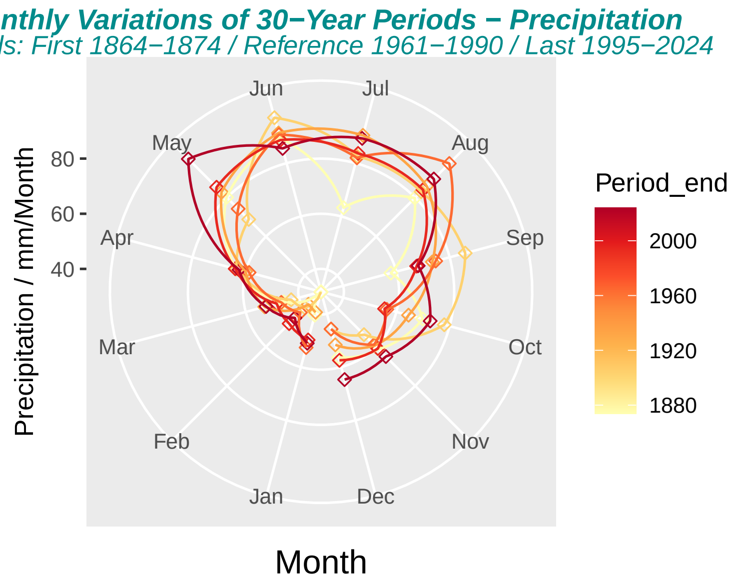
City	Ref_Period	Temperature	Monthly Precipitation	Annual Precipitation
Basel	1961-1990	9.6	64.8	777.9

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

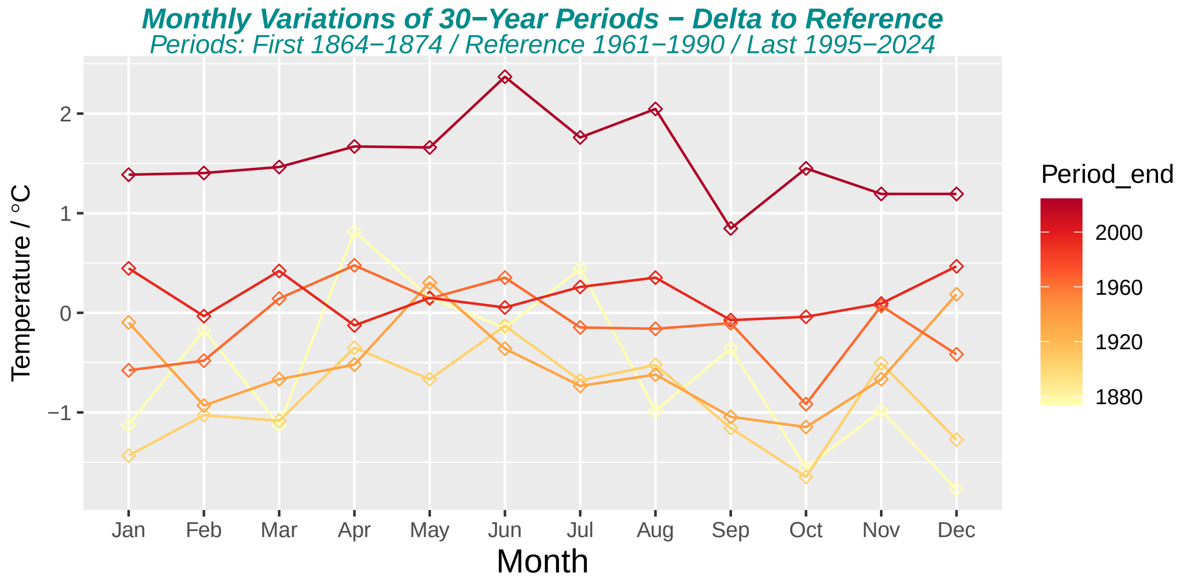


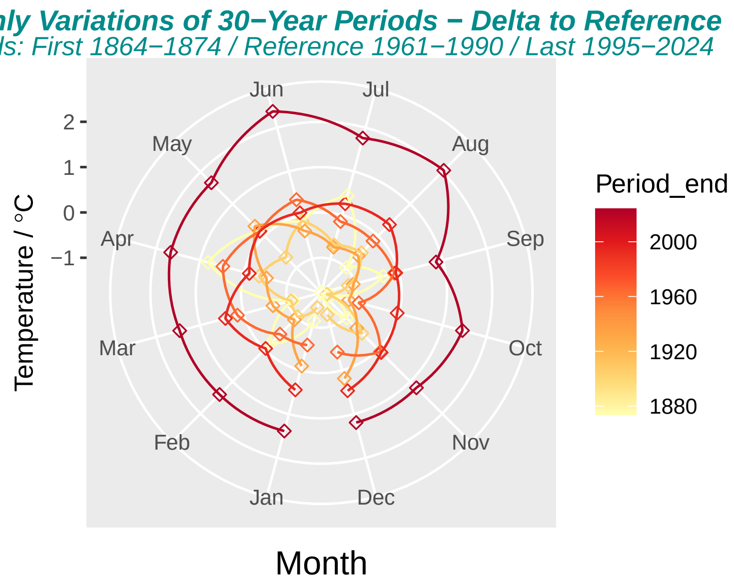


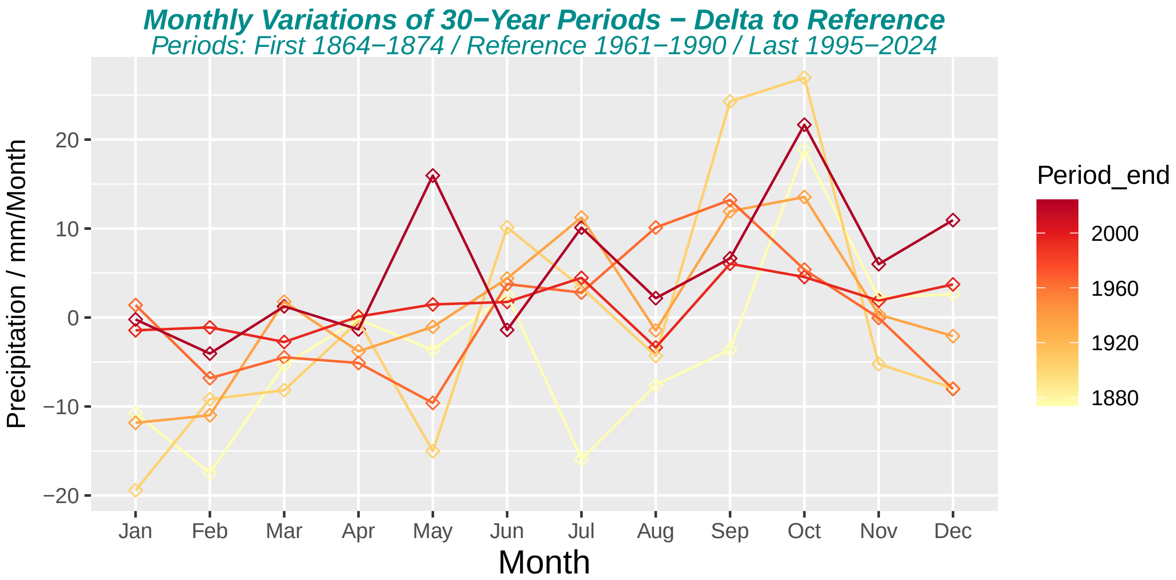

Monthly Variations of 30−Year Periods − Precipitation
Periods: First 1864−1874 / Reference 1961−1990 / Last 1995−2024
Precipitation / mm/Month
100
80
60
40
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2000
1960
1920
1880

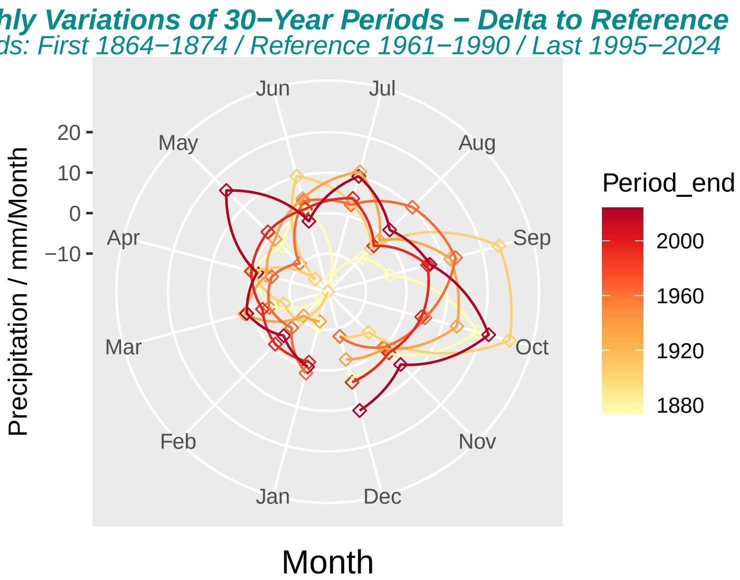

Monthly Variations of 30−Year Periods − Precipitation
Periods: First 1864−1874 / Reference 1961−1990 / Last 1995−2024
Precipitation / mm/Month
80
60
40
Jun
Jul
May
Aug
Apr
Sep
Mar
Oct
Feb
Nov
Jan
Dec
Month
Period_end
2000
1960
1920
1880

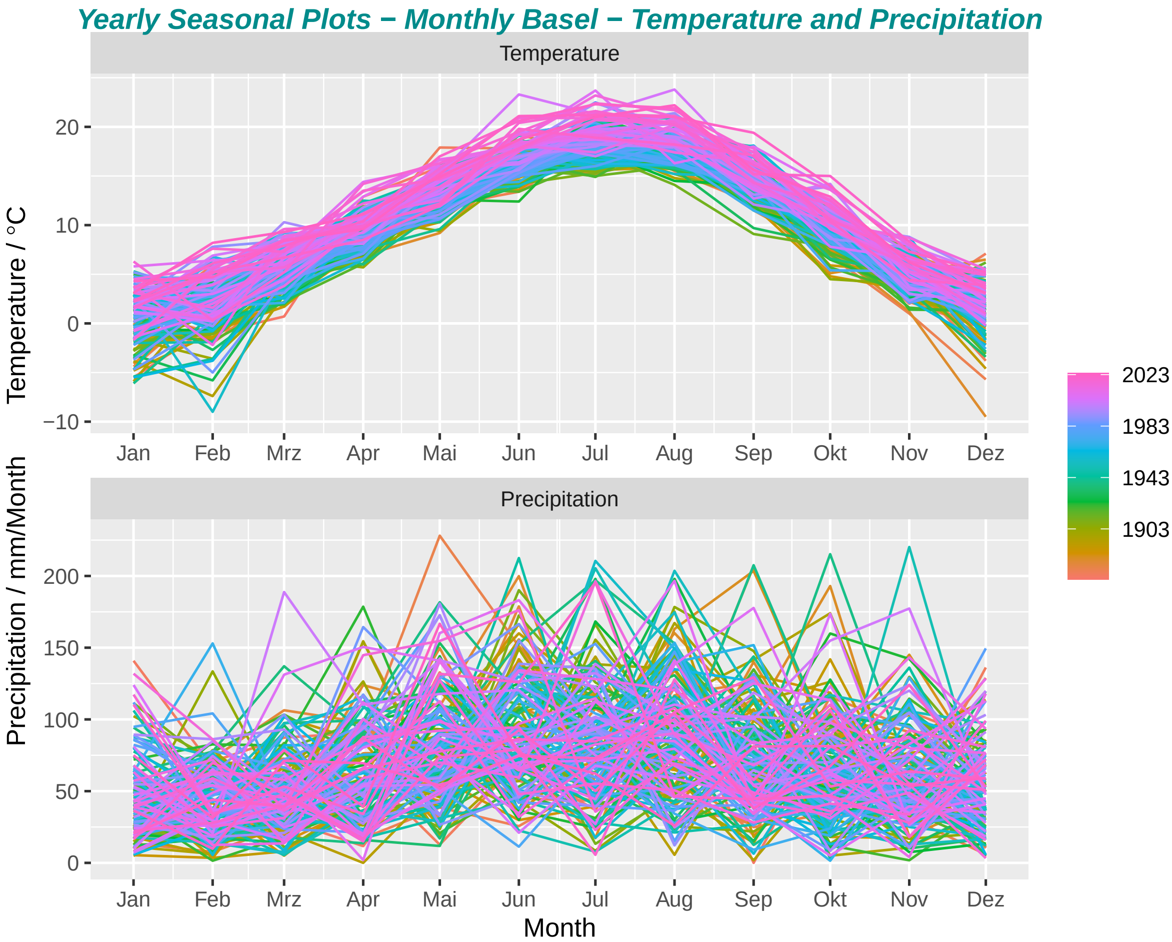
1.2.2 Plot Monthly Delta to Reference Period - Cartesian and Polar Coordinates

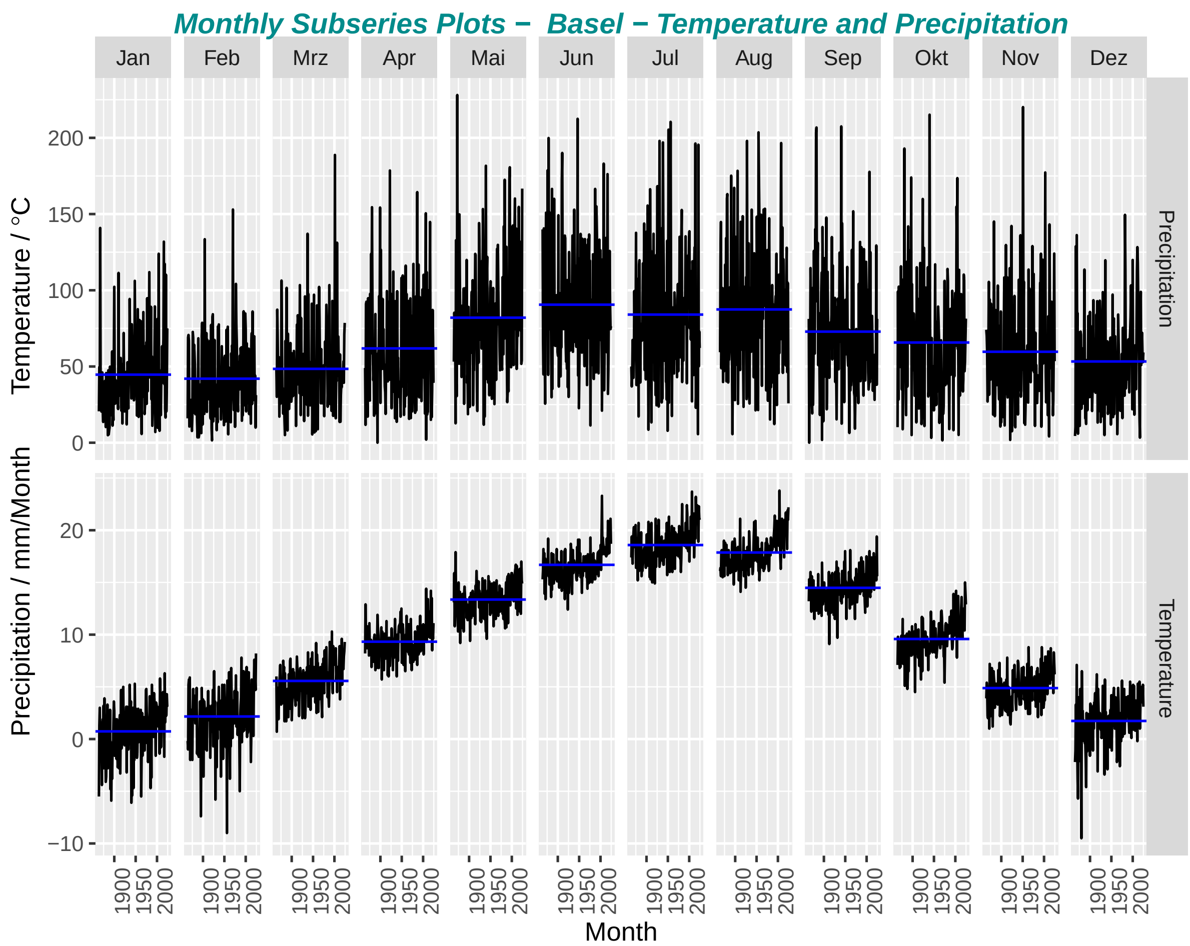





Monthly Variations of 30−Year Periods − Delta to Reference
Periods: First 1864−1874 / Reference 1961−1990 / Last 1995−2024
Precipitation / mm/Month
20
10
0
−10
−20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2000
1960
1920
1880

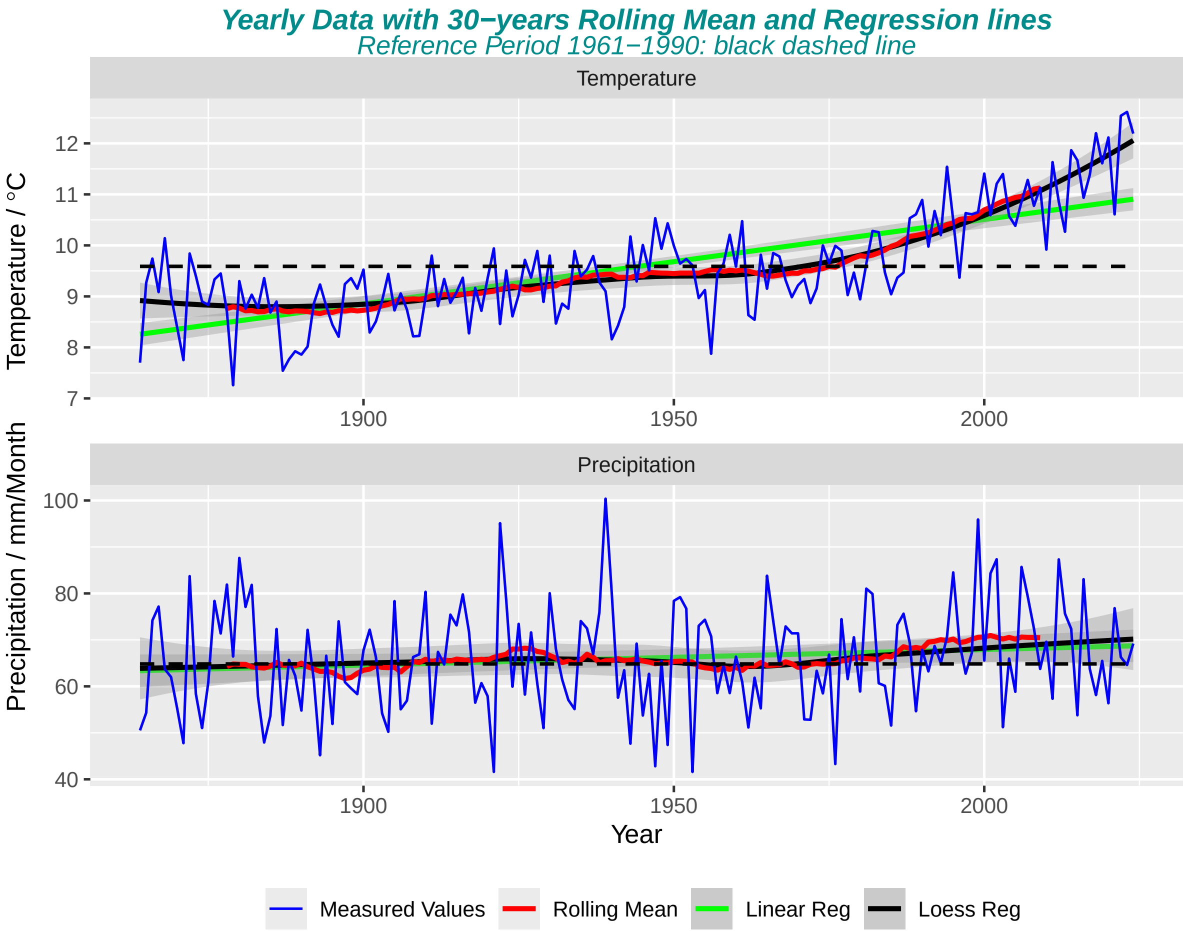

Monthly Variations of 30−Year Periods − Delta to Reference
Periods: First 1864−1874 / Reference 1961−1990 / Last 1995−2024
Precipitation / mm/Month
20
10
0
−10
Jun
Jul
May
Aug
Apr
Sep
Mar
Oct
Feb
Nov
Jan
Dec
Month
Period_end
2000
1960
1920
1880


Yearly Seasonal Plots − Monthly Basel − 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
200
150
100
50
0
Month
2023
1983
1943
1903

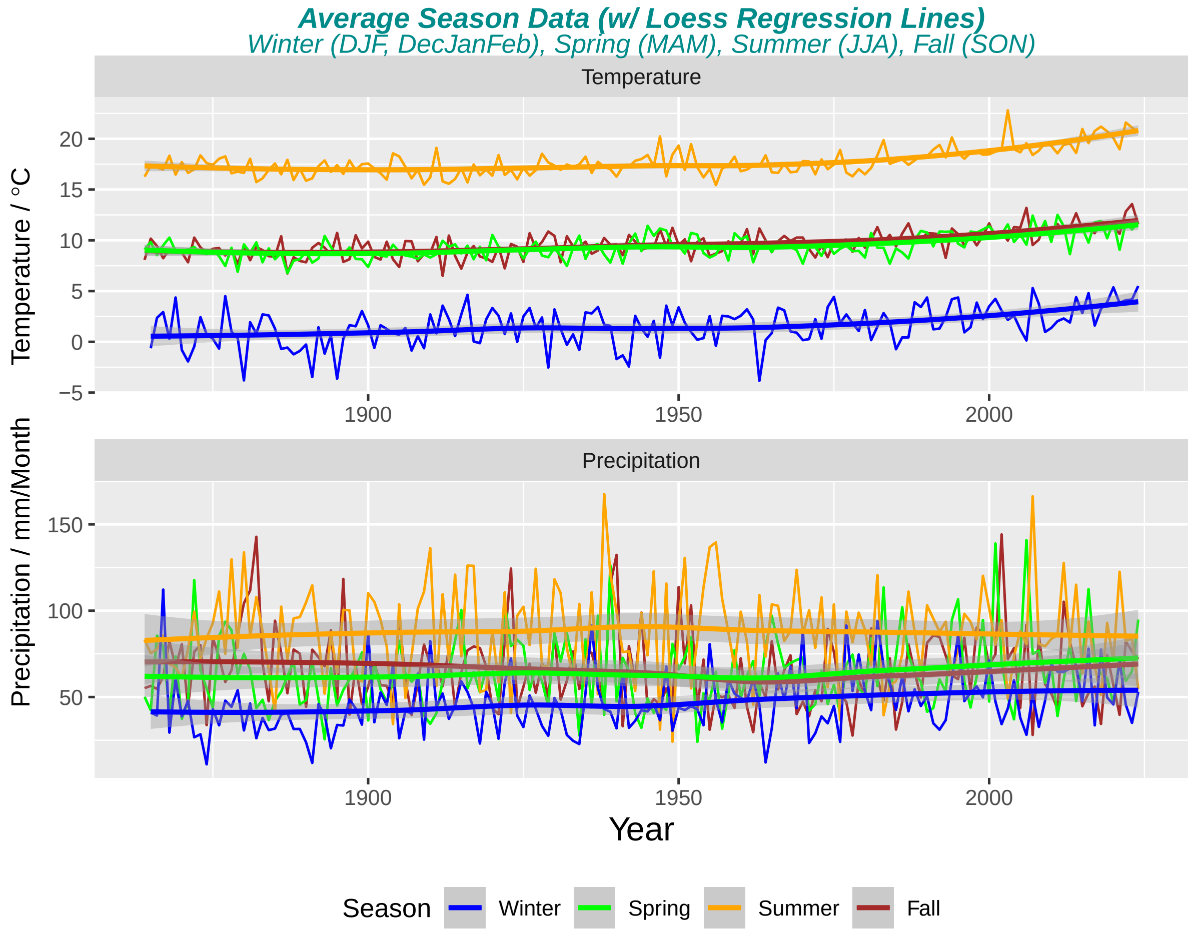

Monthly Subseries Plots – Basel – Temperature and Precipitation
Jan
Feb
Mrz
Apr
Mai
Jun
Jul
Aug
Sep
Okt
Nov
Dez
Precipitation
Temperature
Temperature / °C
Precipitation / mm/Month
Month
1900
1950
2000

1.3 Yearly Basel - 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

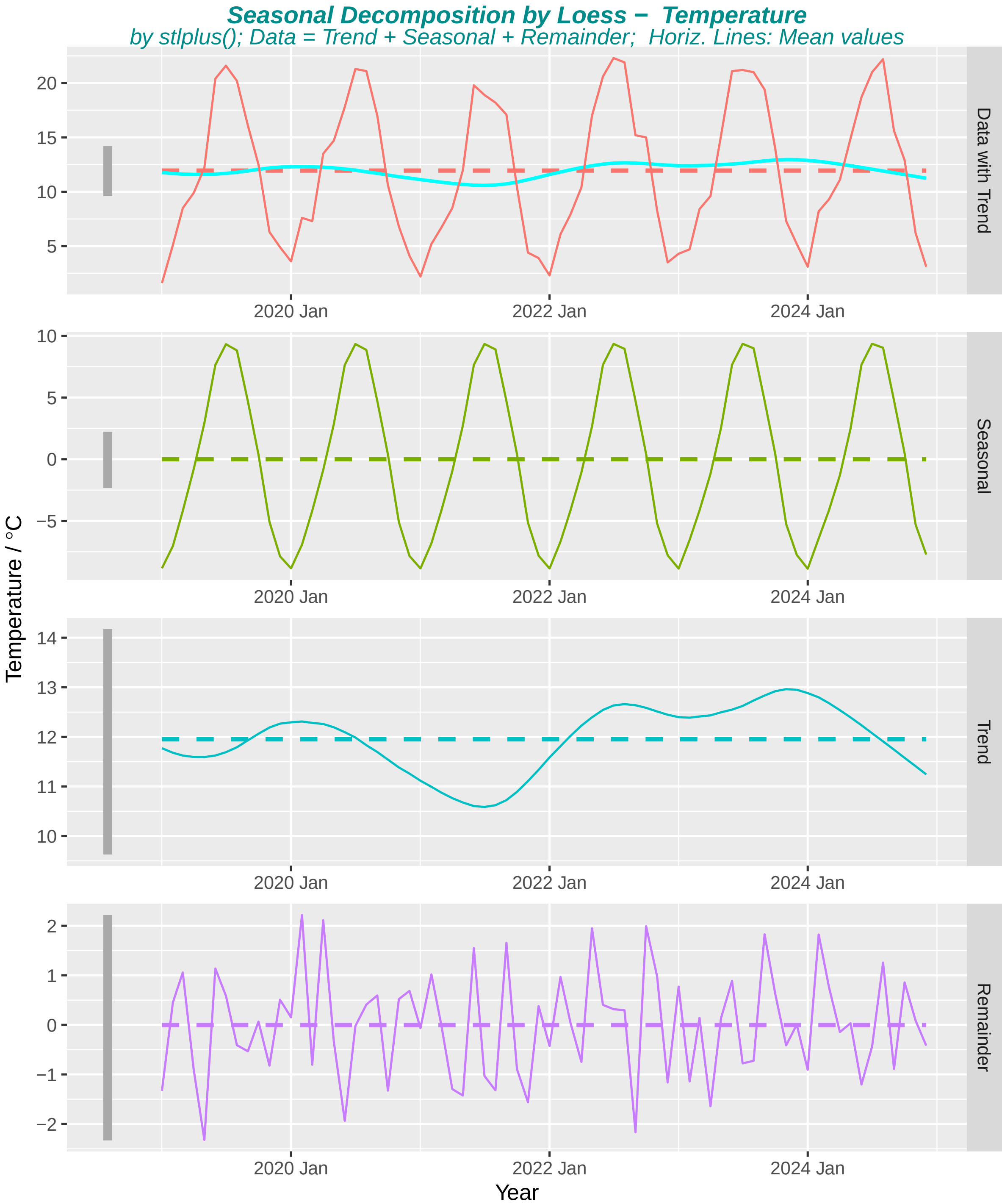
An *additive model* would be used when the variations around the trend do not vary with the level of the time series whereas a *multiplicative model* would be appropriate if the trend is proportional to the level of the time series.

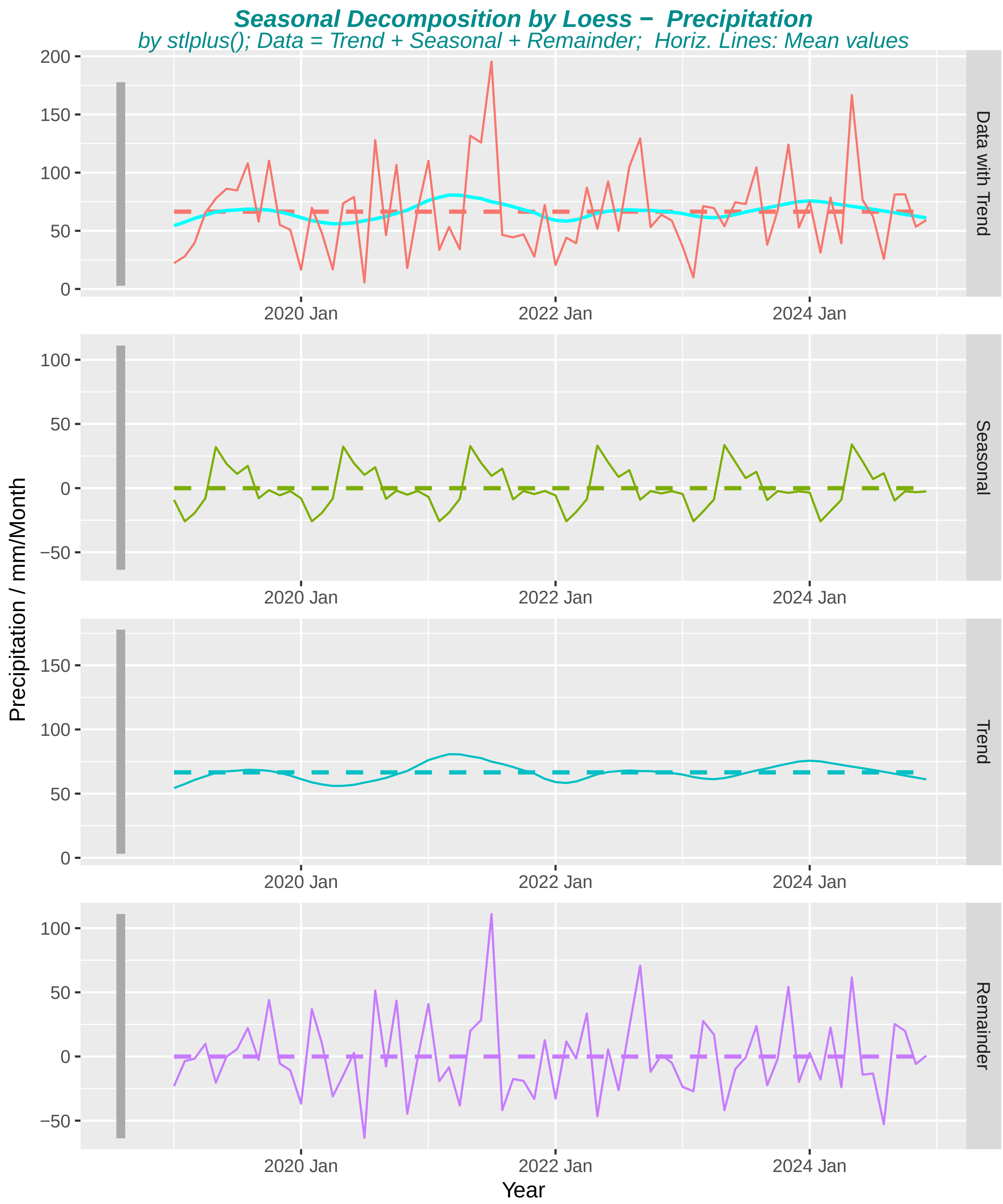
Time series using an

- 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

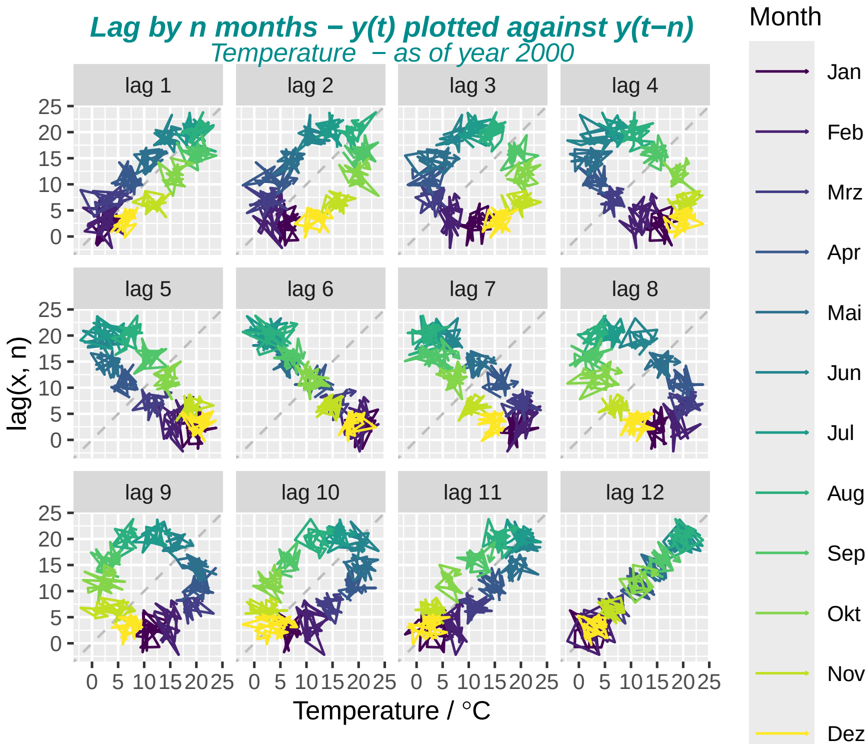
For *Seasonal decomposition of time series by Loess (stlplus)* uses in general an additive error model, it only provides facilities for additive decompositions. It is possible to obtain a multiplicative decomposition by first taking logs of the data.

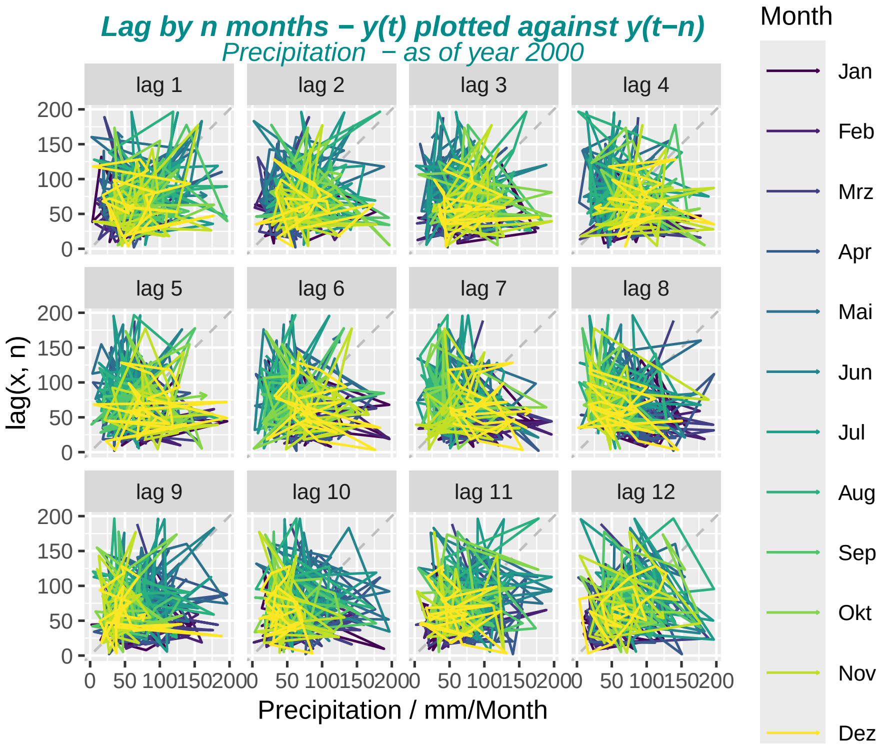

Seasonal Decomposition by Loess − Temperature
by stlplus(); Data = Trend + Seasonal + Remainder; Horiz. Lines: Mean values
Data with Trend
Seasonal
Trend
Remainder
Temperature / °C
Year
2020 Jan
2022 Jan
2024 Jan


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

2.2 Periodicities - Season Frequency

2.2.1 Lag Plot - Differences





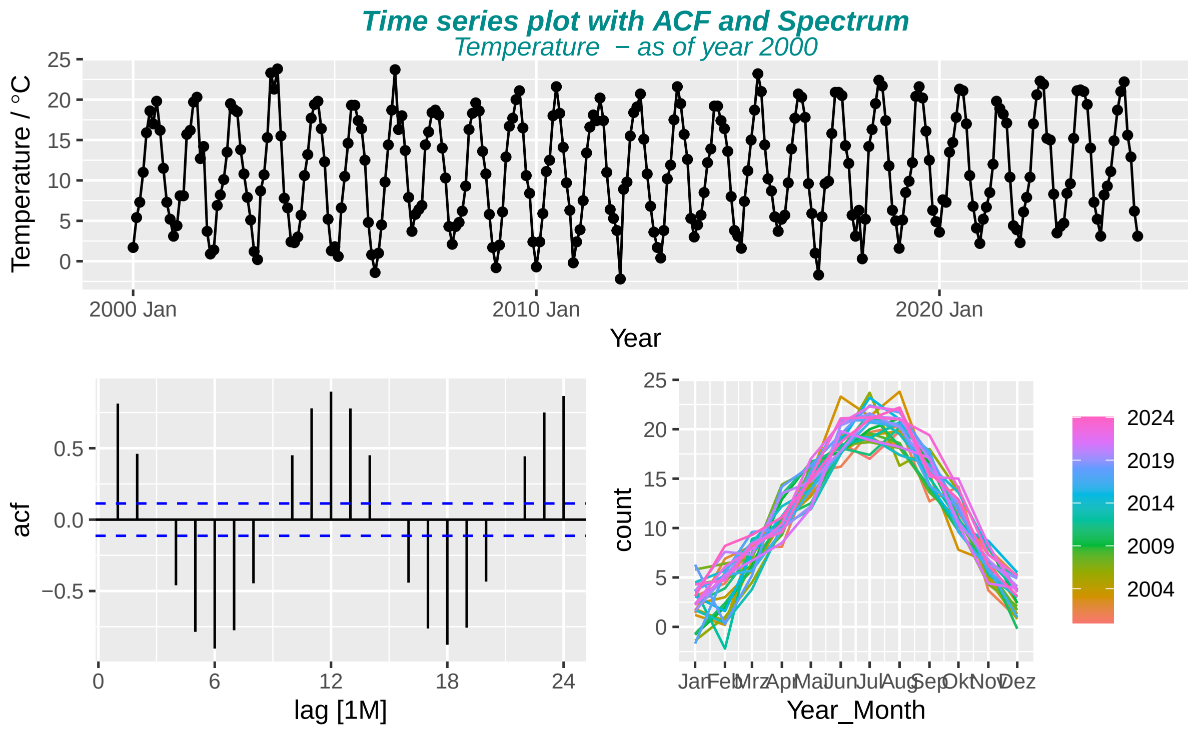
2.2.2 ACF / PACF Correlogram

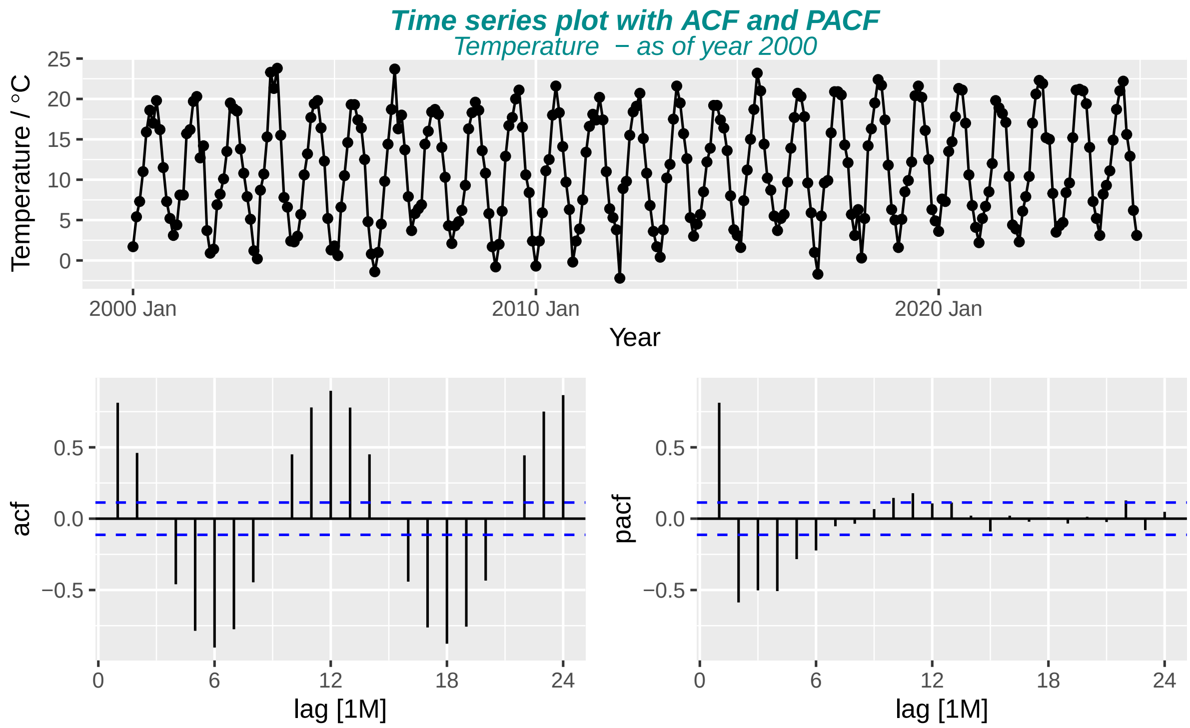
2.2.3 Periodogram - Spectral Density Estimation of a Time Series

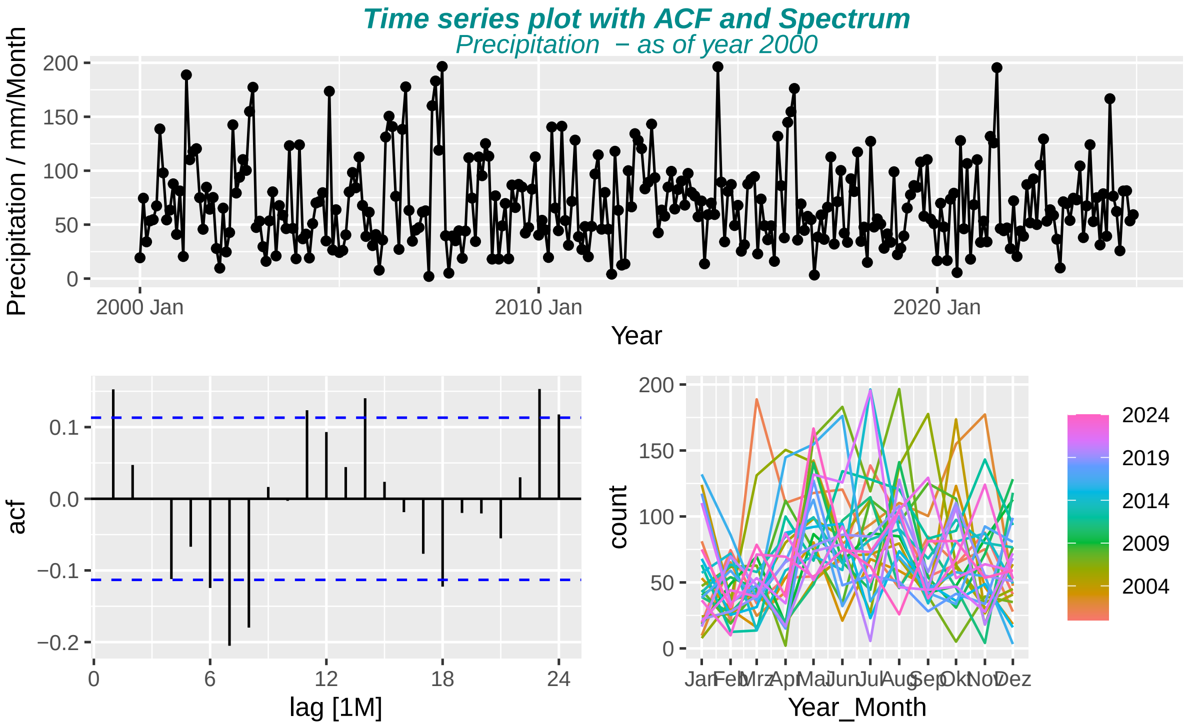
The spectral density characterizes the frequency content of the signal. One purpose of estimating the spectral density is to detect any periodicities in the data, by observing peaks at the frequencies corresponding to these periodicities.

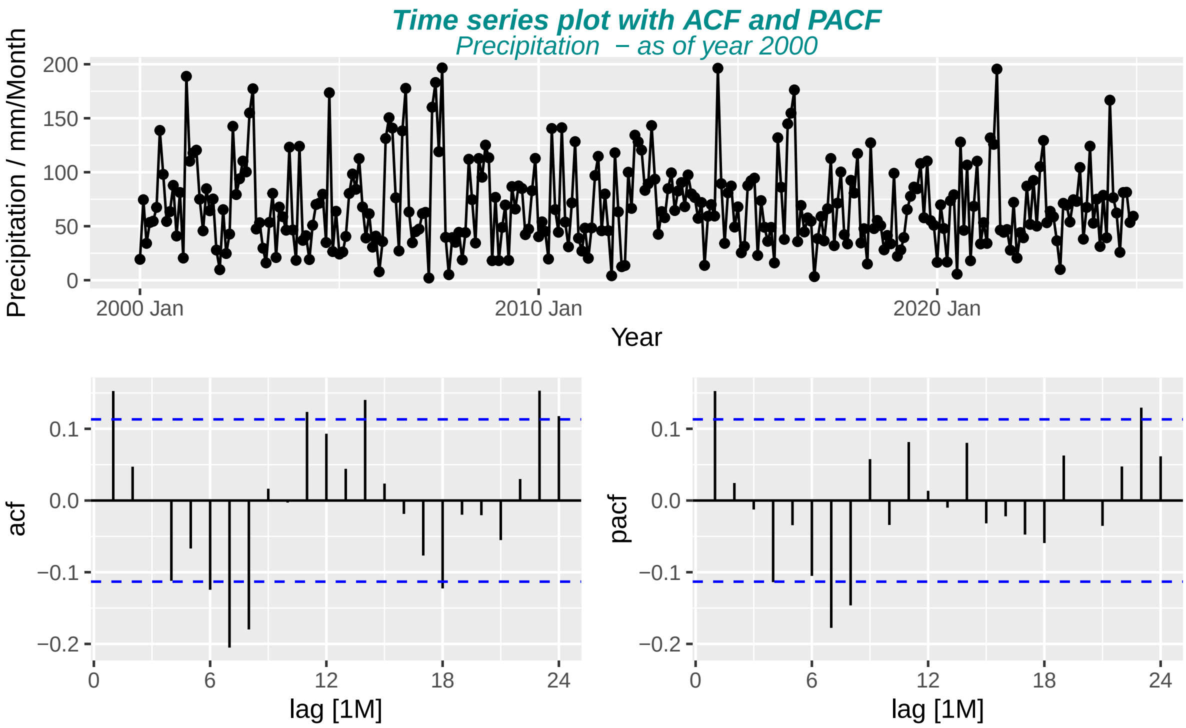
At frequency $\lambda = 1/12$ there is a significant peak => This pattern repeats every full frequency = every 12 months / every year

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







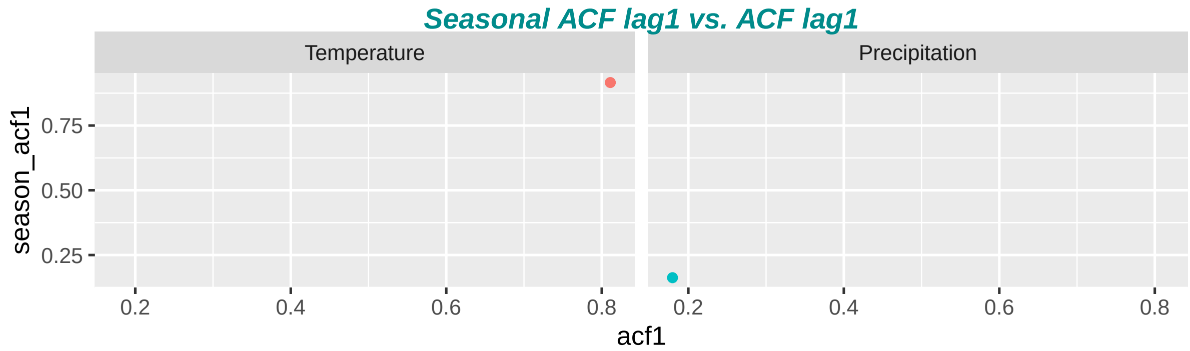


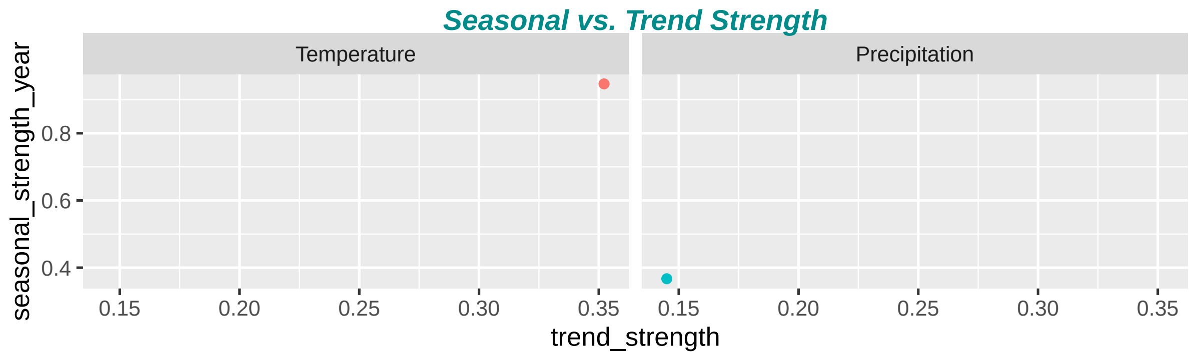
2.2.4 Seasonal vs non Seasonal ACF / Strength (Seasonal/Trend)

- 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 Tempera~ 0.811 3.40       0.412       1.59      -0.408       0.264       0.916
#> 2 Precipi~ 0.180 0.122     -0.450       0.208     -0.658       0.466       0.163
#> [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            0.352                  0.947                  7
#> 2 Precipitation          0.145                  0.367                  9
#> # 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              0.200
#> 2 Precipitation            0.963
```

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 Basel - 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
Basel	Temperature	1864	NA	9.1	16.3	8.1	7.7
Basel	Temperature	1865	-0.6	9.8	17.3	10.2	9.3
Basel	Temperature	1866	2.4	8.5	17.2	9.4	9.7
Basel	Temperature	1867	2.9	9.5	17.0	8.2	9.1
Basel	Temperature	1868	0.3	10.3	18.3	9.1	10.1
Basel	Temperature	1869	4.4	8.9	16.5	8.8	9.0
Basel	Temperature	1870	-0.8	9.0	17.7	8.8	8.4
Basel	Temperature	1871	-1.9	9.1	16.6	7.8	7.8
Basel	Temperature	1872	-0.5	9.3	17.0	10.3	9.8
Basel	Temperature	1873	2.4	8.8	18.4	9.3	9.4
Basel	Temperature	2015	2.8	11.2	21.0	11.1	11.7
Basel	Temperature	2016	4.8	9.8	19.6	11.1	10.9
Basel	Temperature	2017	1.6	11.8	20.8	10.7	11.4
Basel	Temperature	2018	3.2	11.9	21.2	11.8	12.2
Basel	Temperature	2019	3.9	10.2	20.7	11.6	11.6
Basel	Temperature	2020	5.4	11.8	20.1	11.5	12.1
Basel	Temperature	2021	3.8	9.1	19.0	10.6	10.6
Basel	Temperature	2022	4.1	11.8	21.6	12.8	12.5
Basel	Temperature	2023	4.2	11.1	21.1	13.6	12.6
Basel	Temperature	2024	5.5	11.8	20.6	11.6	12.2

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

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Basel	Precipitation	1864	NA	50.2	83.1	55.2	50.5
Basel	Precipitation	1865	41.1	42.4	75.4	56.5	54.3
Basel	Precipitation	1866	39.3	85.6	77.6	54.7	74.2
Basel	Precipitation	1867	112.2	79.1	85.6	61.8	77.2
Basel	Precipitation	1868	29.4	41.3	69.1	82.4	63.7
Basel	Precipitation	1869	60.2	73.6	67.1	67.4	62.0
Basel	Precipitation	1870	38.8	37.3	61.1	80.5	55.2
Basel	Precipitation	1871	47.9	47.5	77.7	44.3	47.8
Basel	Precipitation	1872	26.7	117.7	99.4	76.3	83.7

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Basel	Precipitation	1873	28.4	65.5	72.3	80.0	58.4
Basel	Precipitation	2015	47.5	70.3	63.7	44.6	53.8
Basel	Precipitation	2016	78.0	112.4	93.7	52.4	83.1
Basel	Precipitation	2017	33.6	71.8	67.8	56.1	63.8
Basel	Precipitation	2018	77.5	63.3	51.2	34.4	58.1
Basel	Precipitation	2019	49.7	60.9	93.0	74.4	65.5
Basel	Precipitation	2020	45.7	46.1	70.9	56.9	56.4
Basel	Precipitation	2021	70.7	73.1	122.6	39.7	76.8
Basel	Precipitation	2022	45.6	59.4	82.5	82.1	66.3
Basel	Precipitation	2023	35.0	64.9	84.0	76.5	64.6
Basel	Precipitation	2024	53.0	94.9	54.8	72.0	69.2

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

City	Month	Temperature	Precipitation
Basel	Jan	0.7	44.6
Basel	Feb	2.2	42.0
Basel	Mar	5.6	48.4
Basel	Apr	9.3	61.9
Basel	May	13.4	82.0
Basel	Jun	16.7	90.6
Basel	Jul	18.6	84.1
Basel	Aug	17.9	87.4
Basel	Sep	14.5	72.9
Basel	Oct	9.6	65.7
Basel	Nov	4.9	59.7
Basel	Dec	1.7	53.3

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