Climate Data Visualization -

Atmospheric CO_2 Concentration / Temperature / Precipitation

Wolfgang Vollmer

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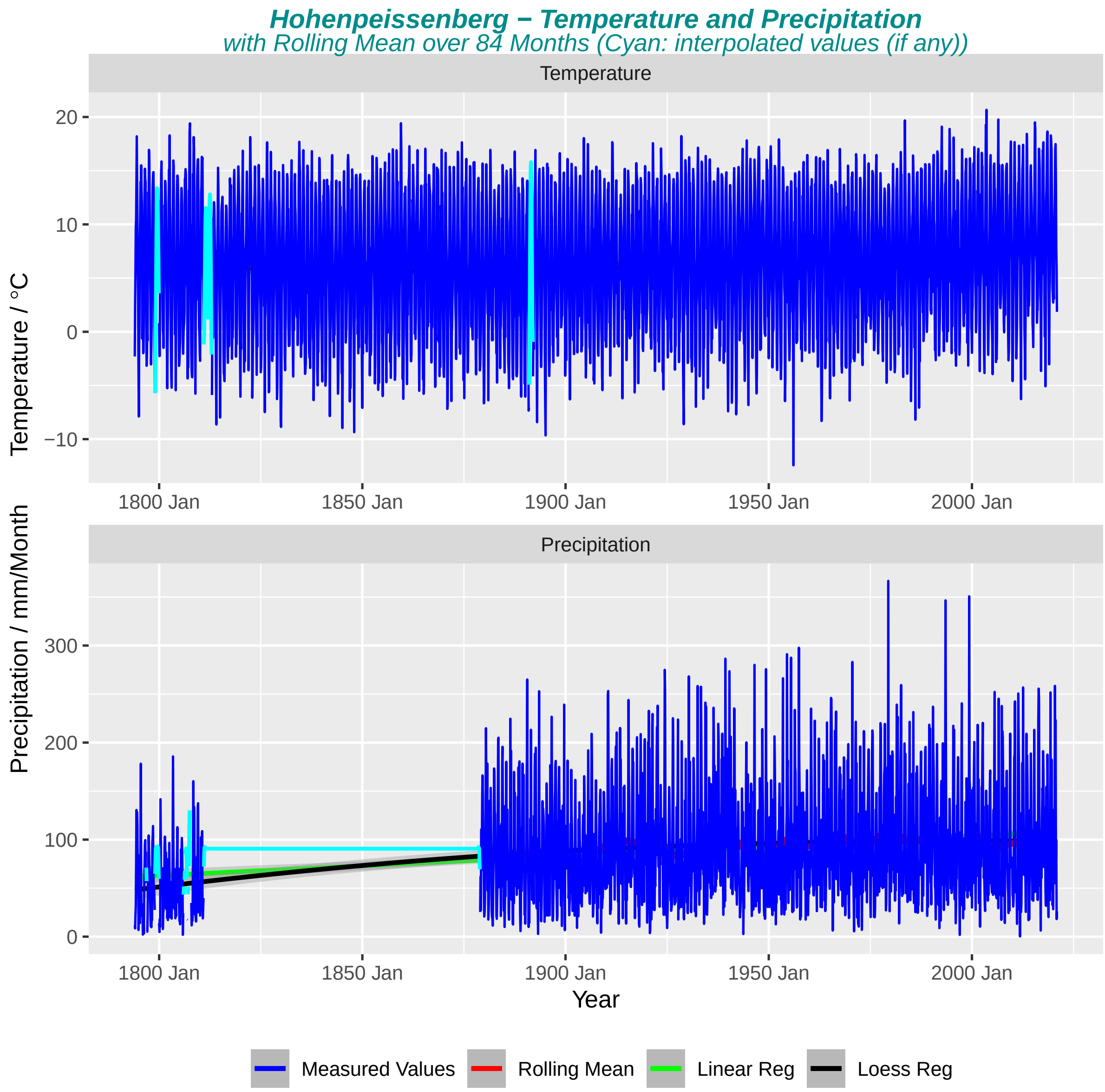
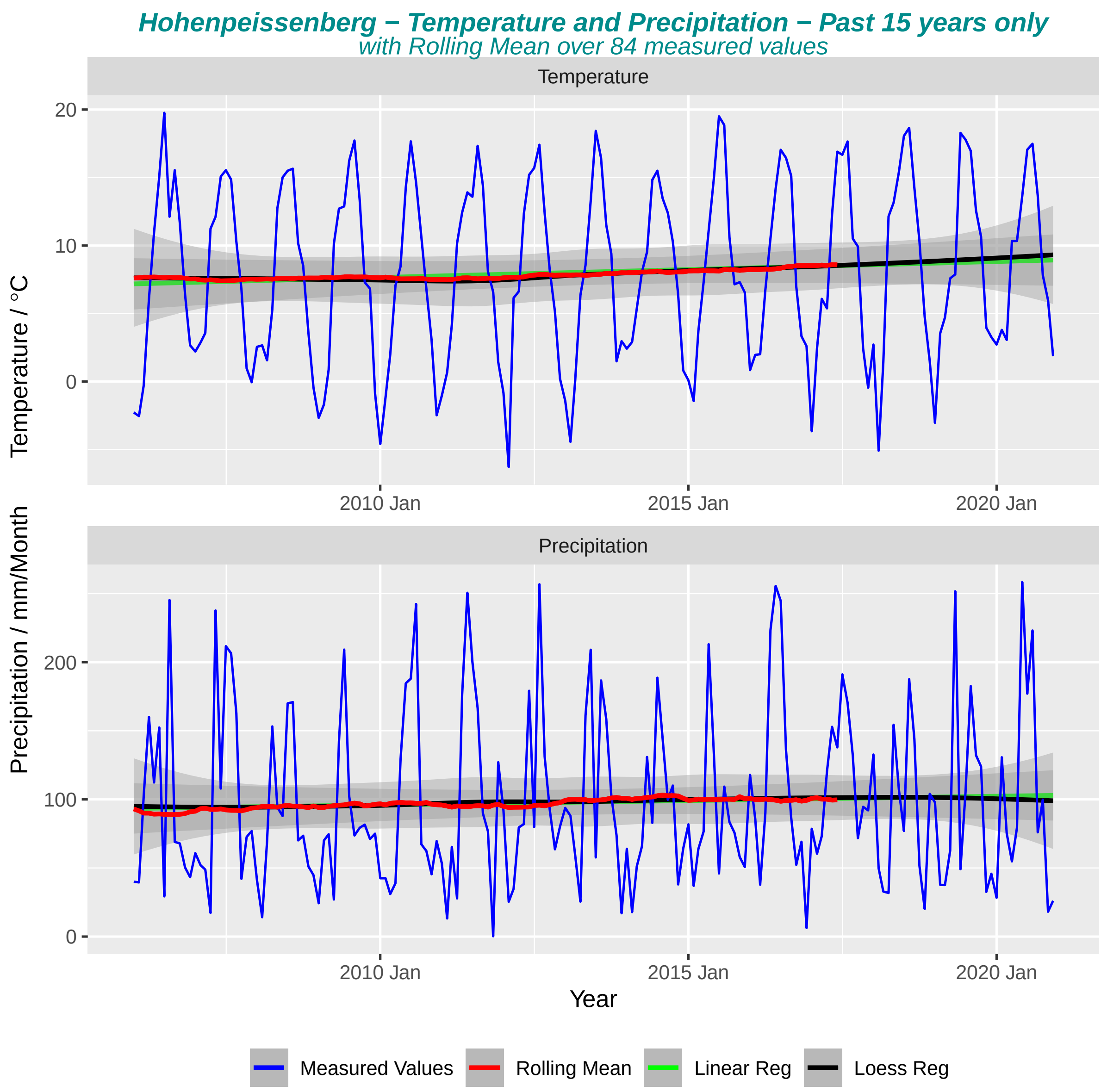
1 Hohenpeissenberg - Visualization of Temperature and Precipitation Data 1794 - 2020

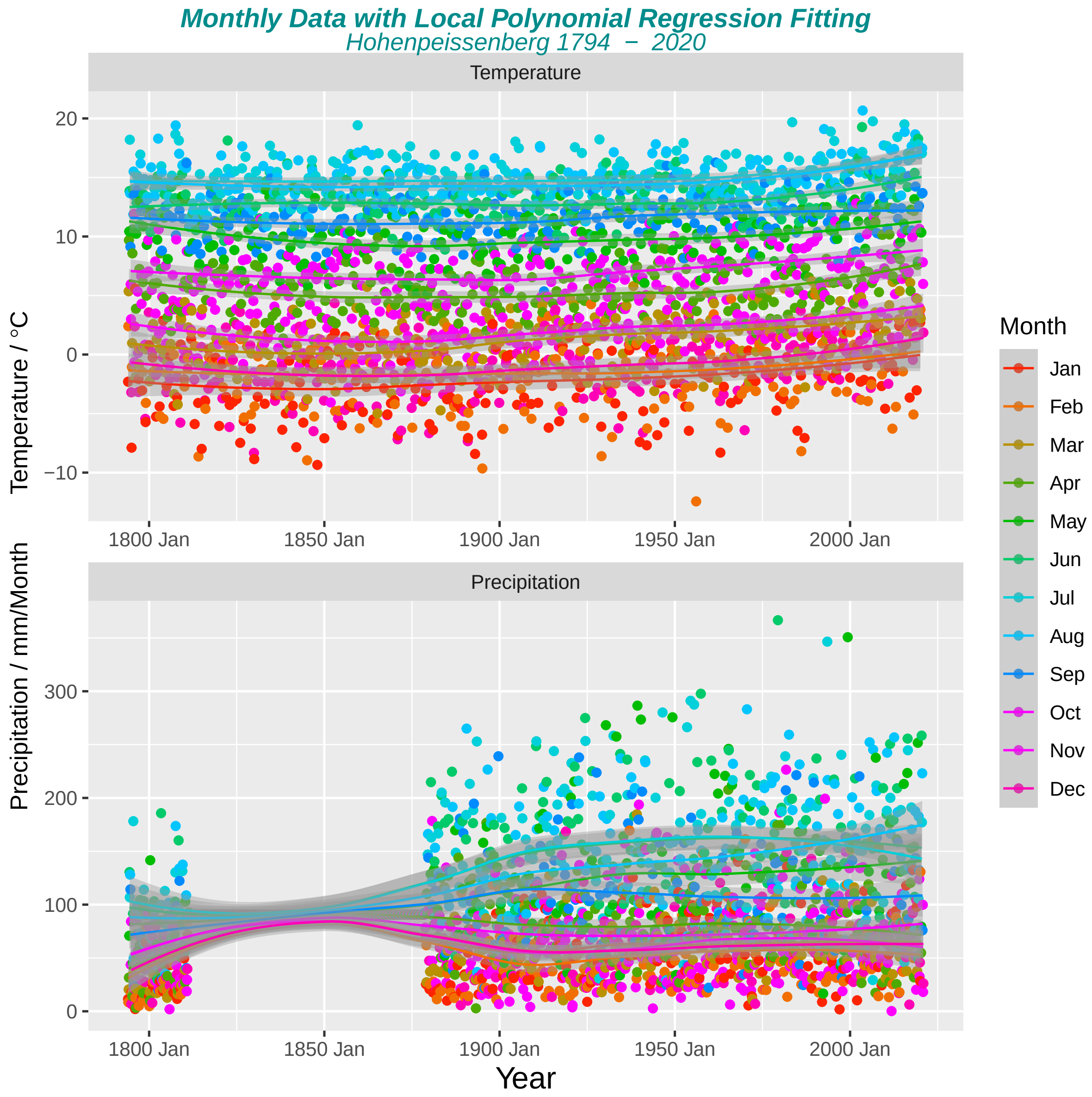
1.1 Monthly Time Plots with Rolling Mean





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

1.2 Yearly plots with monthly breakdown



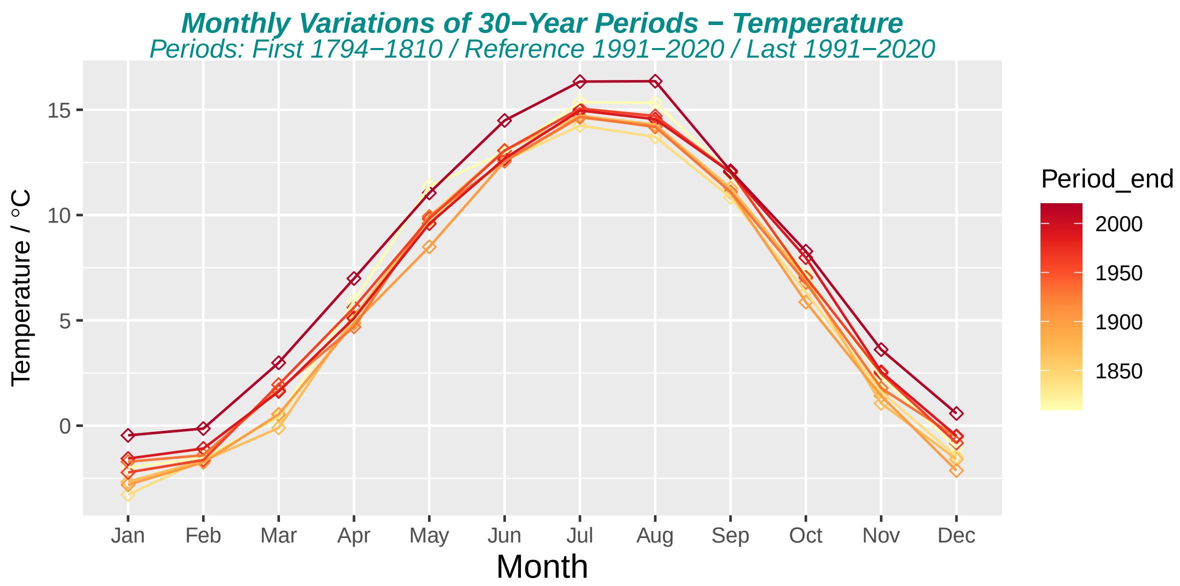
1.2.1 30-year period plots with monthly breakdown - Cartesian and Polar Coordinates

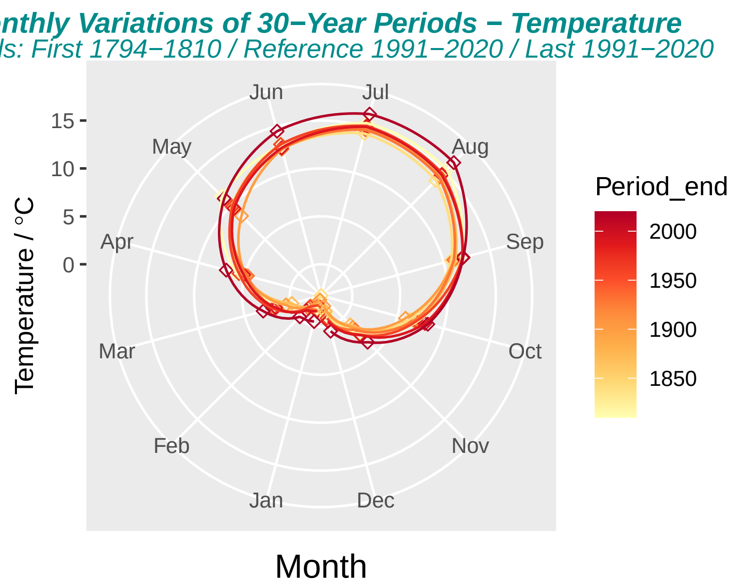
Table 1: 30-years Periods - Average Data (Temperature / degree C and Monthly Precipitation / mm)

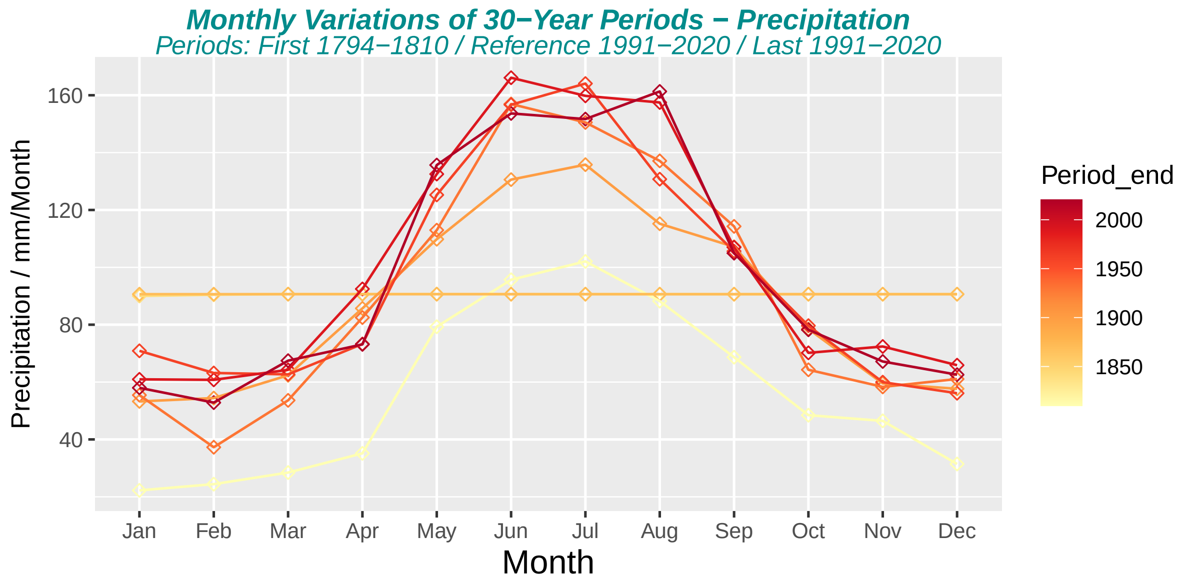
City	Period	Temperature	Monthly Precipitation	Annual Precipitation
Hohenpeissenberg	1794-1810	6.5	55.9	670.5
Hohenpeissenberg	1811-1840	5.7	90.6	1087.0
Hohenpeissenberg	1841-1870	5.9	90.6	1087.7
Hohenpeissenberg	1871-1900	5.6	87.5	1049.9
Hohenpeissenberg	1901-1930	6.1	90.4	1084.3
Hohenpeissenberg	1931-1960	6.4	95.7	1148.1
Hohenpeissenberg	1961-1990	6.5	100.8	1209.8
Hohenpeissenberg	1991-2020	7.7	97.2	1166.7

City	Ref_Period	Temperature	Monthly Precipitation	Annual Precipitation
Hohenpeissenberg	1991-2020	7.7	97.2	1166.7

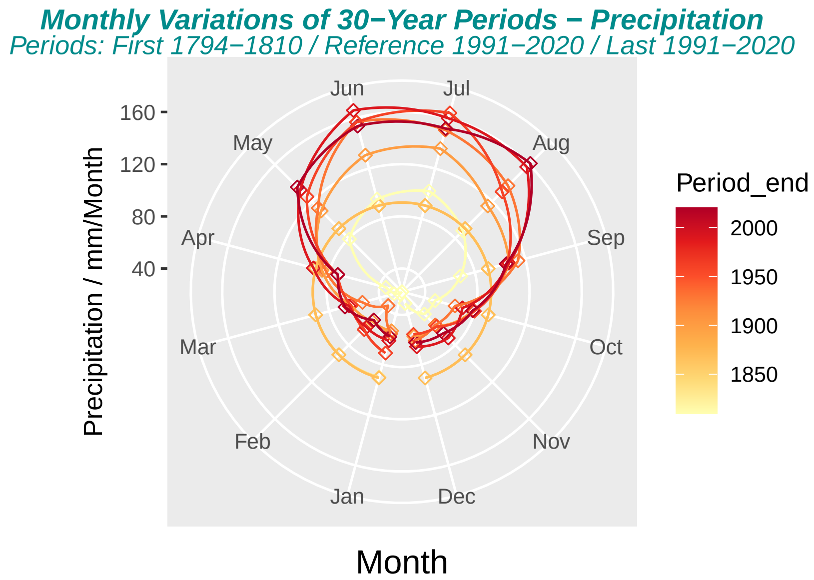
Note: First Period shorter in general (starts with first data year = 1794)





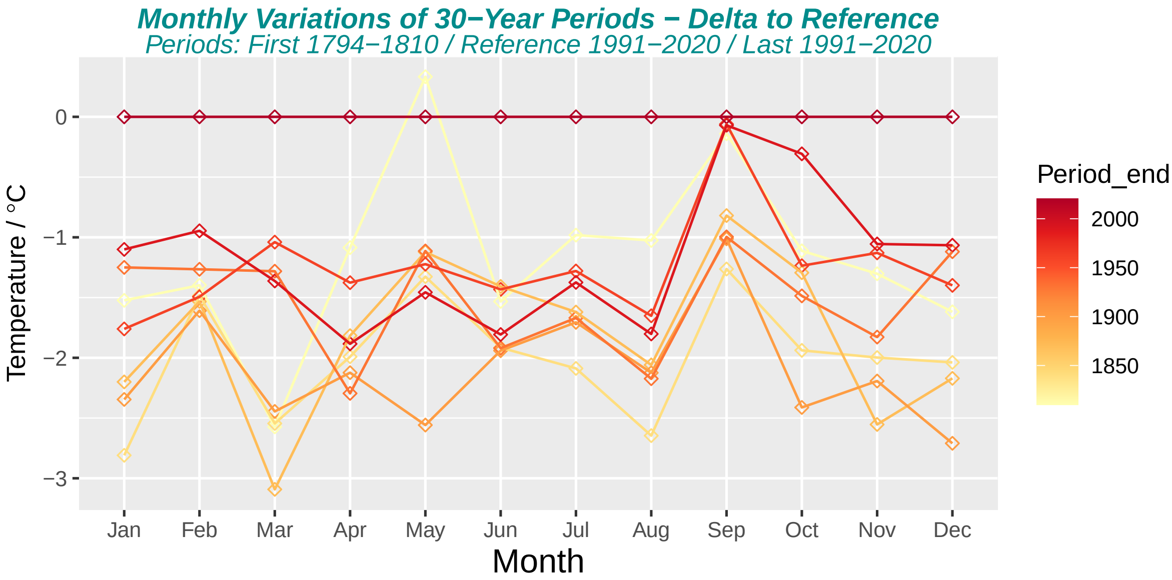


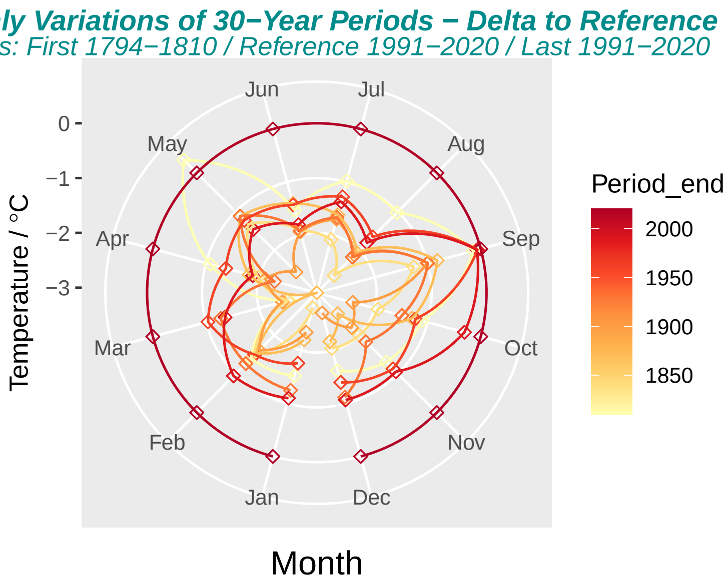
Monthly Variations of 30−Year Periods − Precipitation
Periods: First 1794−1810 / Reference 1991−2020 / Last 1991−2020
Precipitation / mm/Month
160
120
80
40
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2000
1950
1900
1850

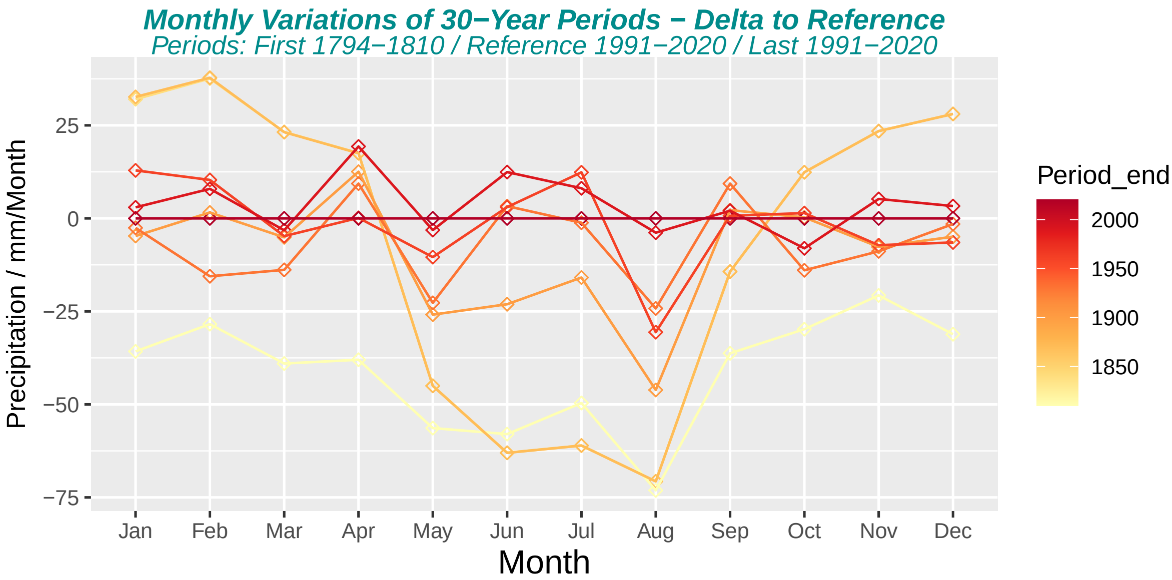


Monthly Variations of 30−Year Periods − Precipitation
Periods: First 1794−1810 / Reference 1991−2020 / Last 1991−2020
Precipitation / mm/Month
160
120
80
40
Jun
Jul
May
Aug
Apr
Sep
Mar
Oct
Feb
Nov
Jan
Dec
Month
Period_end
2000
1950
1900
1850

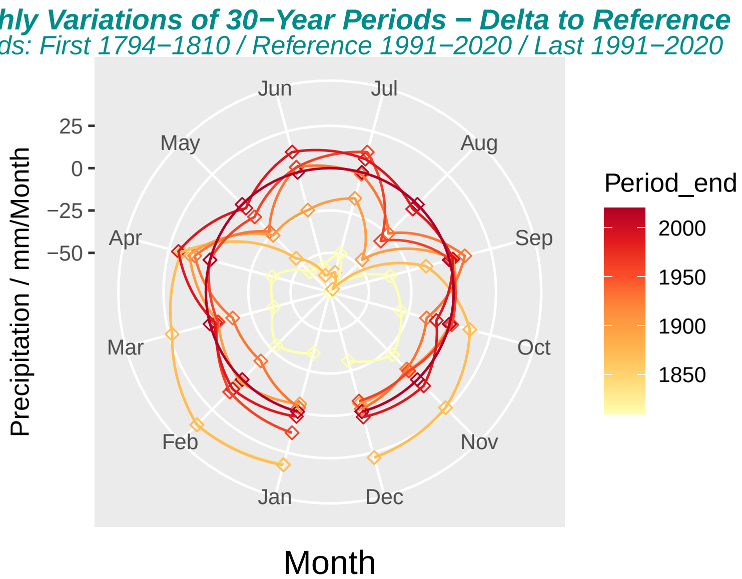
1.2.2 Plot Monthly Delta to Reference Period - Cartesian and Polar Coordinates



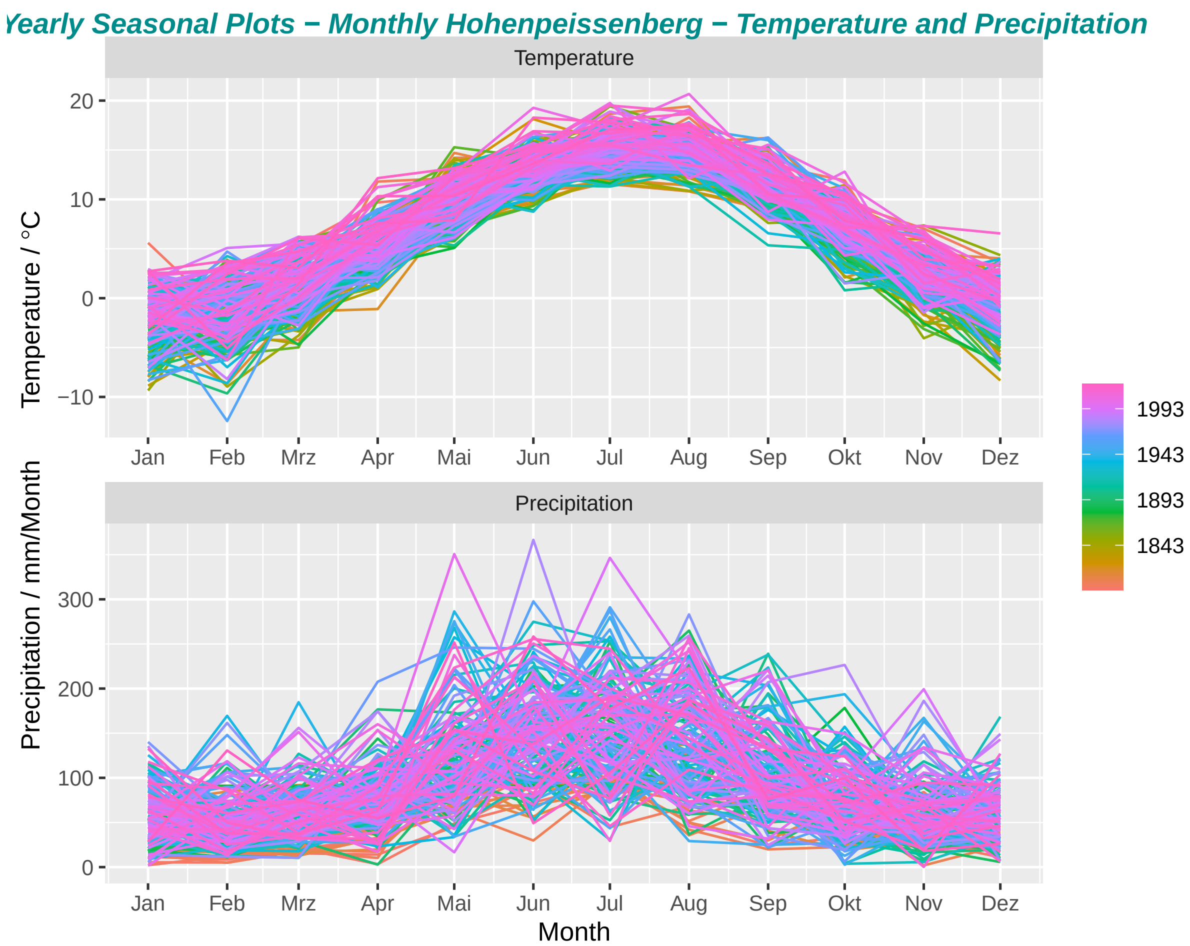


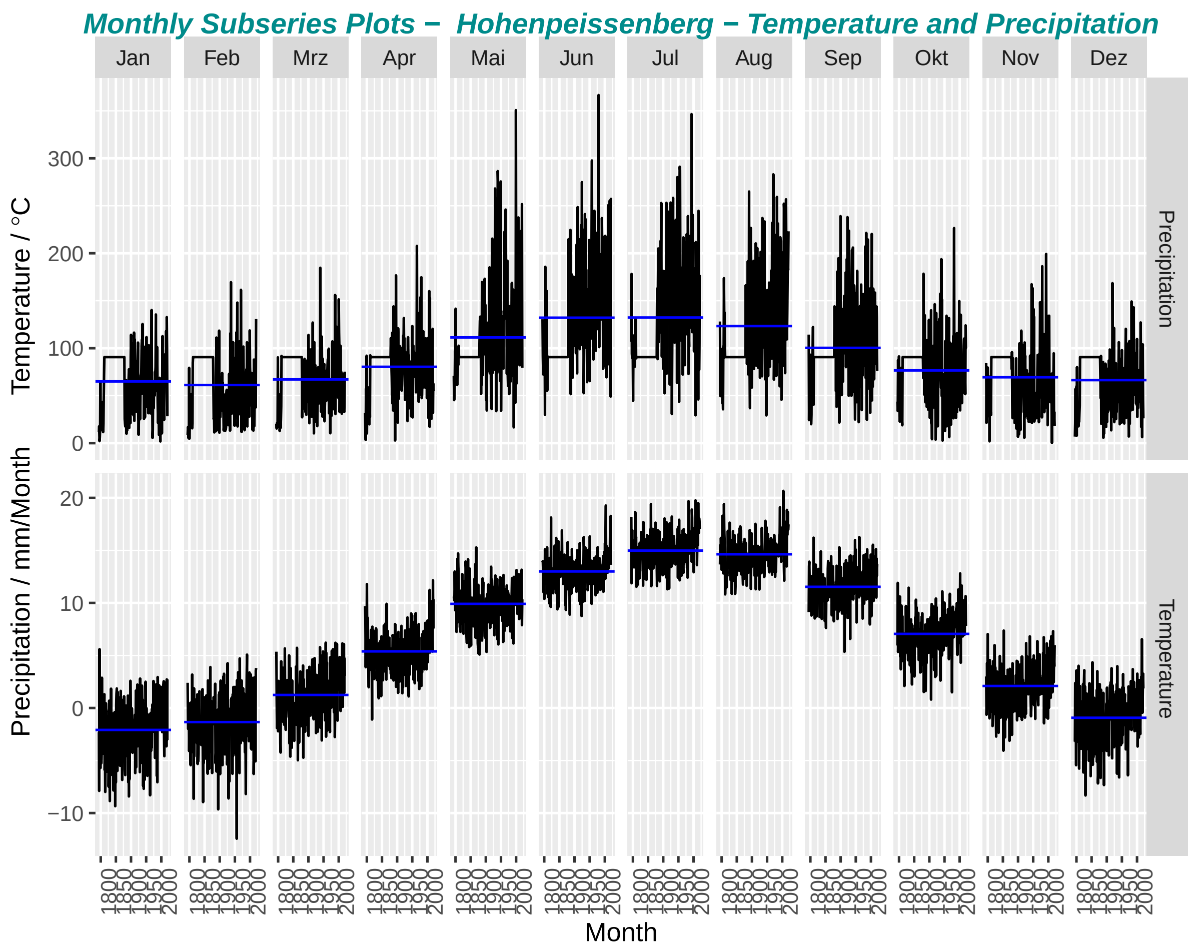


Monthly Variations of 30−Year Periods − Delta to Reference
Periods: First 1794−1810 / Reference 1991−2020 / Last 1991−2020
Precipitation / mm/Month
25
0
−25
−50
−75
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Period_end
2000
1950
1900
1850



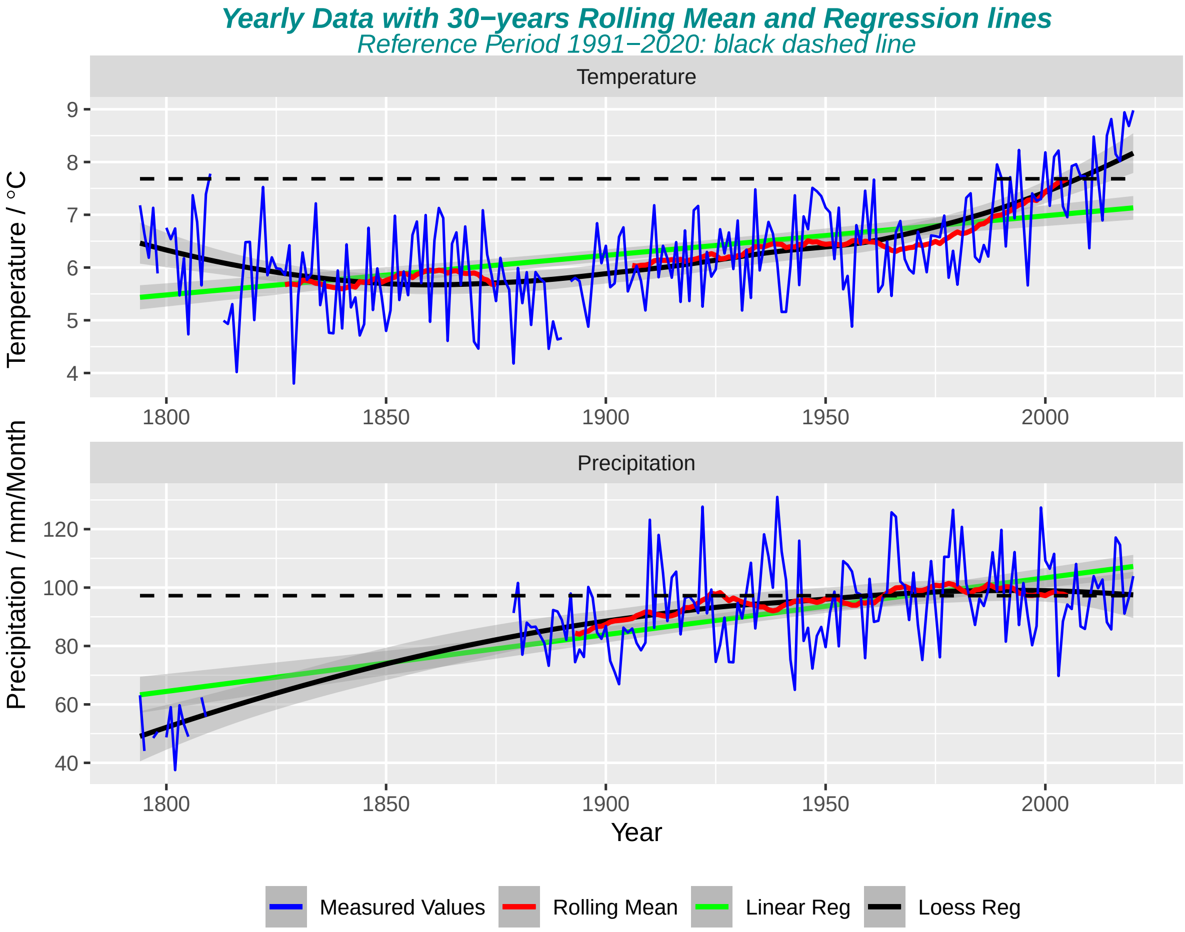
Monthly Variations of 30−Year Periods − Delta to Reference
Periods: First 1794−1810 / Reference 1991−2020 / Last 1991−2020
Precipitation / mm/Month
25
0
−25
−50
Jun
Jul
May
Aug
Apr
Sep
Mar
Oct
Feb
Nov
Jan
Dec
Month
Period_end
2000
1950
1900
1850


Yearly Seasonal Plots − Monthly Hohenpeissenberg − 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
300
200
100
0
Jan
Feb
Mrz
Apr
Mai
Jun
Jul
Aug
Sep
Okt
Nov
Dez
Month
1993
1943
1893
1843

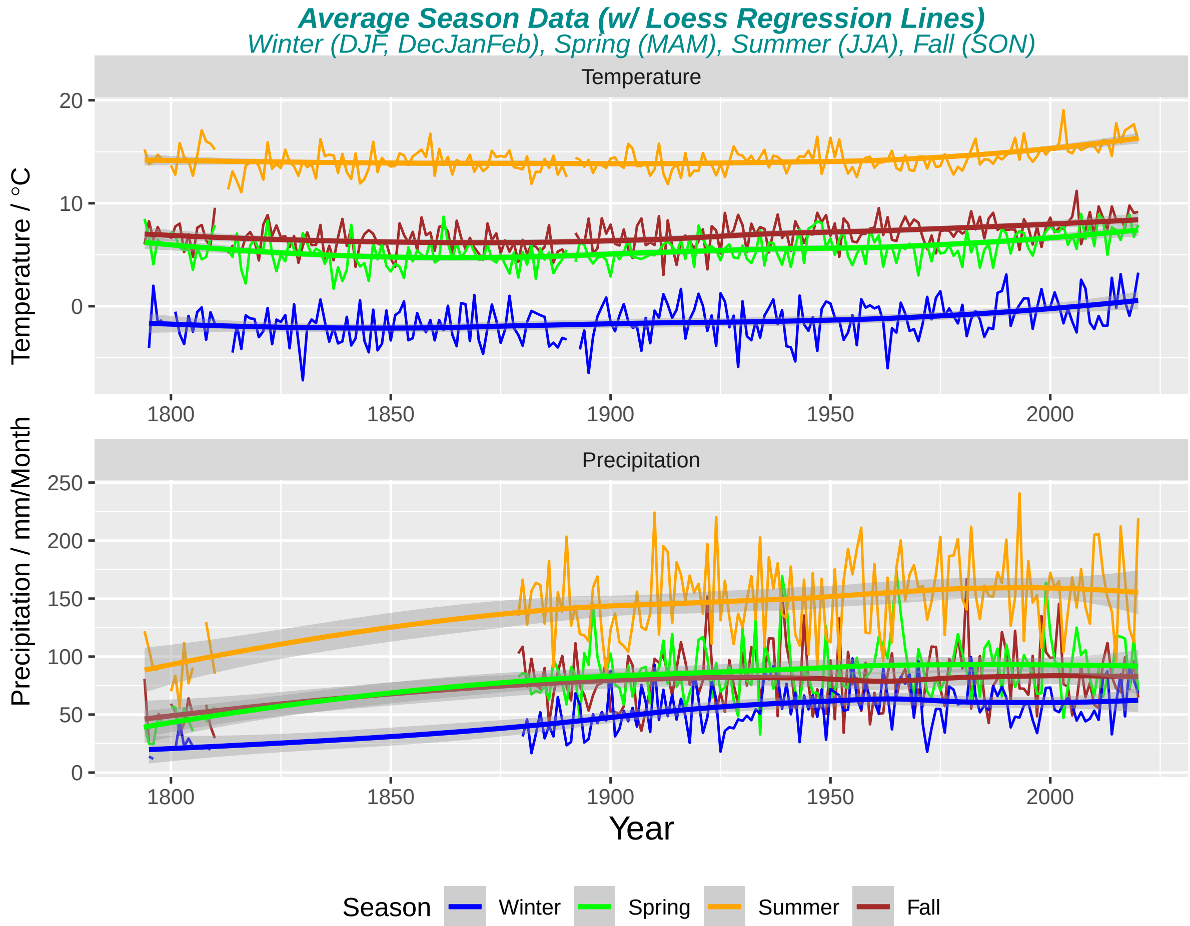


1.3 Yearly Hohenpeissenberg - Temperature and Precipitation

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

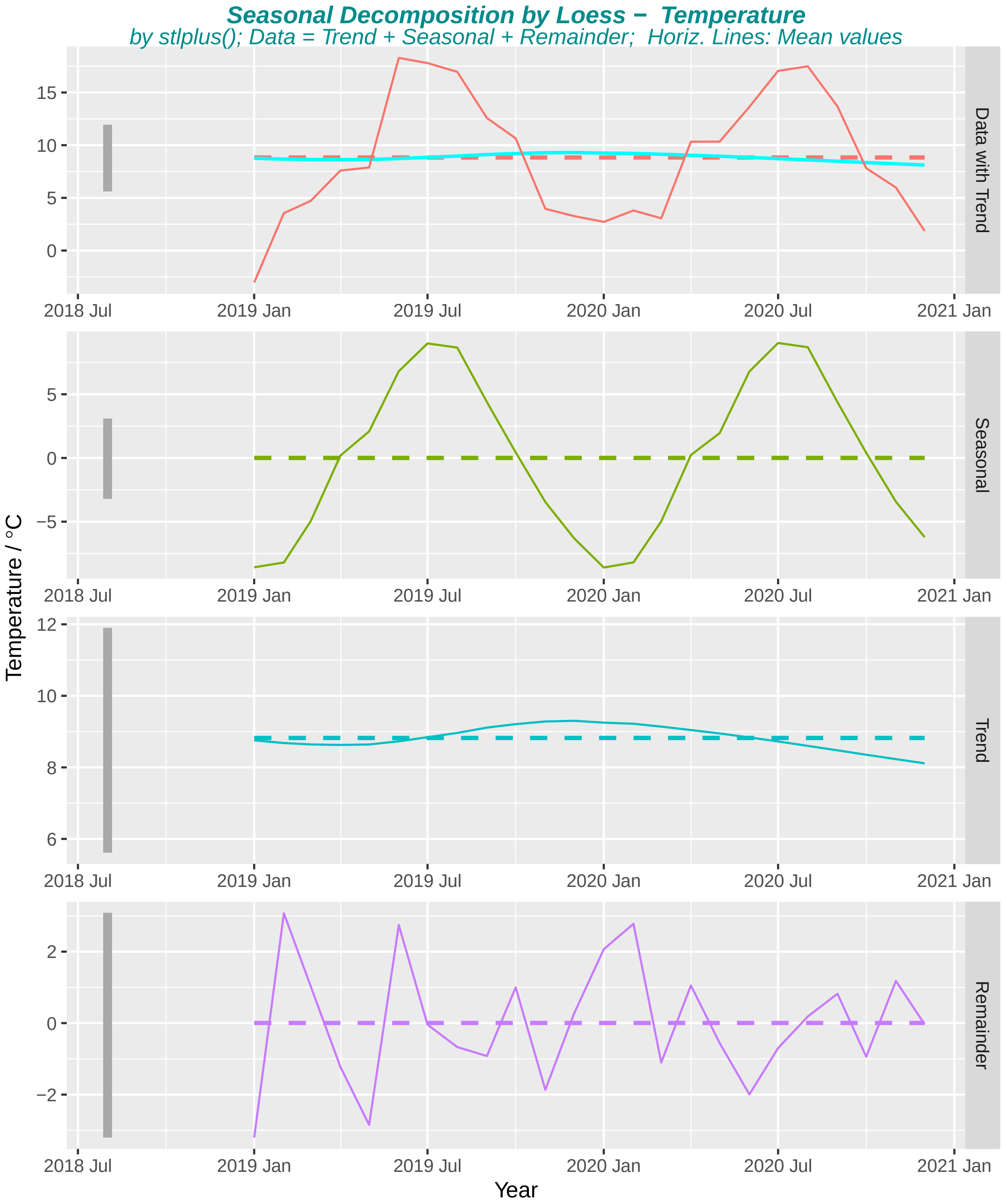
An *additive model* would be used when the variations around the trend do not vary with the level of the time series whereas a *multiplicative model* would be appropriate if the trend is proportional to the level of the time series.

Time series using an

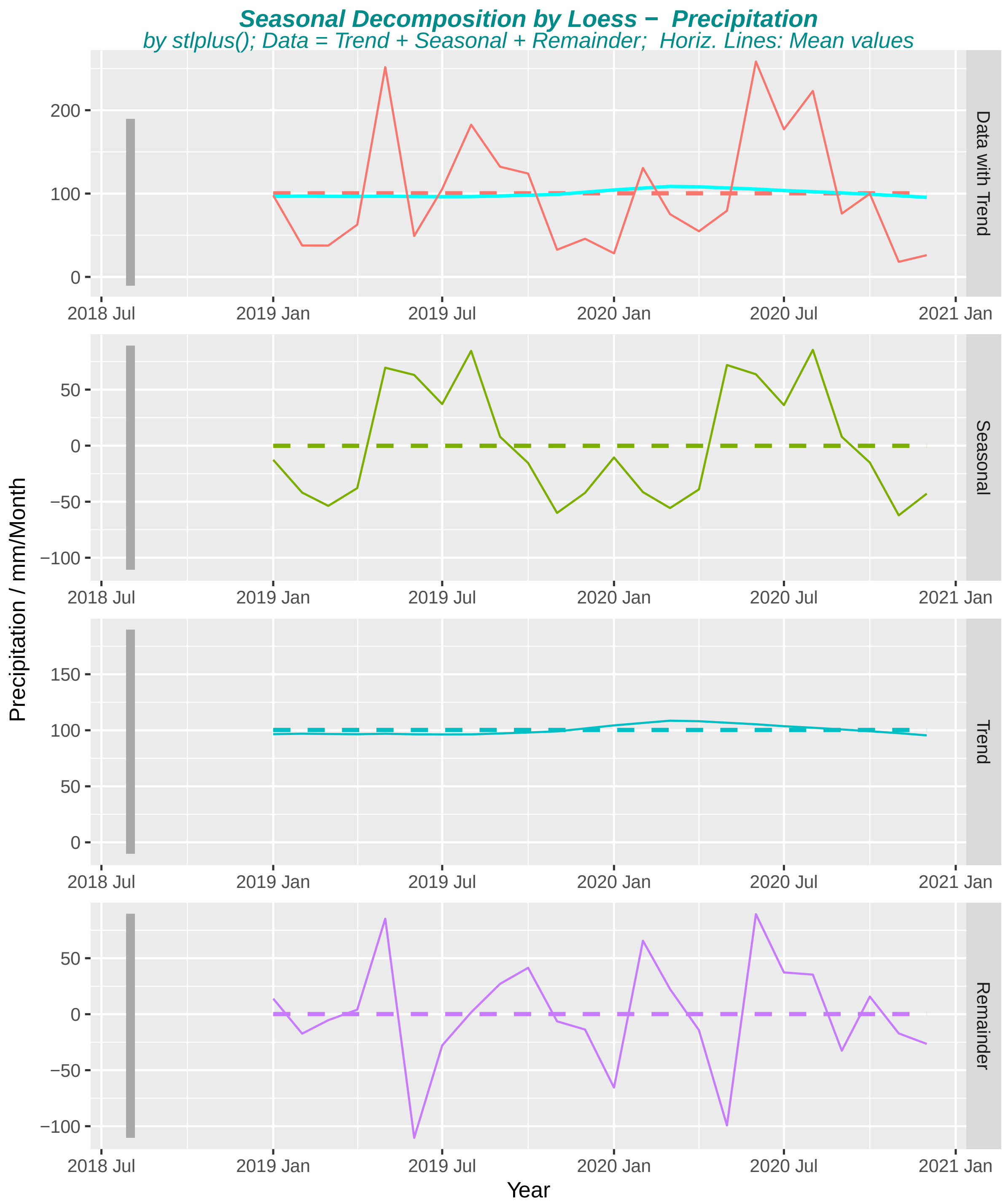
- additive model: $y_t = T_t + C_t + S_t + \epsilon_t$
- multiplicative model: $y_t = T_t * C_t * S_t * \epsilon_t$

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 modle, it only provides facilities for additive decompositions. It is possible to obtain a multiplicative decomposition by first taking logs of the data.

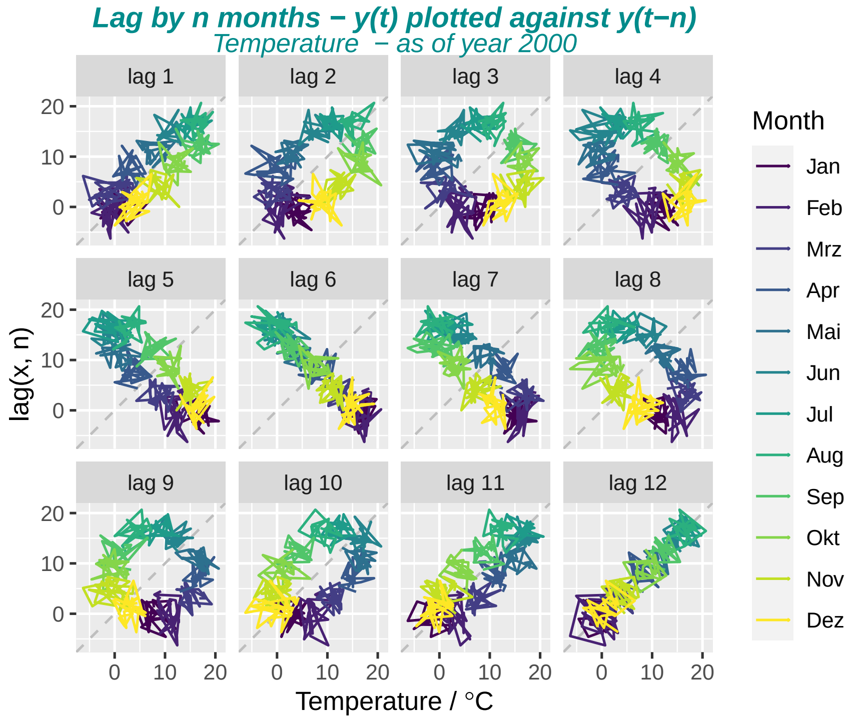


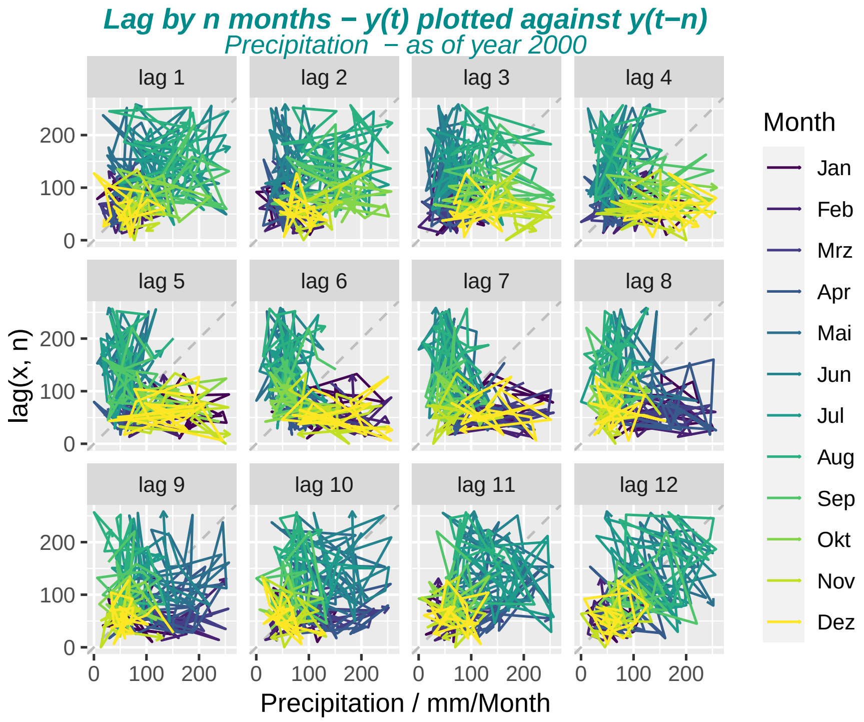
Seasonal Decomposition by Loess − Temperature
by stlplus(); Data = Trend + Seasonal + Remainder; Horiz. Lines: Mean values
Data with Trend
Seasonal
Trend
Remainder
Temperature / °C
Year
2018 Jul
2019 Jan
2019 Jul
2020 Jan
2020 Jul
2021 Jan



2.2 Periodicities - Season Frequency

2.2.1 Lag Plot - Differences





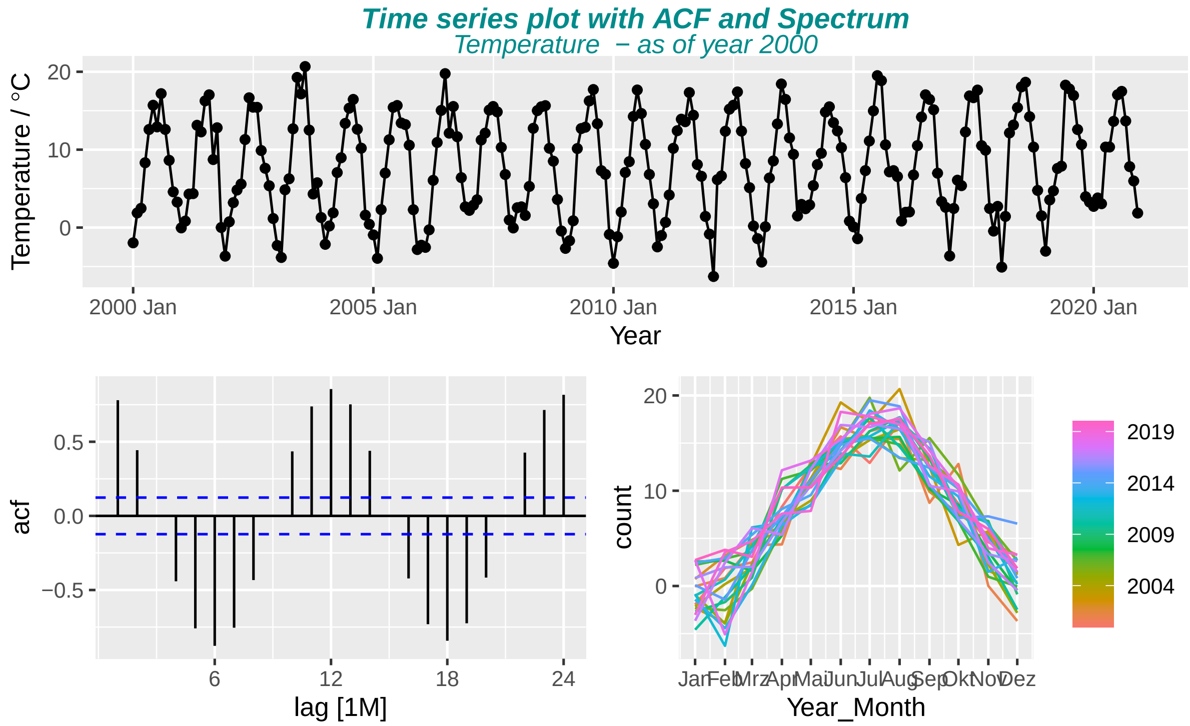
2.2.2 ACF / PACF Correlogram

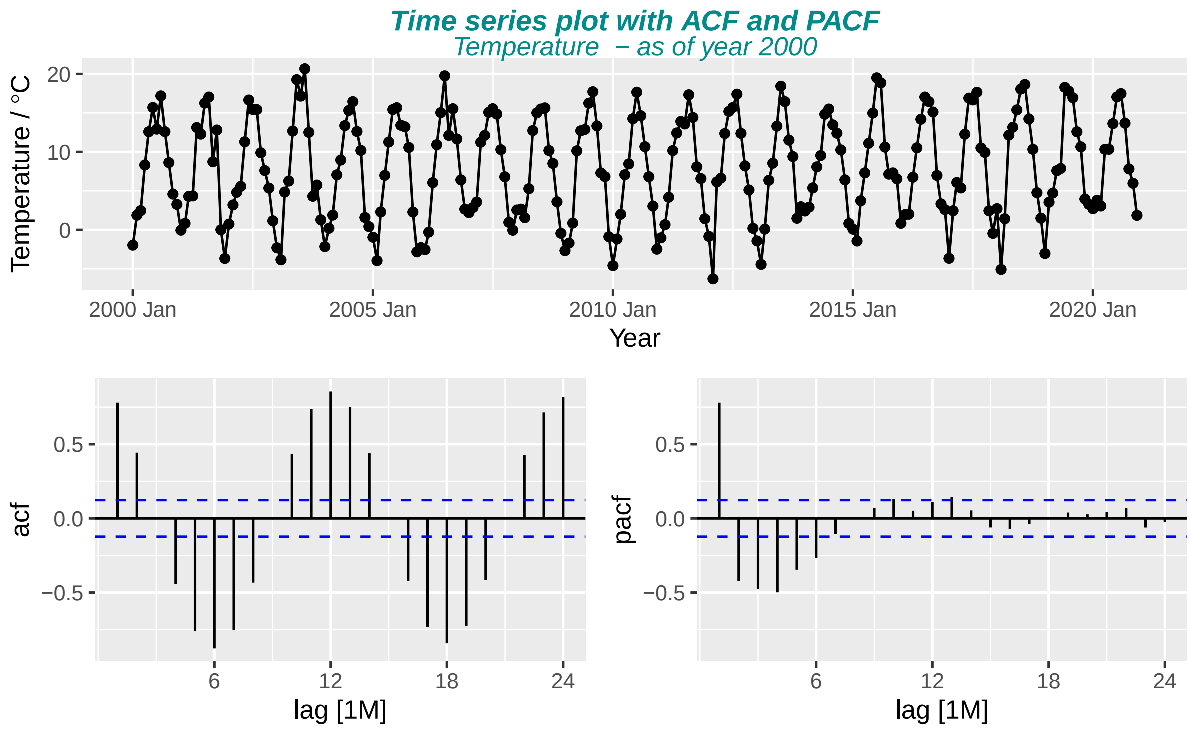
2.2.3 Periodogram - Spectral Density Estimation of a Time Series

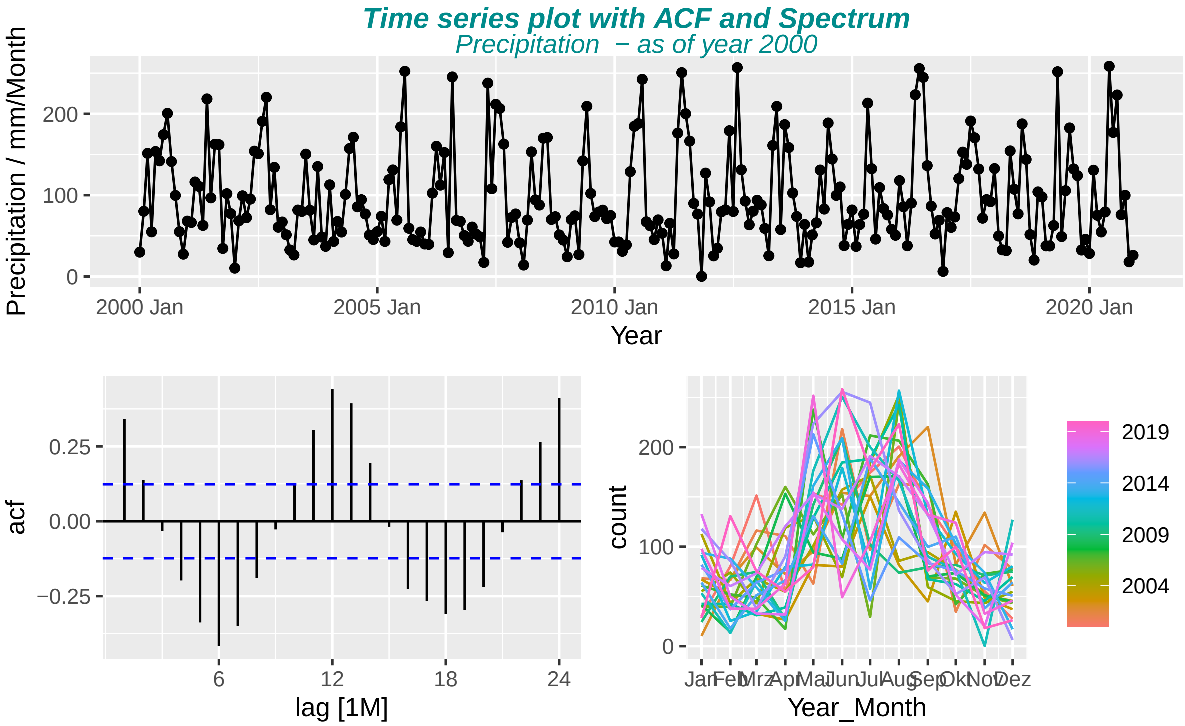
The spectral density characterizes the frequency content of the signal. One purpose of estimating the spectral density is to detect any periodicities in the data, by observing peaks at the frequencies corresponding to these periodicities.

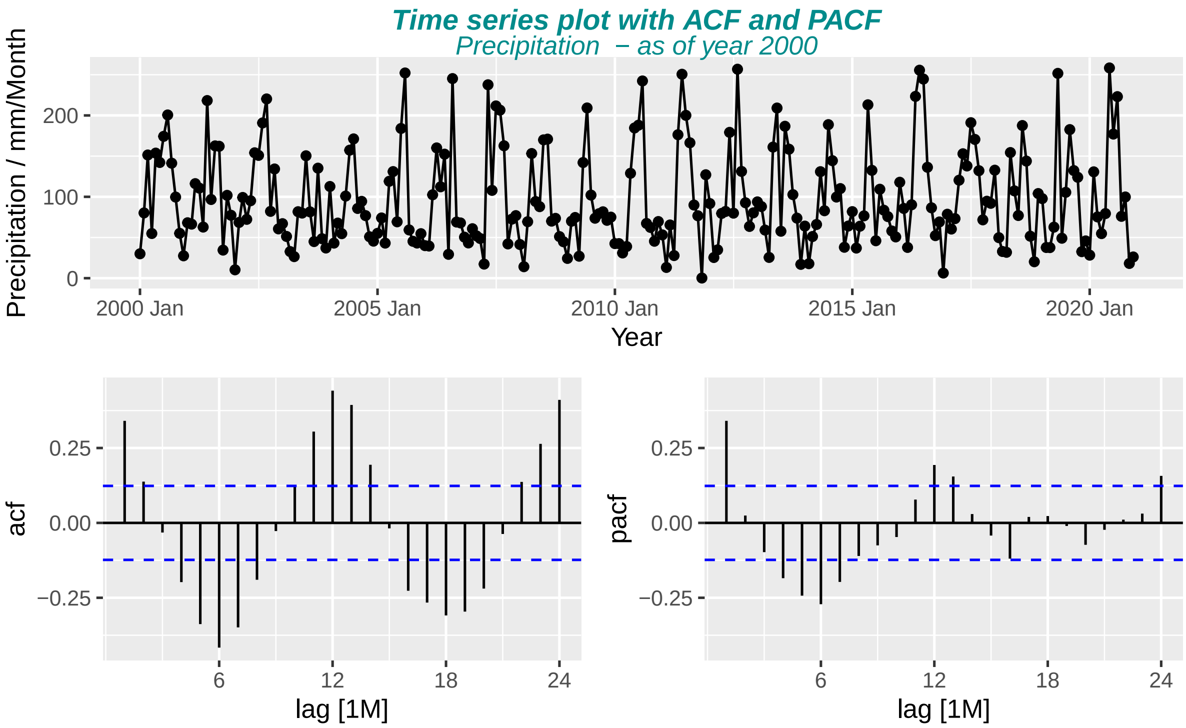
At frequency $\lambda = 1/12$ there is a significant peak => This pattern repeats every full frequency = every 12 months / every year

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







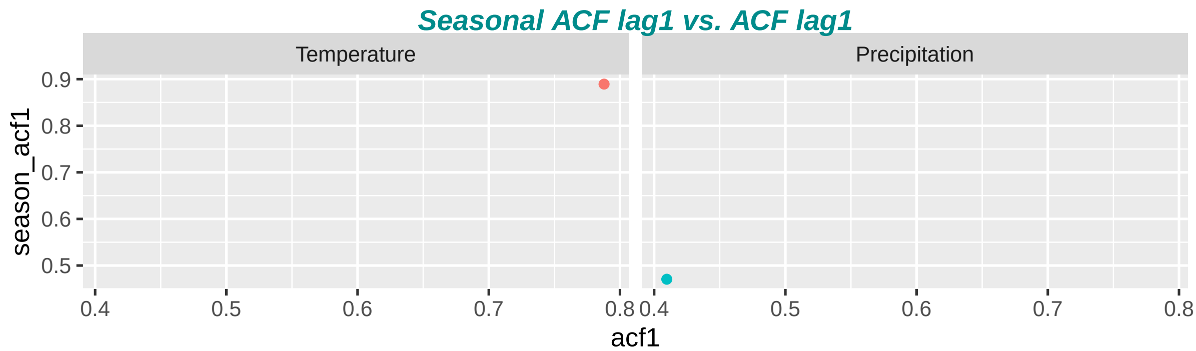


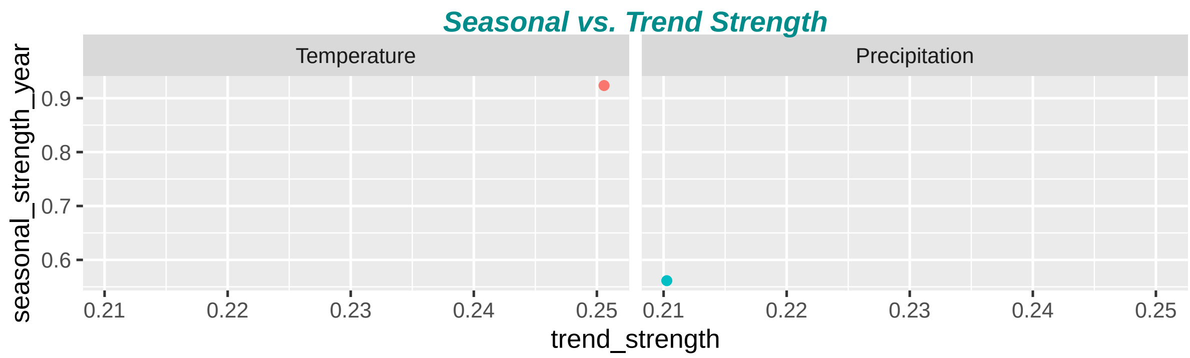
2.2.4 Seasonal vs non Seasonal ACF / Strength (Seasonal/Trend)

- 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~ 0.788 3.29       0.287       1.16      -0.484       0.302       0.889
#> 2 Precipi~ 0.410 0.556     -0.346       0.142     -0.635       0.433       0.471
#> [1] "Check Trend & Seasonal Strength close to 0 / 1 : weak / strong and compare them"
#> # A tibble: 2 x 10
#>   Measure trend_strength seasonal_streng~ seasonal_peak_y~ seasonal_trough~
#>   <fct>            <dbl>            <dbl>            <dbl>            <dbl>
#> 1 Temper~          0.251            0.923                7                1
#> 2 Precip~          0.210            0.561                7                2
#> # ... with 5 more variables: 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              0.263
#> 2 Precipitation            0.850
```

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 Hohenpeissenberg - 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
Hohenpeissenberg	Temperature	1794	NA	8.5	15.2	6.0	7.2
Hohenpeissenberg	Temperature	1795	-4.0	6.7	13.8	8.3	6.6
Hohenpeissenberg	Temperature	1796	2.0	4.1	14.1	6.5	6.2
Hohenpeissenberg	Temperature	1797	-1.6	6.5	14.7	7.7	7.1
Hohenpeissenberg	Temperature	1798	-1.3	5.9	14.3	6.7	5.9
Hohenpeissenberg	Temperature	1799	NA	NA	NA	NA	NA
Hohenpeissenberg	Temperature	1800	NA	7.2	13.7	6.5	6.8
Hohenpeissenberg	Temperature	1801	-0.5	6.8	12.8	7.8	6.5
Hohenpeissenberg	Temperature	1802	-2.7	5.7	15.8	8.0	6.7
Hohenpeissenberg	Temperature	1803	-3.7	5.4	14.5	5.3	5.5
Hohenpeissenberg	Temperature	2011	-0.9	8.9	14.9	9.7	8.5
Hohenpeissenberg	Temperature	2012	-1.9	8.4	16.1	8.6	7.7
Hohenpeissenberg	Temperature	2013	-1.9	5.0	16.1	7.5	6.9
Hohenpeissenberg	Temperature	2014	2.8	7.7	14.6	9.7	8.5
Hohenpeissenberg	Temperature	2015	-0.2	7.4	17.8	8.4	8.8
Hohenpeissenberg	Temperature	2016	3.1	6.4	15.9	8.5	8.1
Hohenpeissenberg	Temperature	2017	0.5	7.9	17.1	7.6	8.0
Hohenpeissenberg	Temperature	2018	-0.9	8.9	17.4	9.8	8.9
Hohenpeissenberg	Temperature	2019	0.7	6.7	17.7	9.1	8.7
Hohenpeissenberg	Temperature	2020	3.3	7.9	16.1	9.2	9.0

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

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Hohenpeissenberg	Precipitation	1794	NA	41.0	121.8	80.7	63.1
Hohenpeissenberg	Precipitation	1795	13.8	24.9	106.4	26.5	44.1
Hohenpeissenberg	Precipitation	1796	11.8	24.5	88.7	NA	NA
Hohenpeissenberg	Precipitation	1797	NA	46.6	89.2	51.1	48.5
Hohenpeissenberg	Precipitation	1798	11.3	44.6	93.6	47.7	50.7
Hohenpeissenberg	Precipitation	1799	NA	NA	NA	NA	NA
Hohenpeissenberg	Precipitation	1800	NA	56.6	70.0	59.3	48.7
Hohenpeissenberg	Precipitation	1801	19.9	56.1	83.4	52.8	59.1
Hohenpeissenberg	Precipitation	1802	43.7	37.3	56.1	32.9	37.5

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Hohenpeissenberg	Precipitation	1803	22.4	55.3	111.8	42.7	59.7
Hohenpeissenberg	Precipitation	2011	45.3	89.8	205.7	55.6	103.9
Hohenpeissenberg	Precipitation	2012	81.4	65.5	172.0	95.8	99.8
Hohenpeissenberg	Precipitation	2013	87.4	81.9	151.2	111.7	102.8
Hohenpeissenberg	Precipitation	2014	32.9	82.7	138.7	82.6	88.2
Hohenpeissenberg	Precipitation	2015	61.0	117.9	95.9	72.4	85.7
Hohenpeissenberg	Precipitation	2016	84.8	117.1	212.2	69.3	117.2
Hohenpeissenberg	Precipitation	2017	48.4	115.5	166.5	99.5	114.6
Hohenpeissenberg	Precipitation	2018	91.5	73.0	124.0	71.9	91.1
Hohenpeissenberg	Precipitation	2019	79.8	117.3	112.4	96.3	96.6
Hohenpeissenberg	Precipitation	2020	68.3	69.8	219.5	64.6	103.9

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

City	Month	Temperature	Precipitation
Hohenpeissenberg	Jan	-2.1	65.0
Hohenpeissenberg	Feb	-1.3	61.2
Hohenpeissenberg	Mar	1.2	67.1
Hohenpeissenberg	Apr	5.4	80.4
Hohenpeissenberg	May	9.9	111.3
Hohenpeissenberg	Jun	13.0	132.1
Hohenpeissenberg	Jul	15.0	132.3
Hohenpeissenberg	Aug	14.6	123.3
Hohenpeissenberg	Sep	11.5	100.3
Hohenpeissenberg	Oct	7.1	76.6
Hohenpeissenberg	Nov	2.1	69.4
Hohenpeissenberg	Dec	-0.9	66.4

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