

Climate Data Visualization - Atmospheric CO_2 Concentration / Temperature / Precipitation

Wolfgang Vollmer

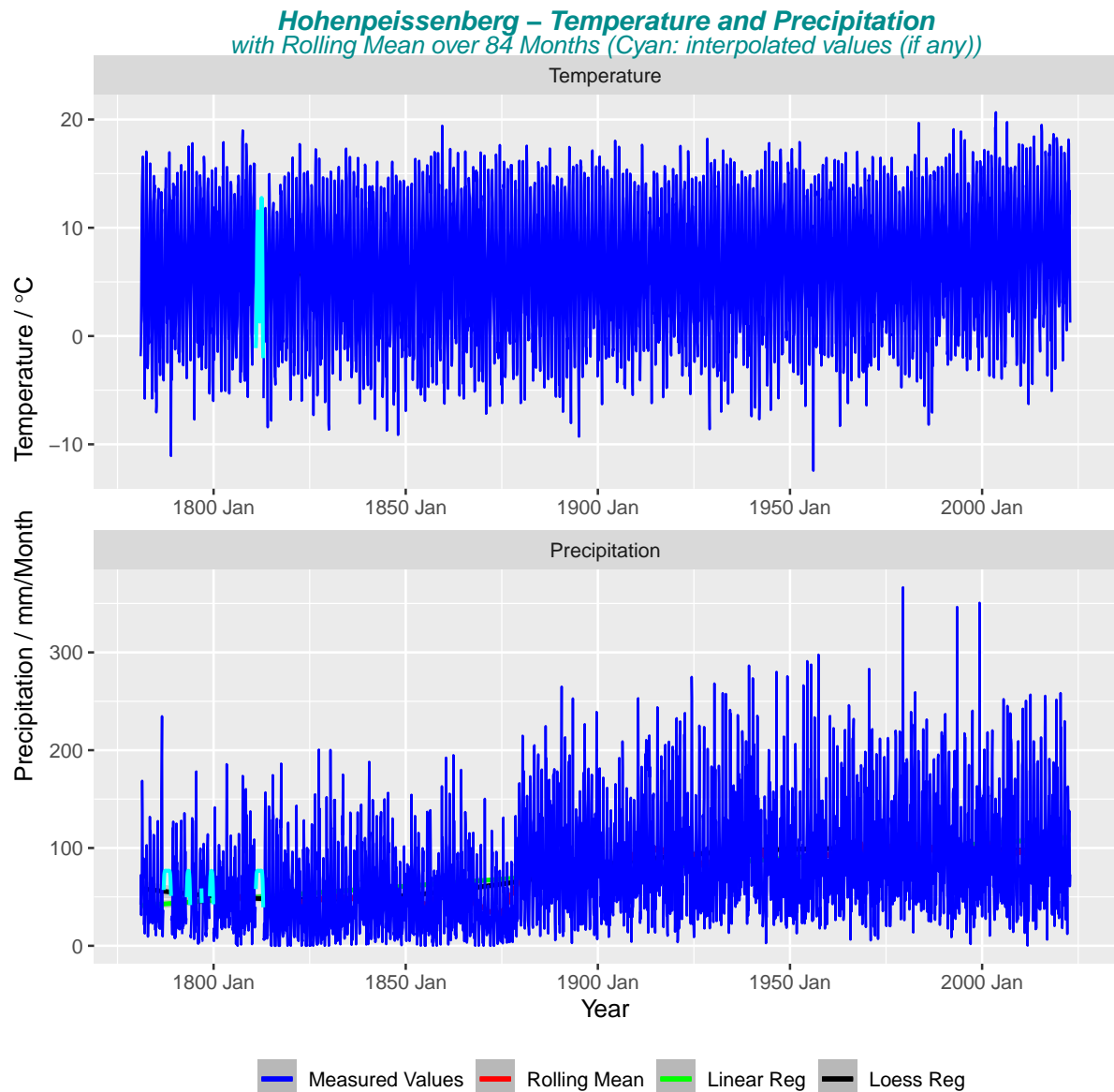
2023-02-18

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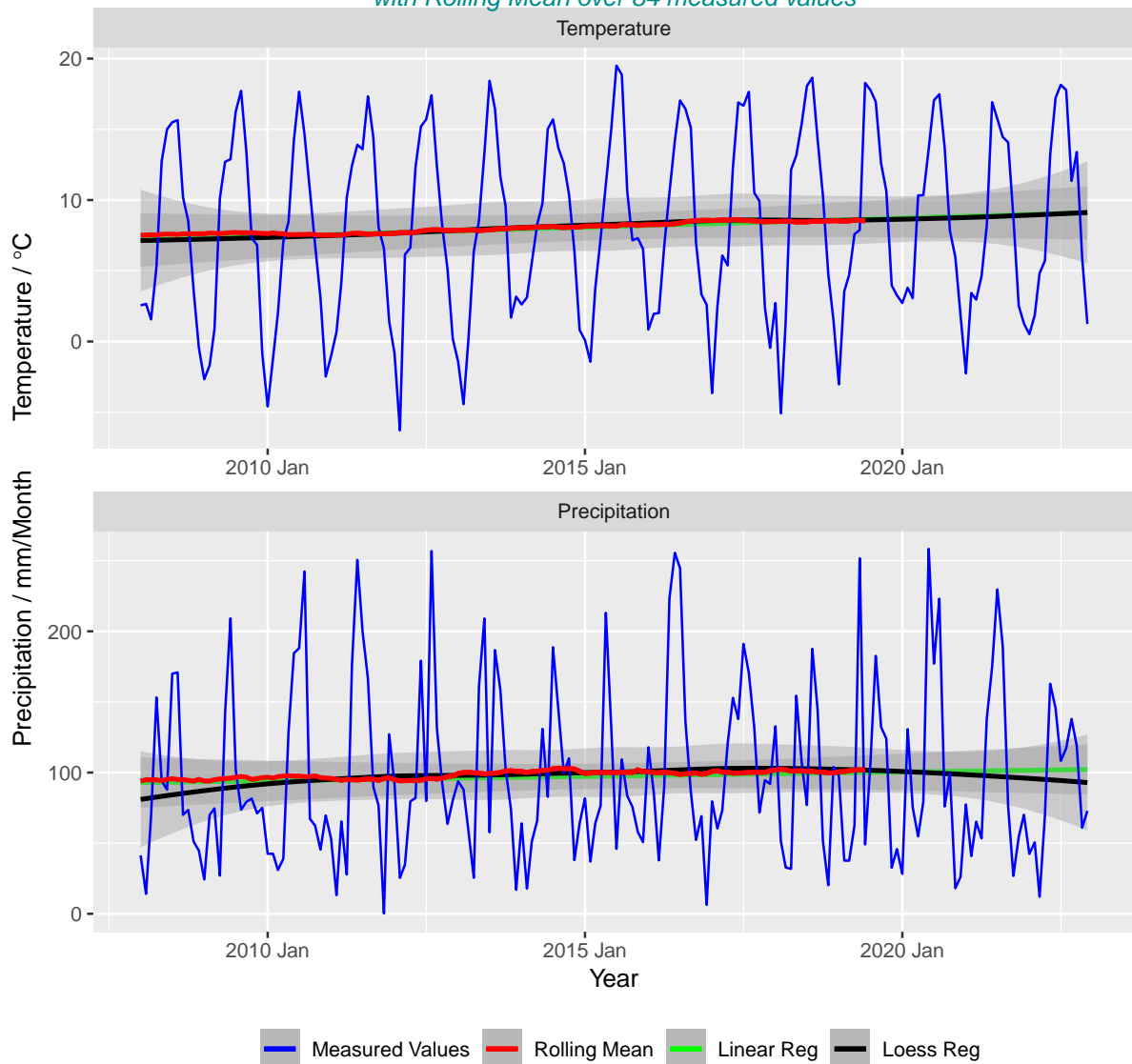
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1 Hohenpeissenberg - Visualization of Temperature and Precipitation Data 1781 - 2022

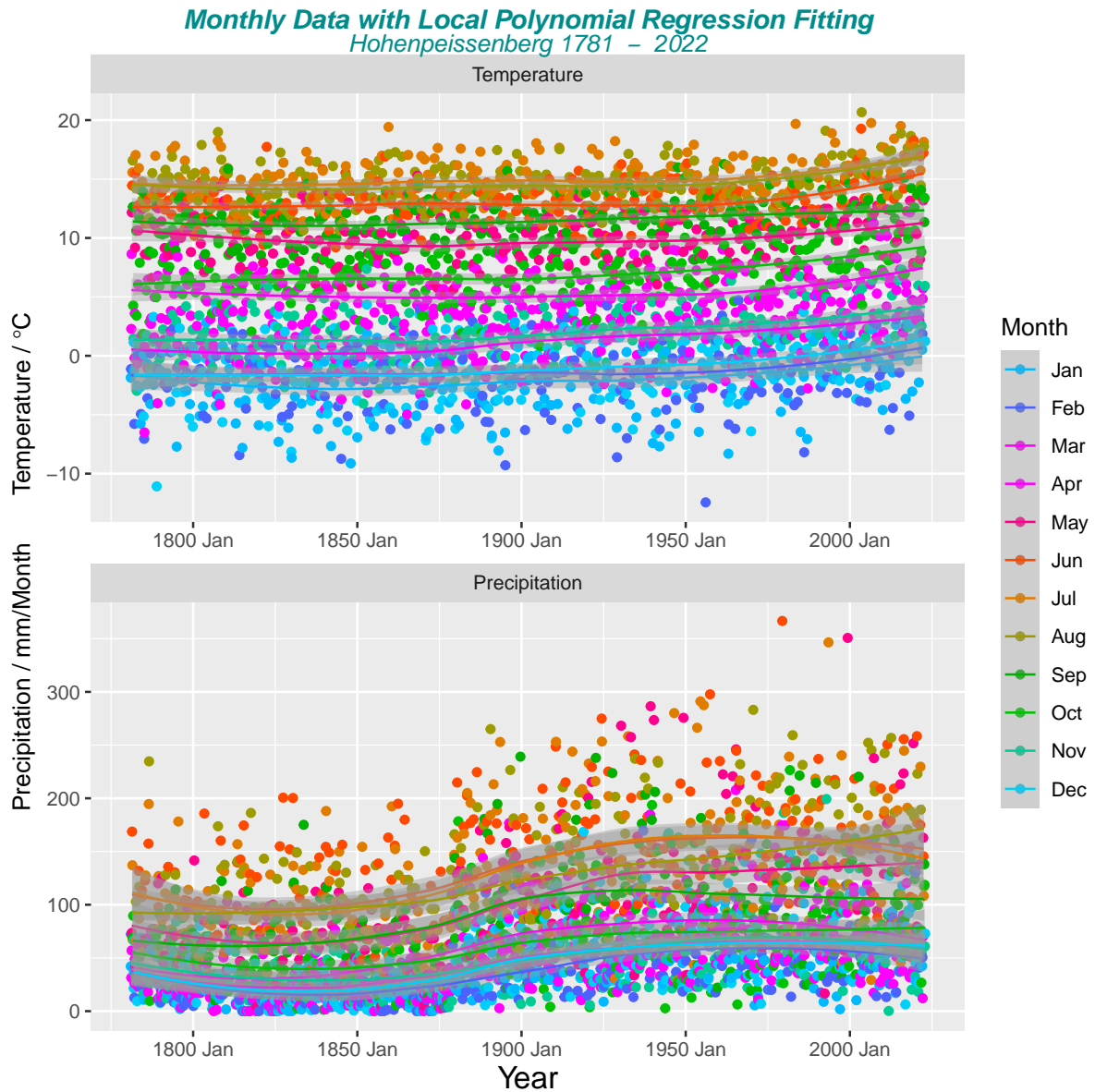
1.1 Monthly Time Plots with Rolling Mean



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



1.2 Yearly plots with monthly breakdown



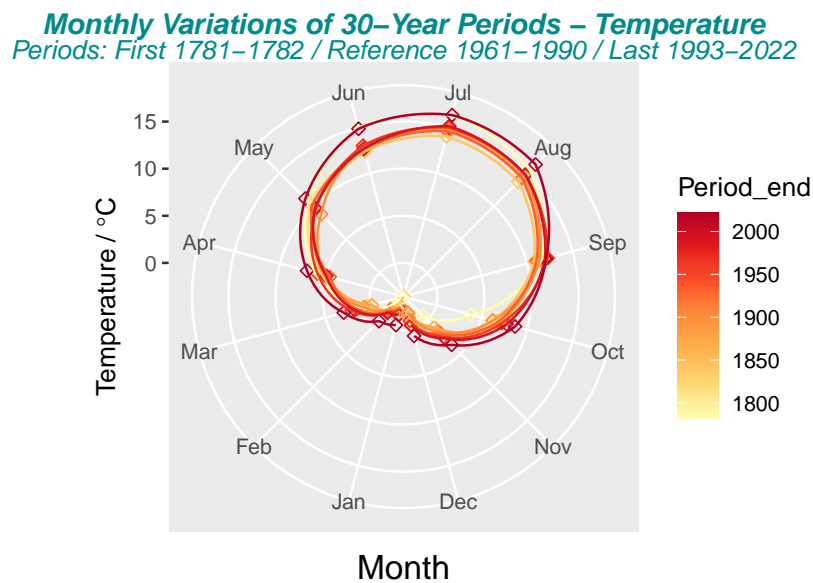
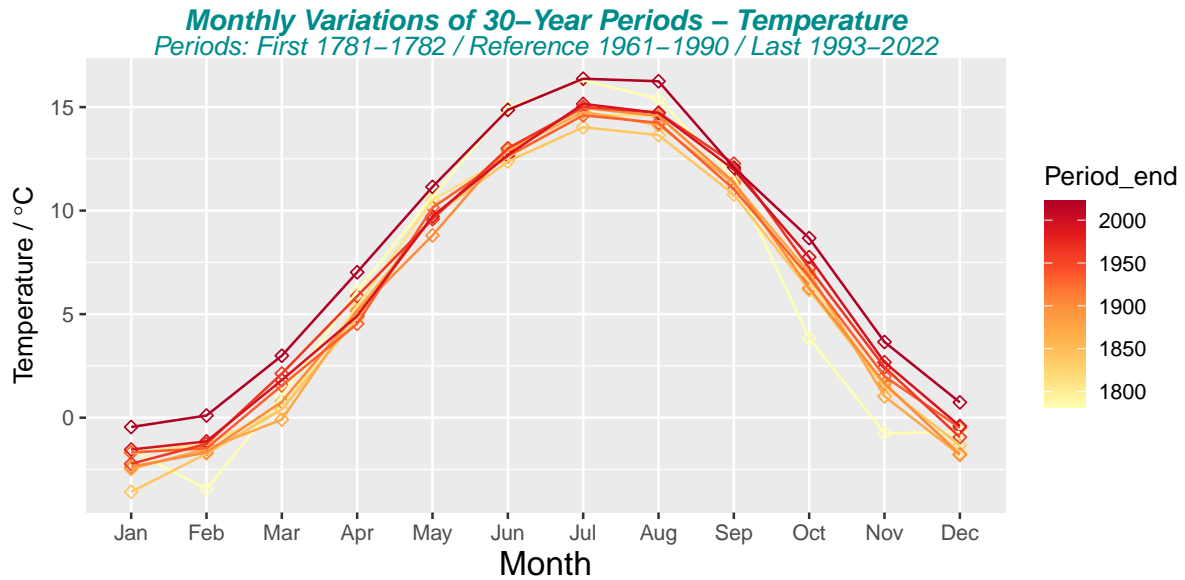
1.2.1 30-year period plots with monthly breakdown - Cartesian and Polar Coordinates

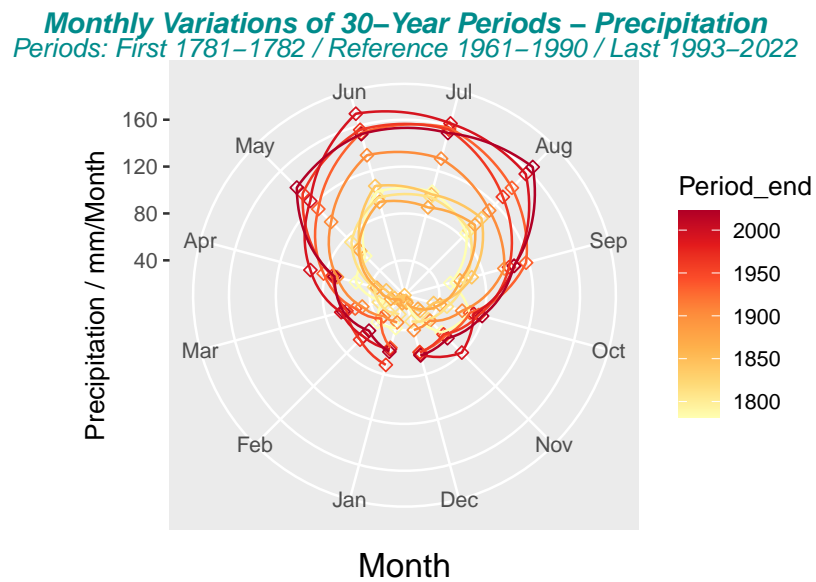
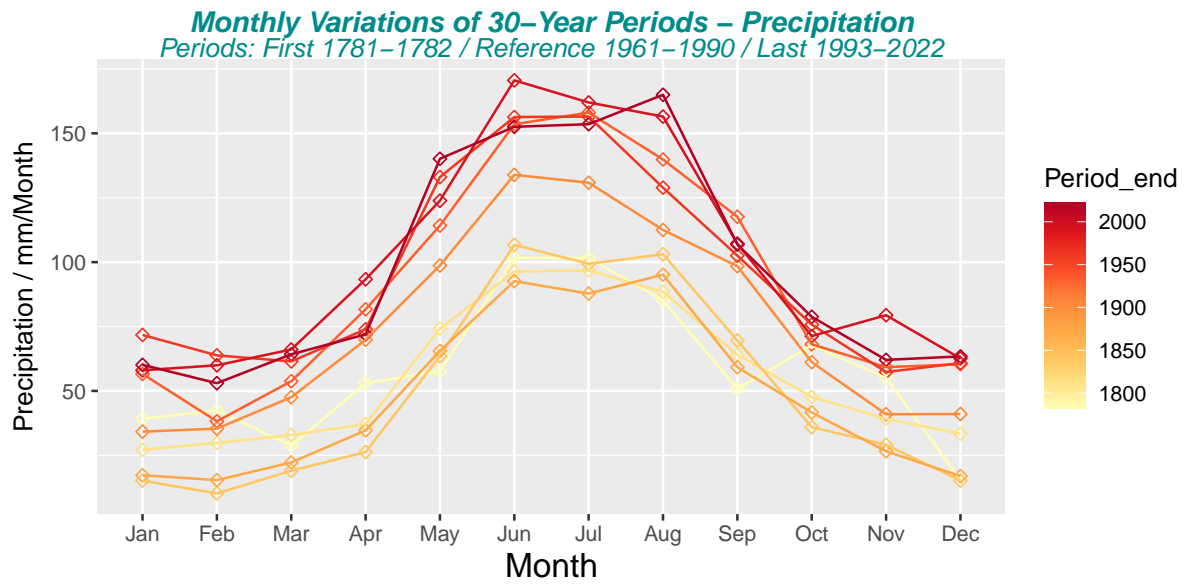
Table 1: 30-years Periods - Average Data (Temperature / degree C and Monthly Precipitation / mm)

City	Period	Temperature	Monthly Precipitation	Annual Precipitation
Hohenpeissenberg	1781-1782	6.1	58.2	698.5
Hohenpeissenberg	1783-1812	6.1	55.6	667.0
Hohenpeissenberg	1813-1842	5.6	49.4	593.1
Hohenpeissenberg	1843-1872	5.8	47.9	574.9
Hohenpeissenberg	1873-1902	5.9	75.4	904.4
Hohenpeissenberg	1903-1932	6.2	91.8	1101.2
Hohenpeissenberg	1933-1962	6.5	95.2	1142.1
Hohenpeissenberg	1963-1992	6.5	100.9	1210.8
Hohenpeissenberg	1993-2022	7.8	97.6	1171.6

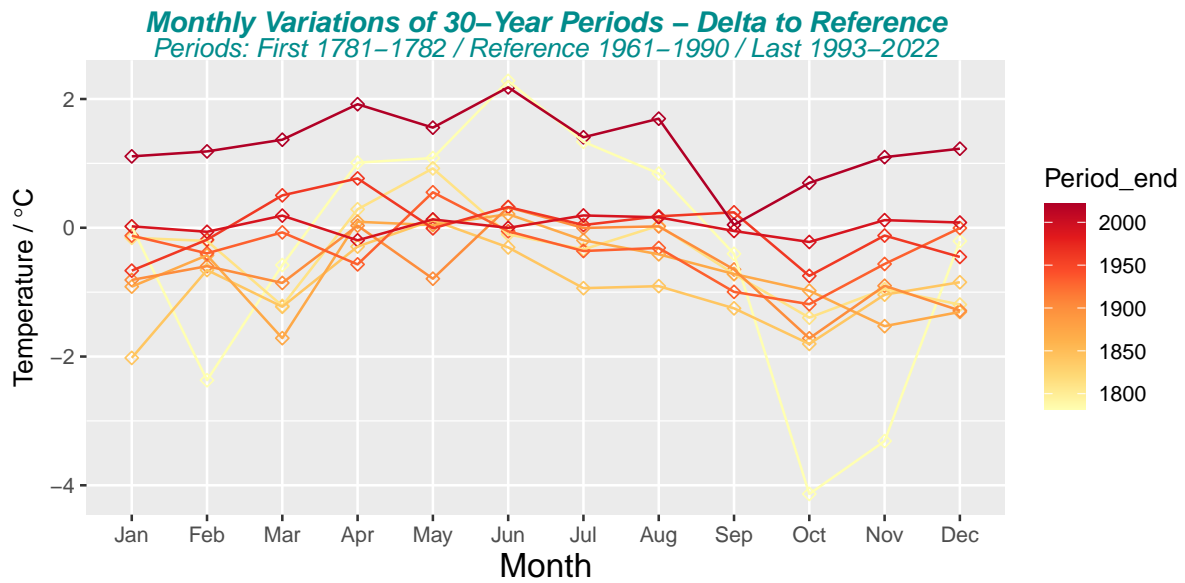
City	Ref_Period	Temperature	Monthly Precipitation	Annual Precipitation
Hohenpeissenberg	1961-1990	6.5	100.8	1209.8

Note: First Period shorter in general (starts with first data year = 1781)

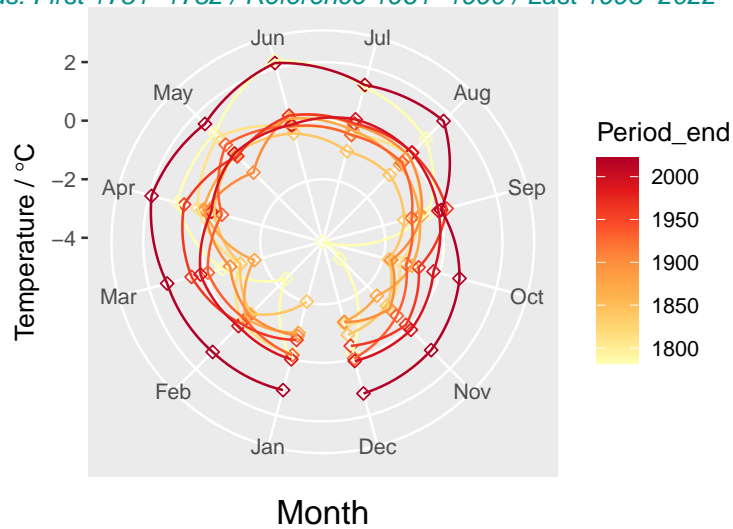


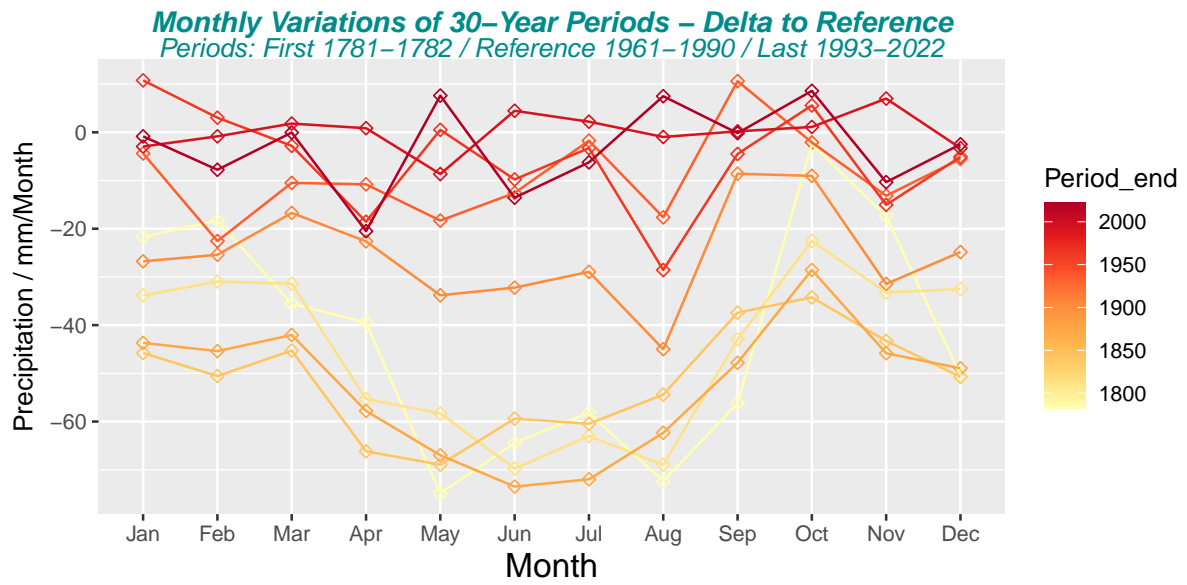


1.2.2 Plot Monthly Delta to Reference Period - Cartesian and Polar Coordinates

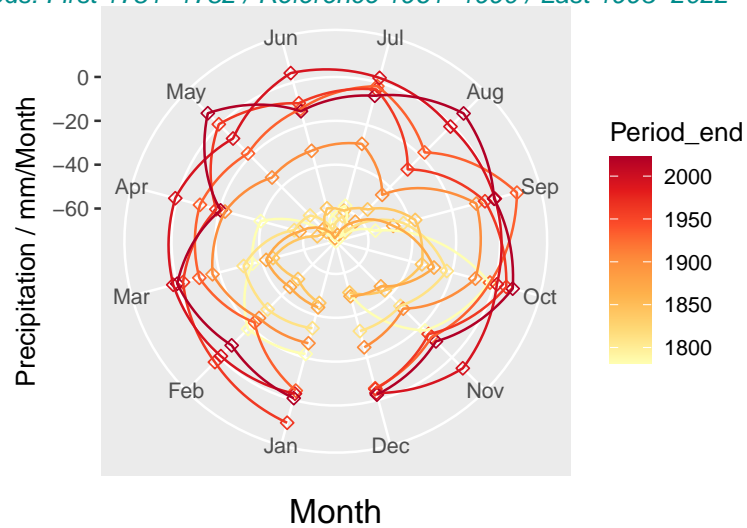


Monthly Variations of 30-Year Periods – Delta to Reference
Periods: First 1781–1782 / Reference 1961–1990 / Last 1993–2022

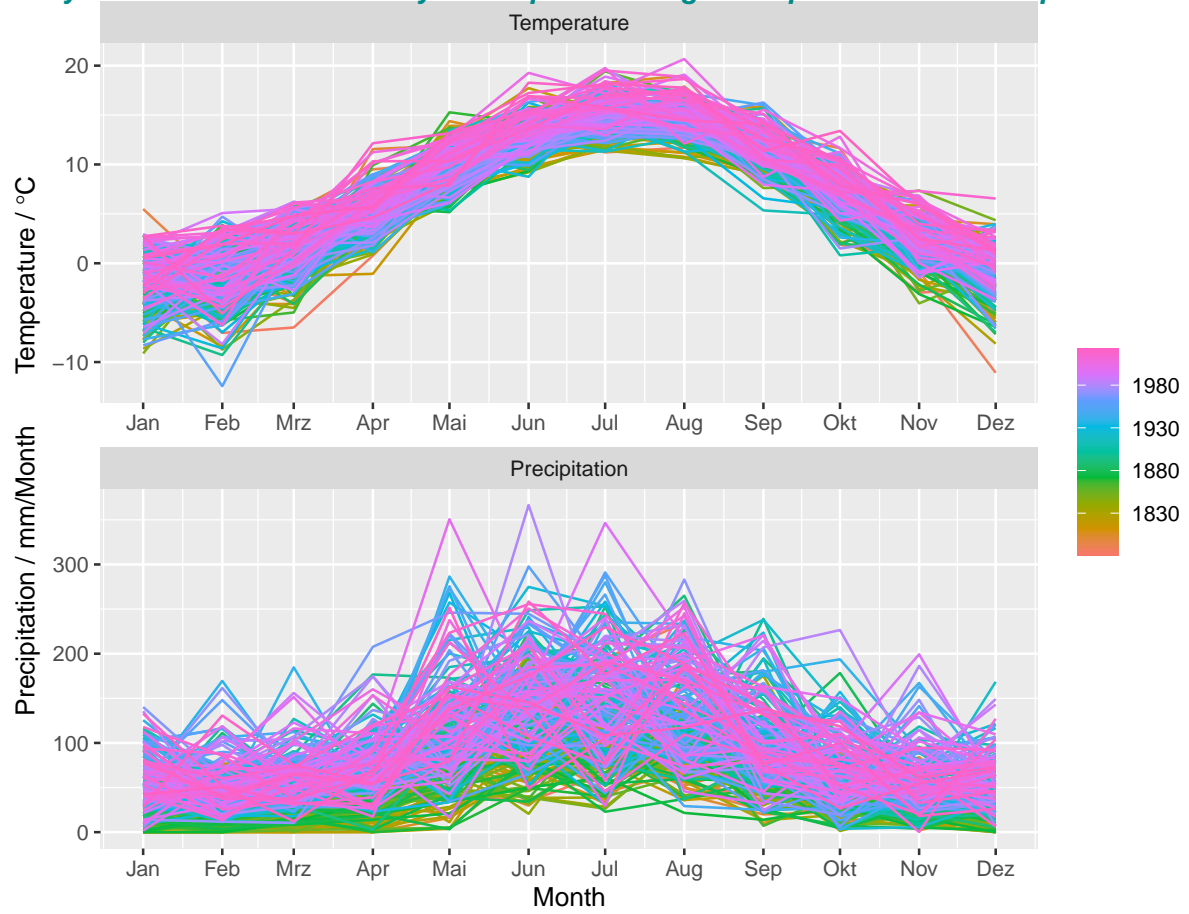


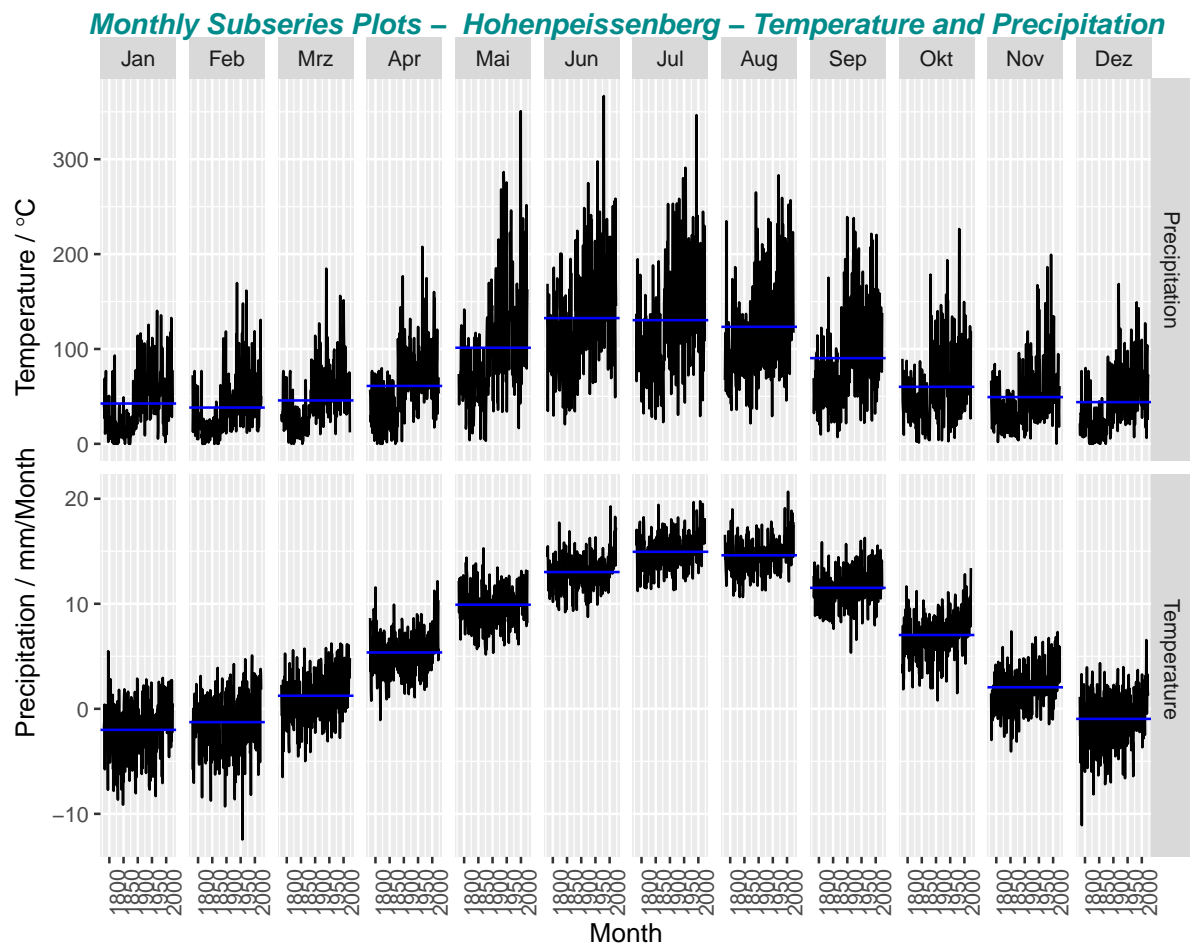


Monthly Variations of 30-Year Periods – Delta to Reference
Periods: First 1781–1782 / Reference 1961–1990 / Last 1993–2022



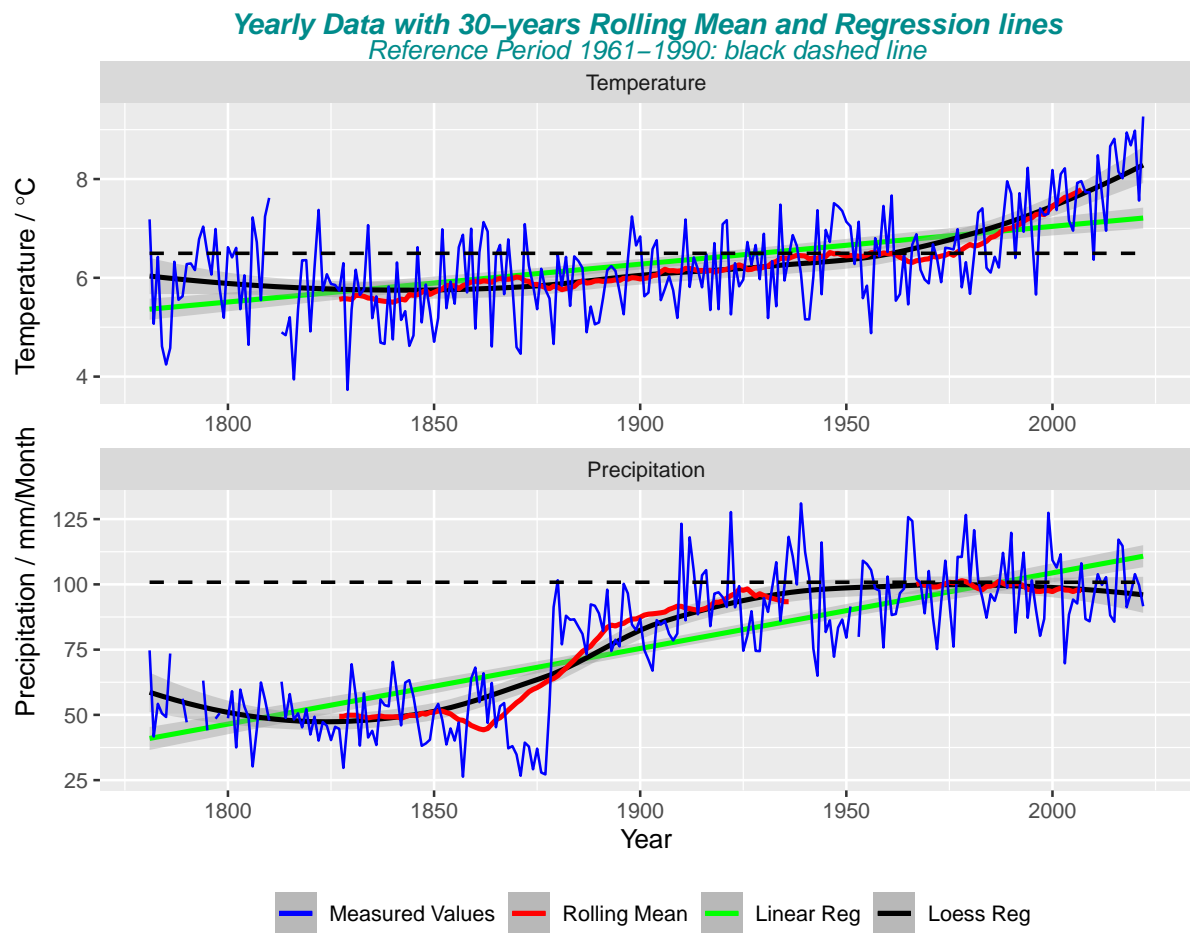
Yearly Seasonal Plots – Monthly Hohenpeissenberg – Temperature and Precipitation



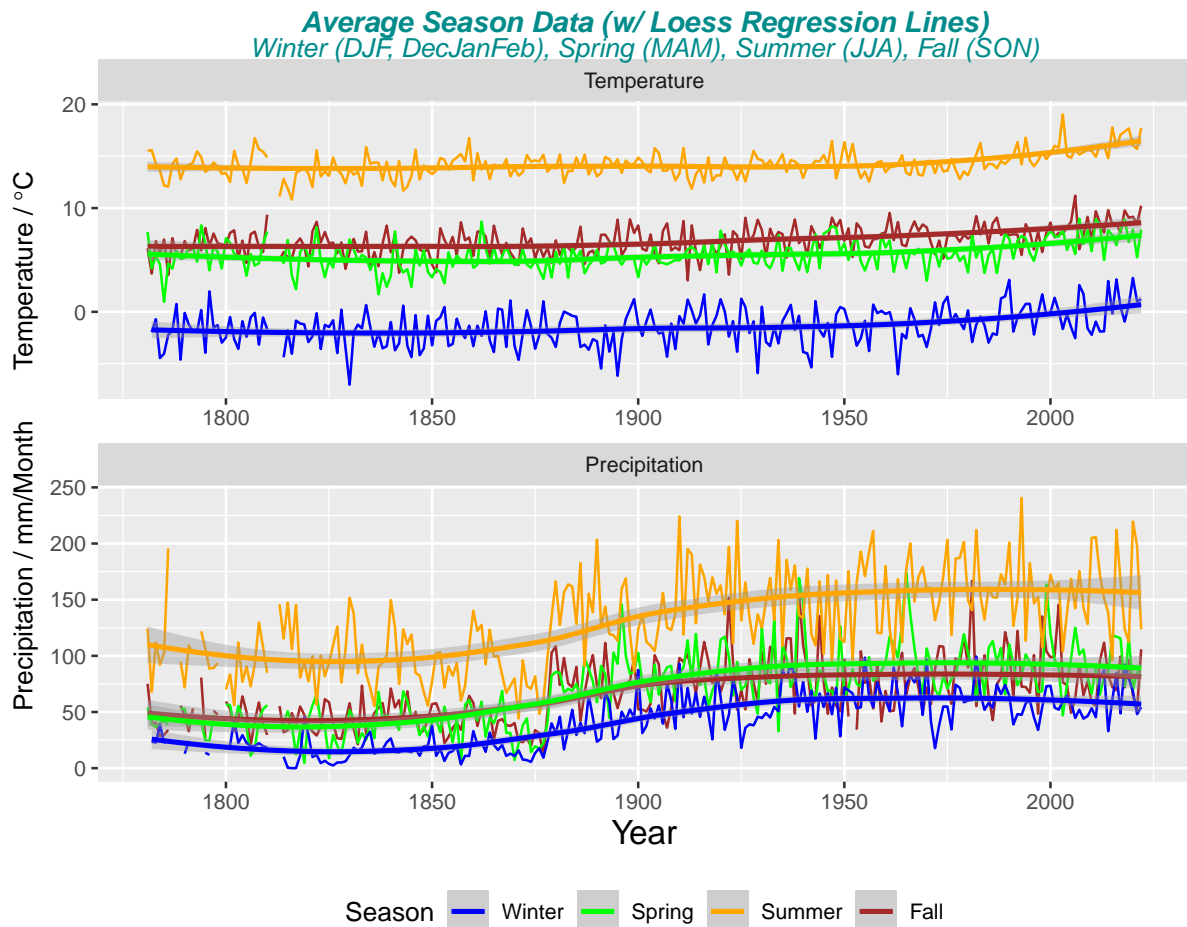


1.3 Yearly Hohenpeissenberg - Temperature and Precipitation

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.

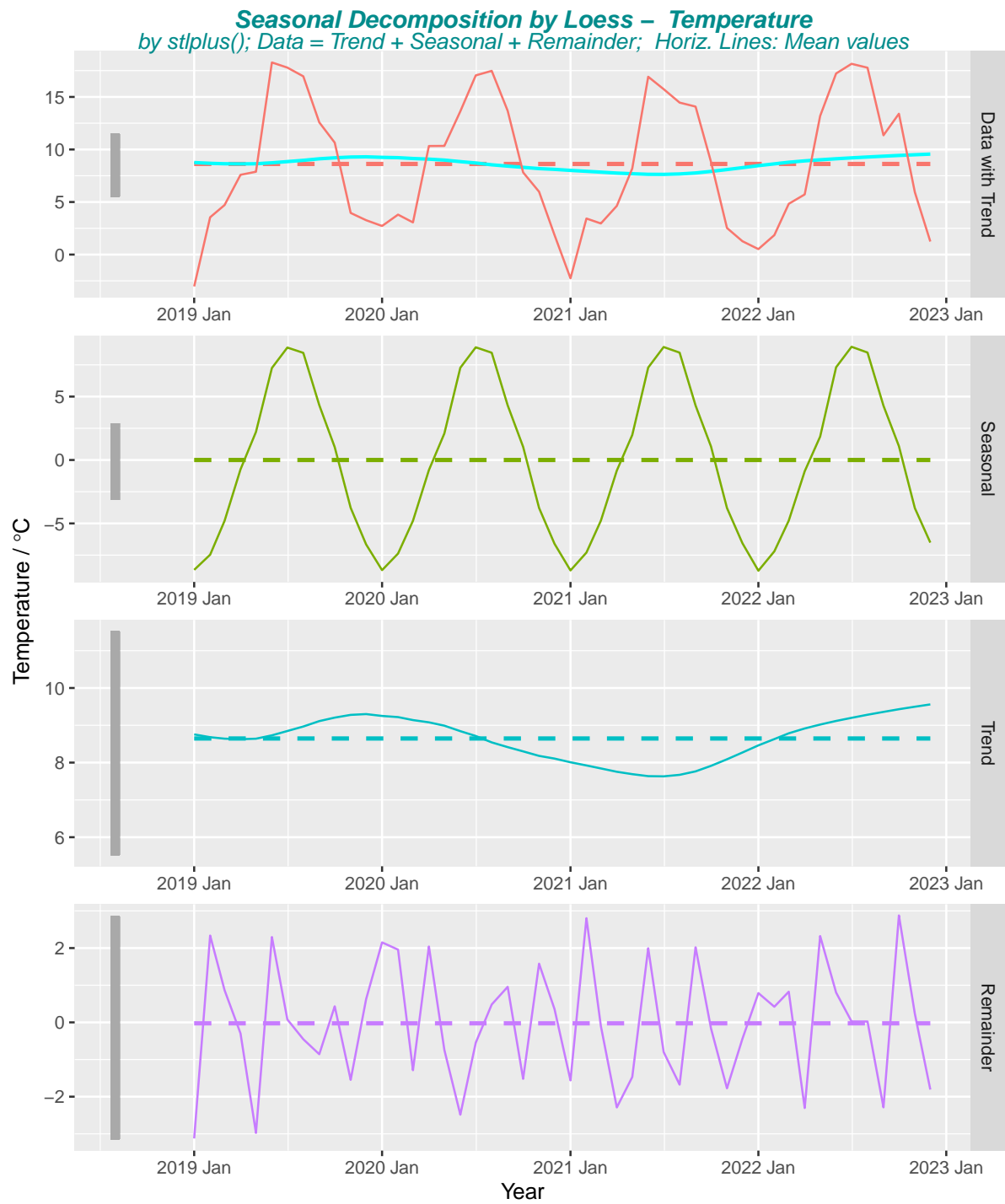
Time series using an

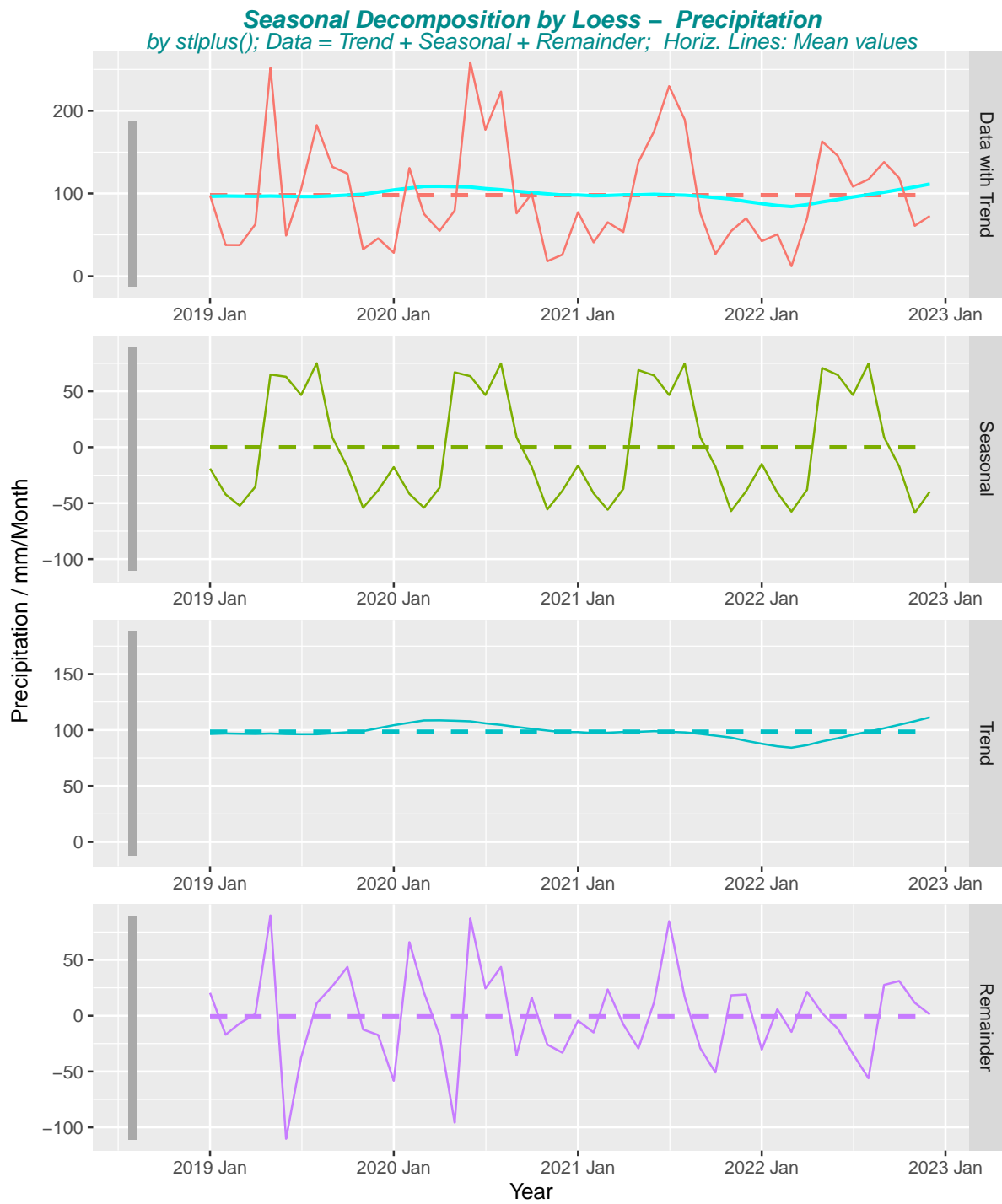
- additive model: $y_t = T_t + C_t + S_t + \epsilon_t$
- multiplicative model: $y_t = T_t * C_t * S_t * \epsilon_t$

Trend / Cycle / Seasonal / Noise component

Cyclical components is often grouped into the Trend component

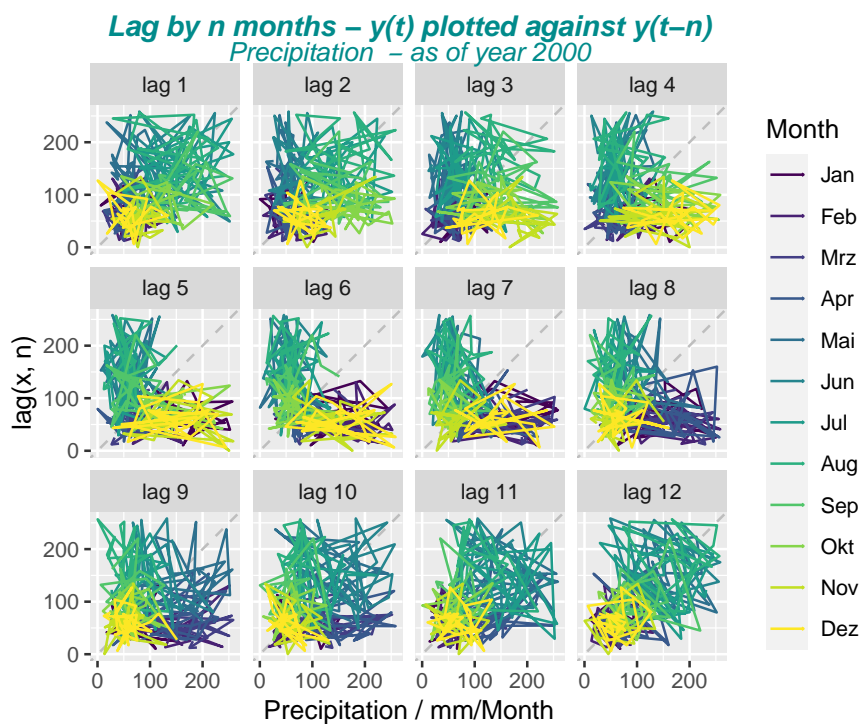
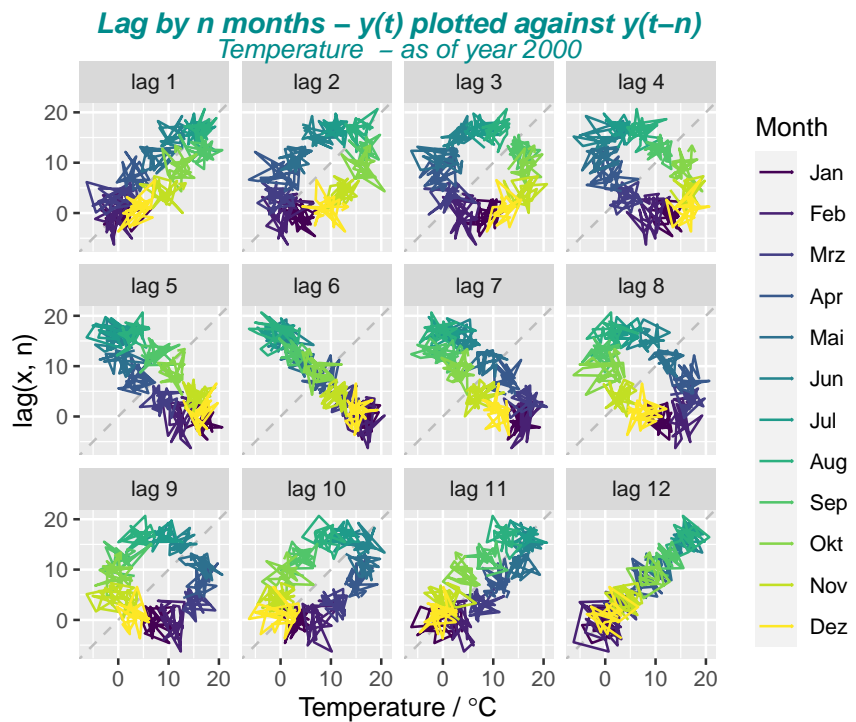
For *Seasonal decomposition of time series by Loess (stlplus)* uses in general an additive error model, it only provides facilities for additive decompositions. It is possible to obtain a multiplicative decomposition by first taking logs of the data.





2.2 Periodicities - Season Frequency

2.2.1 Lag Plot - Differences



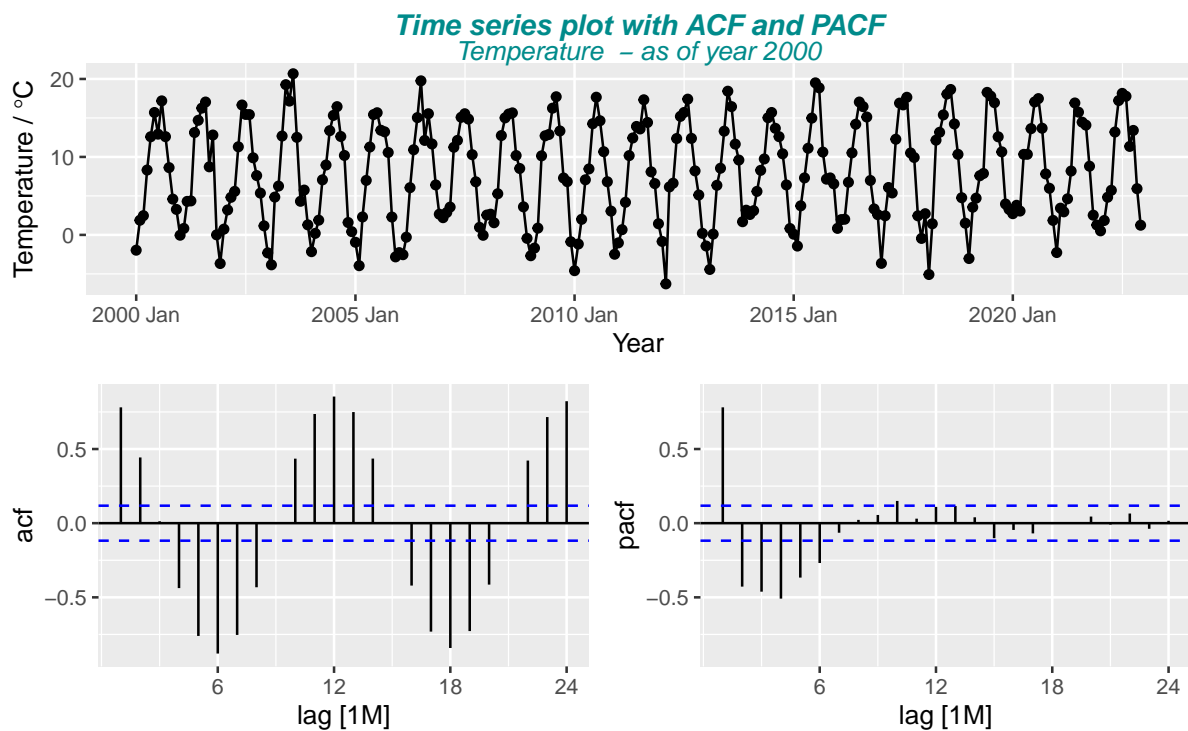
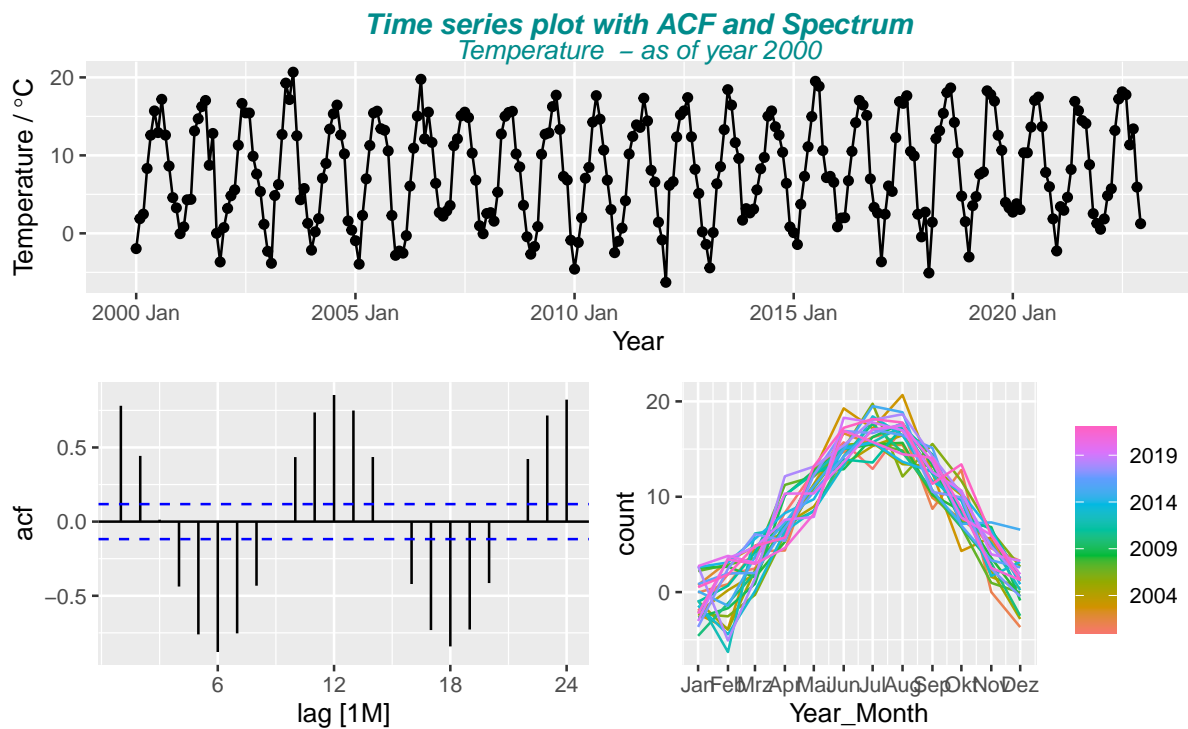
2.2.2 ACF / PACF Correlogram

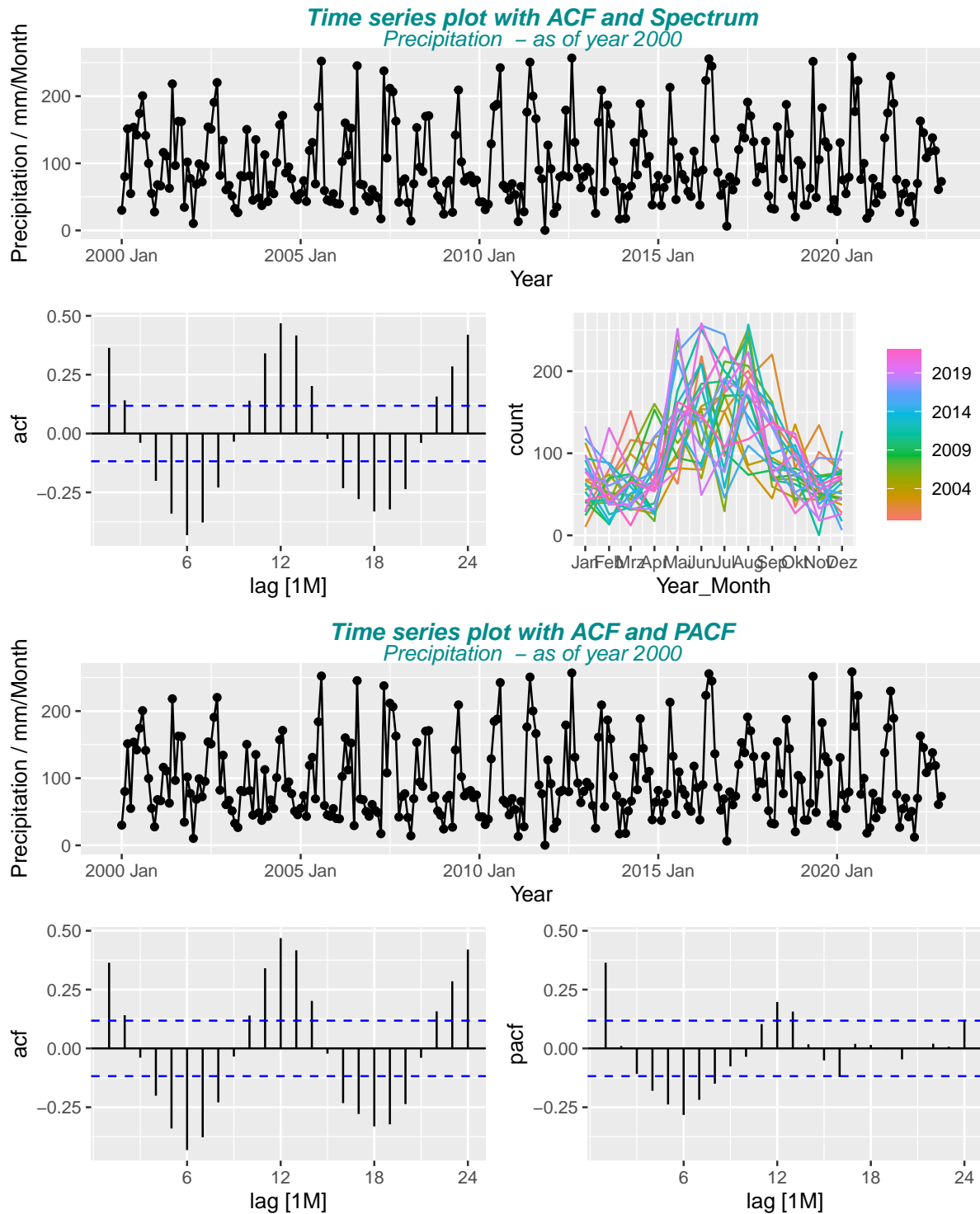
2.2.3 Periodogram - Spectral Density Estimation of a Time Series

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.



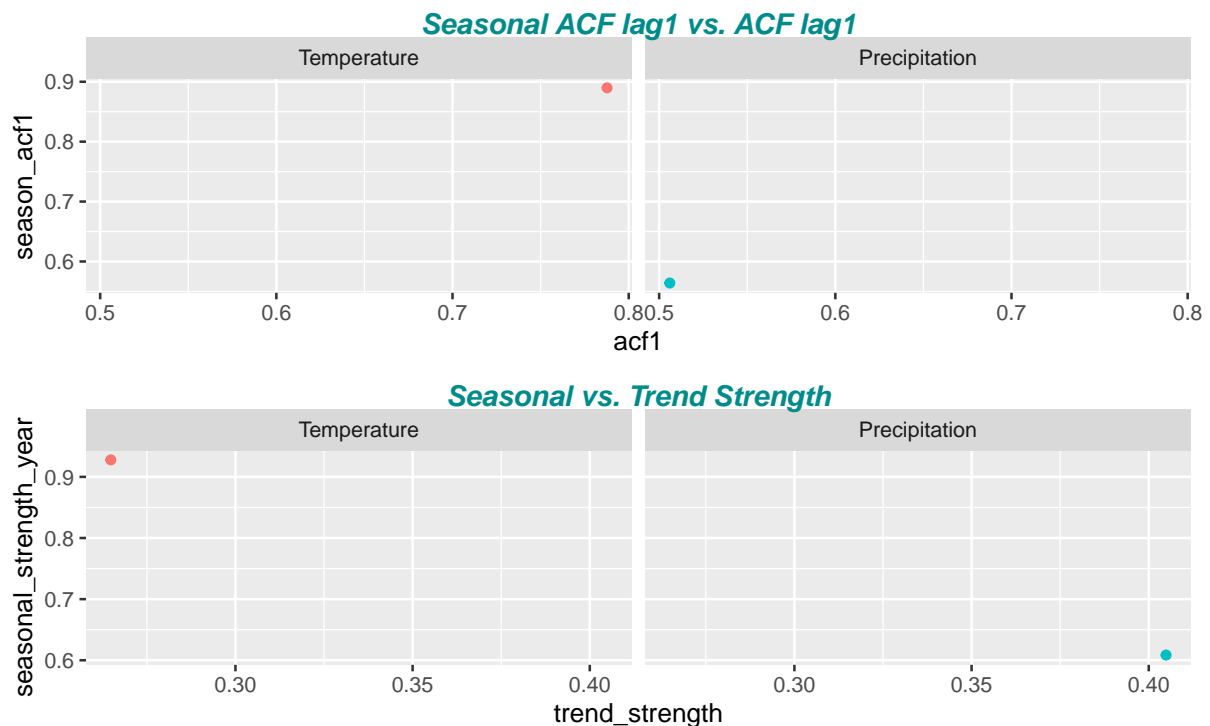


2.2.4 Seasonal vs non Seasonal ACF / Strength (Seasonal/Trend)

- 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 0.788 3.28      0.285      1.16      -0.483      0.300      0.890
#> 2 Precipitation 0.506 0.592     -0.331      0.139     -0.638      0.439      0.564
#> # ... 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 linea_~6 curva_~7 stl_e_~8
#>   <fct>      <dbl>      <dbl>      <dbl>      <dbl>      <dbl>      <dbl>      <dbl>      <dbl>
#> 1 Temperature 0.265      0.928          7          1 2.84e-6    28.6      18.1 -0.0421
#> 2 Precipitation 0.405      0.609          7          2 4.84e-1   1038.     -47.6 -0.0961
#> # ... 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      0.265
#> 2 Precipitation     0.819
```

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	1781	NA	7.7	15.5	6.1	7.2
Hohenpeissenberg	Temperature	1782	-2.0	4.2	15.6	3.7	5.1
Hohenpeissenberg	Temperature	1783	-0.7	5.3	14.3	6.8	6.4
Hohenpeissenberg	Temperature	1784	-4.5	4.6	13.6	5.5	4.6
Hohenpeissenberg	Temperature	1785	-4.0	1.0	12.2	7.0	4.2
Hohenpeissenberg	Temperature	1786	-2.2	4.7	12.1	3.5	4.6
Hohenpeissenberg	Temperature	1787	-1.8	4.2	14.2	7.1	6.3
Hohenpeissenberg	Temperature	1788	0.8	5.9	14.8	5.6	5.6
Hohenpeissenberg	Temperature	1789	-4.6	5.1	12.8	5.3	5.6
Hohenpeissenberg	Temperature	1790	-0.1	5.2	14.0	6.8	6.3
Hohenpeissenberg	Temperature	2013	-1.9	5.0	16.1	7.6	7.0
Hohenpeissenberg	Temperature	2014	3.0	7.9	14.8	9.8	8.7
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
Hohenpeissenberg	Temperature	2021	1.0	5.3	15.7	8.5	7.6
Hohenpeissenberg	Temperature	2022	1.2	7.9	17.7	10.2	9.3

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

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Hohenpeissenberg	Precipitation	1781	NA	54.0	124.4	75.1	74.7
Hohenpeissenberg	Precipitation	1782	23.5	38.9	67.9	40.6	41.7
Hohenpeissenberg	Precipitation	1783	22.8	36.7	111.9	40.3	54.2
Hohenpeissenberg	Precipitation	1784	38.9	40.2	92.2	28.6	50.6
Hohenpeissenberg	Precipitation	1785	22.8	42.1	102.5	29.6	49.2
Hohenpeissenberg	Precipitation	1786	24.0	38.5	195.6	34.2	73.5
Hohenpeissenberg	Precipitation	1787	NA	NA	NA	NA	NA

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Hohenpeissenberg	Precipitation	1788	NA	NA	NA	NA	NA
Hohenpeissenberg	Precipitation	1789	NA	53.1	94.9	55.6	56.2
Hohenpeissenberg	Precipitation	1790	12.9	52.7	72.0	46.9	47.1
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	48.8	115.5	166.5	99.5	114.7
Hohenpeissenberg	Precipitation	2018	92.1	73.0	124.0	71.9	91.2
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
Hohenpeissenberg	Precipitation	2021	48.1	85.5	198.0	52.4	99.7
Hohenpeissenberg	Precipitation	2022	54.4	81.7	123.6	105.9	91.6

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

City	Month	Temperature	Precipitation
Hohenpeissenberg	Jan	-2.0	42.5
Hohenpeissenberg	Feb	-1.3	38.3
Hohenpeissenberg	Mar	1.2	45.8
Hohenpeissenberg	Apr	5.4	61.0
Hohenpeissenberg	May	9.9	101.3
Hohenpeissenberg	Jun	13.0	132.6
Hohenpeissenberg	Jul	15.0	130.4
Hohenpeissenberg	Aug	14.6	123.4
Hohenpeissenberg	Sep	11.5	90.3
Hohenpeissenberg	Oct	7.0	60.1
Hohenpeissenberg	Nov	2.0	49.3
Hohenpeissenberg	Dec	-1.0	44.0

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>