

Climate Data Visualization - Atmospheric CO_2 Concentration / Temperature / Precipitation

Wolfgang Vollmer

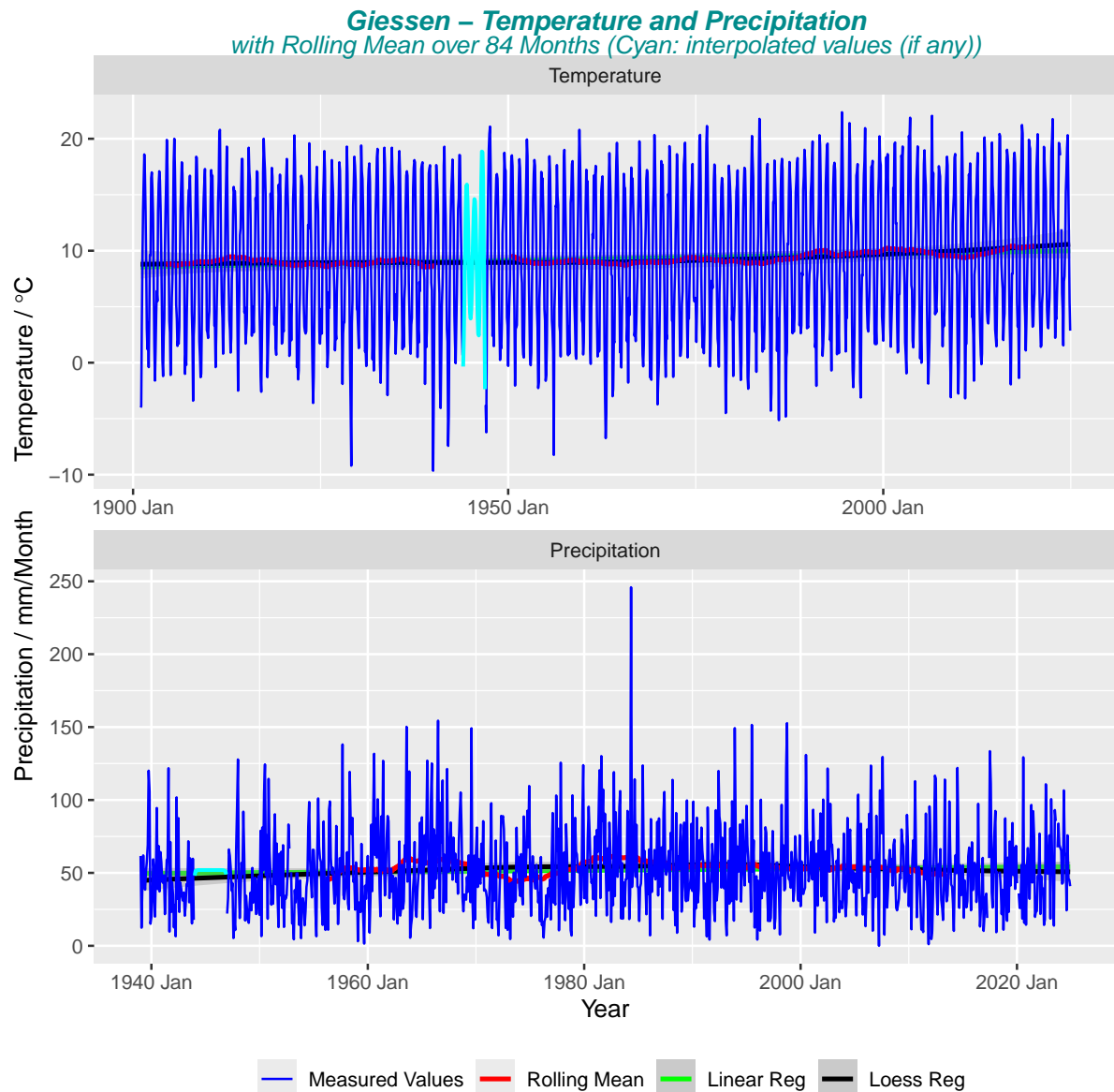
2025-01-03

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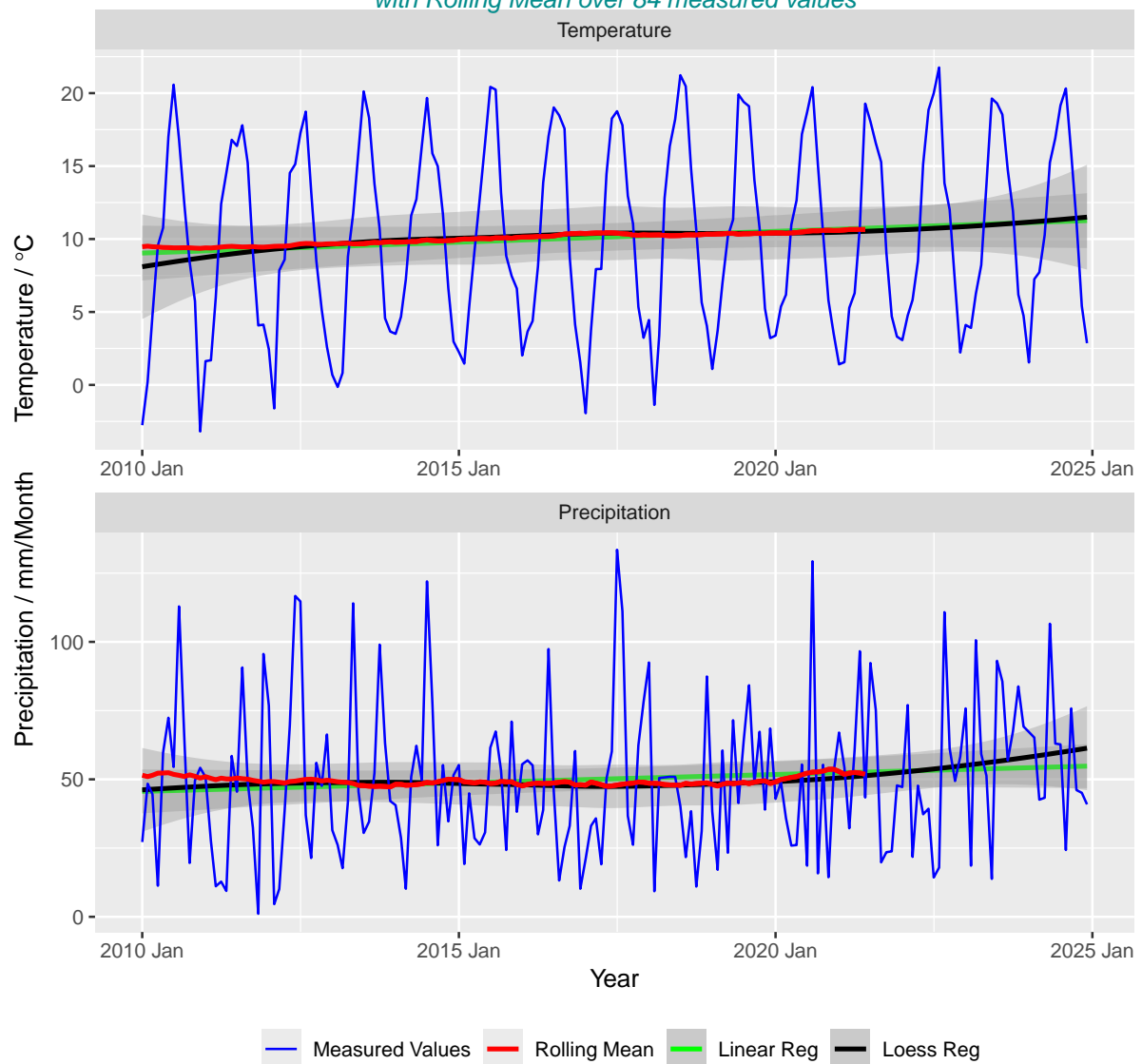
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1 Giessen - Visualization of Temperature and Precipitation Data 1901 - 2024

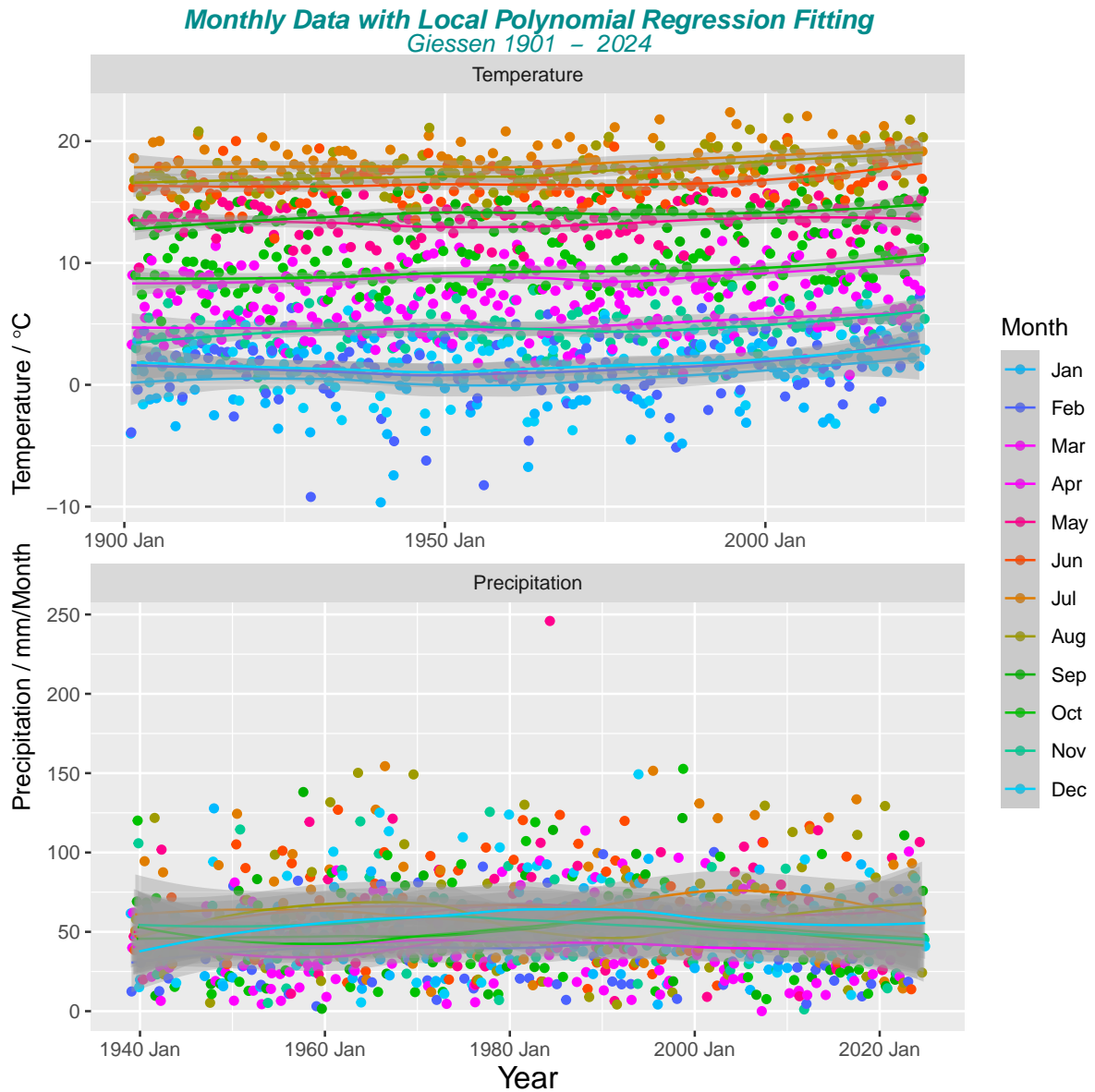
1.1 Monthly Time Plots with Rolling Mean



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



1.2 Yearly plots with monthly breakdown



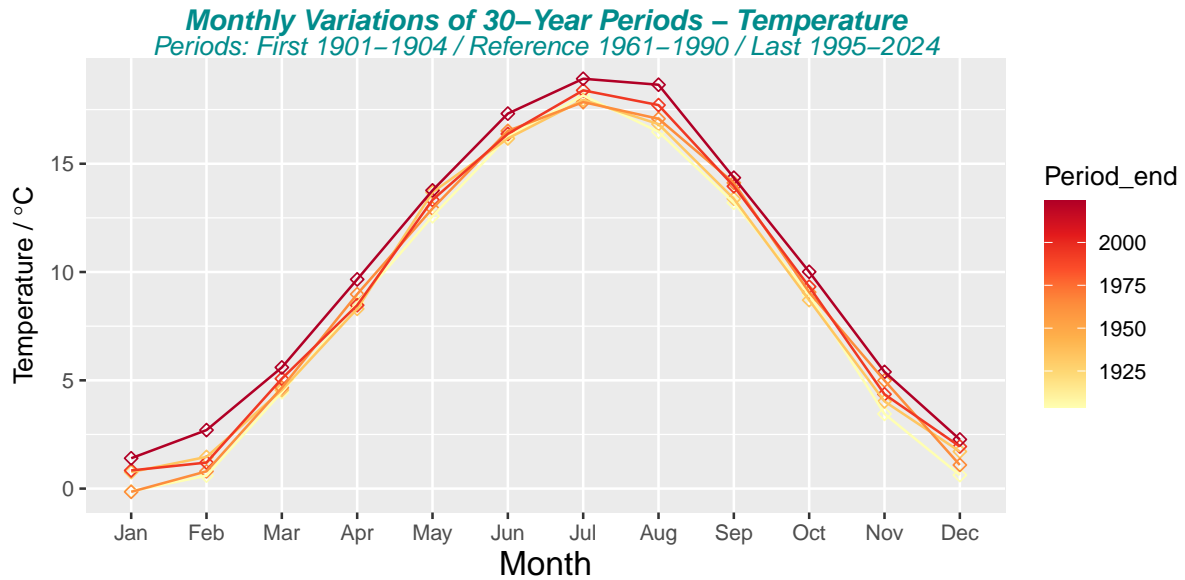
1.2.1 30-year period plots with monthly breakdown - Cartesian and Polar Coordinates

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

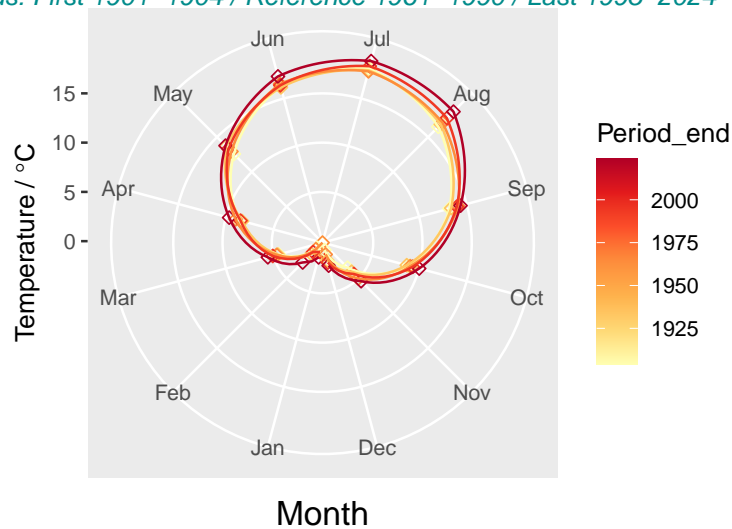
City	Period	Temperature	Monthly Precipitation	Annual Precipitation
Giessen	1901-1904	8.6	NA	NA
Giessen	1905-1934	9.0	NA	NA
Giessen	1935-1964	9.0	48.5	581.6
Giessen	1965-1994	9.2	55.0	659.7
Giessen	1995-2024	10.0	51.9	622.3

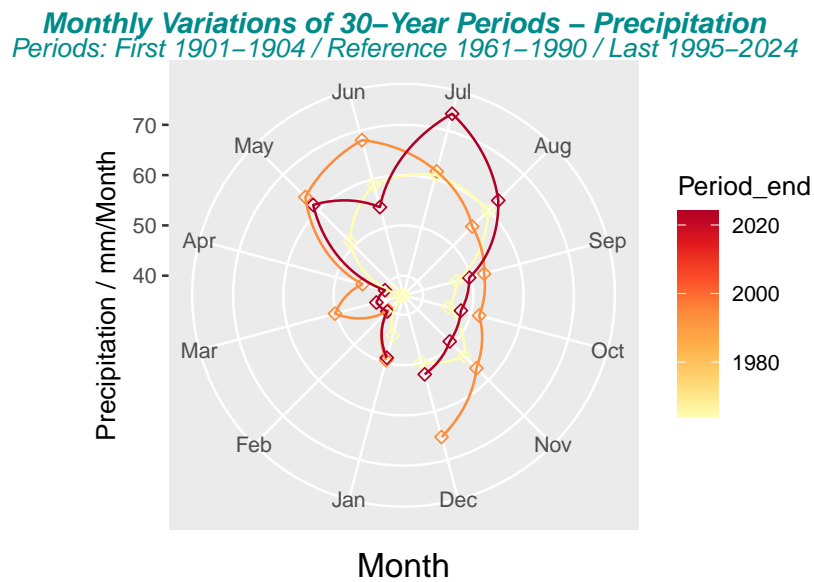
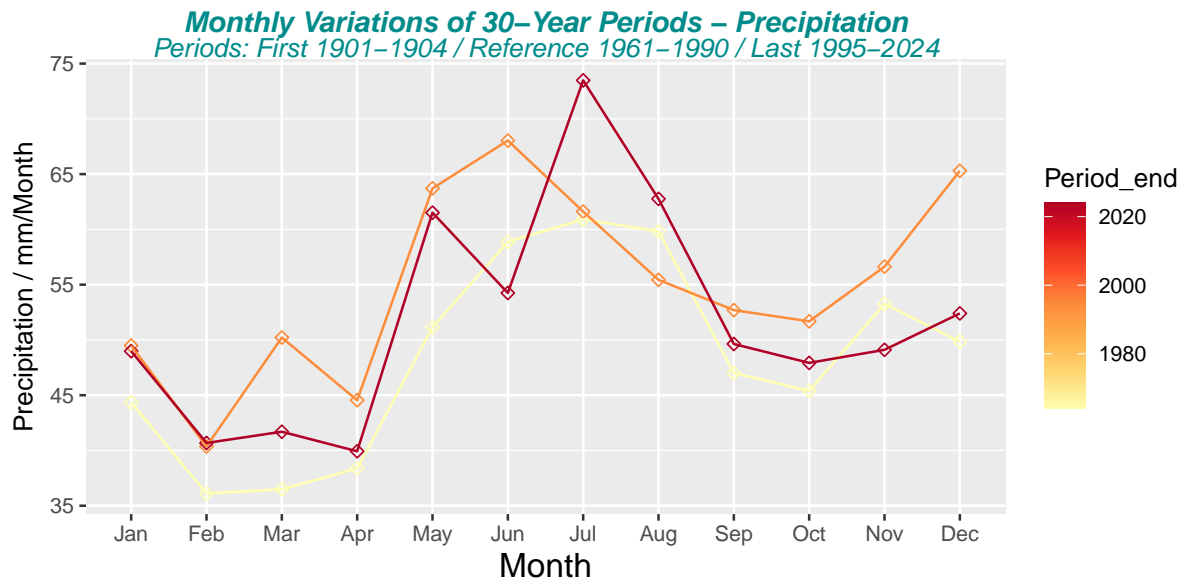
City	Ref_Period	Temperature	Monthly Precipitation	Annual Precipitation
Giessen	1961-1990	9.1	54.4	652.6

Note: First Period shorter in general (starts with first data year = 1901)

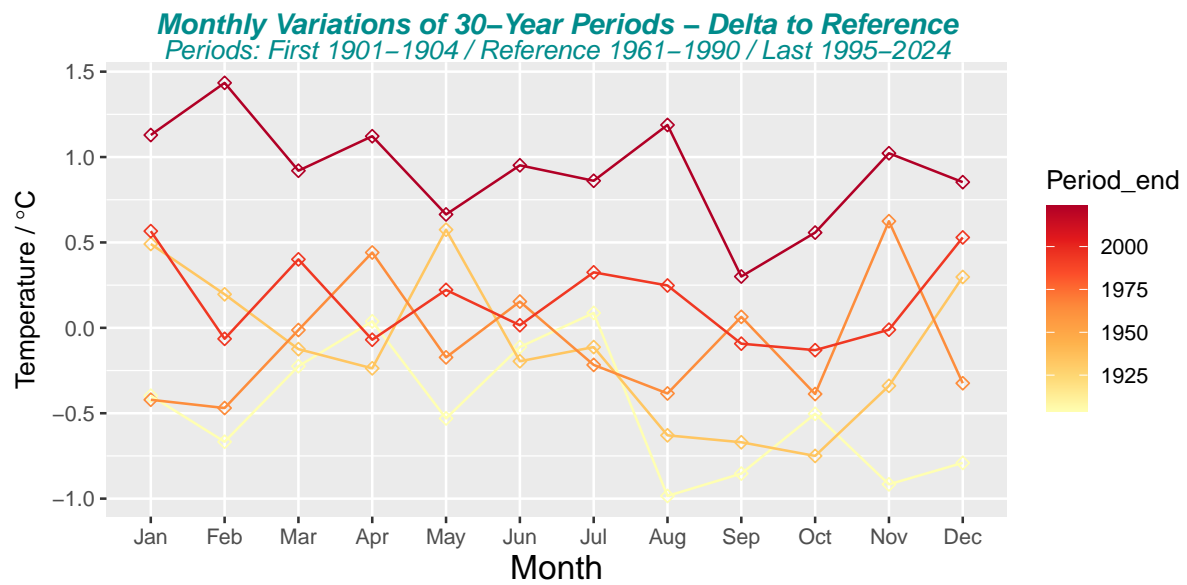


Monthly Variations of 30-Year Periods – Temperature
Periods: First 1901–1904 / Reference 1961–1990 / Last 1995–2024

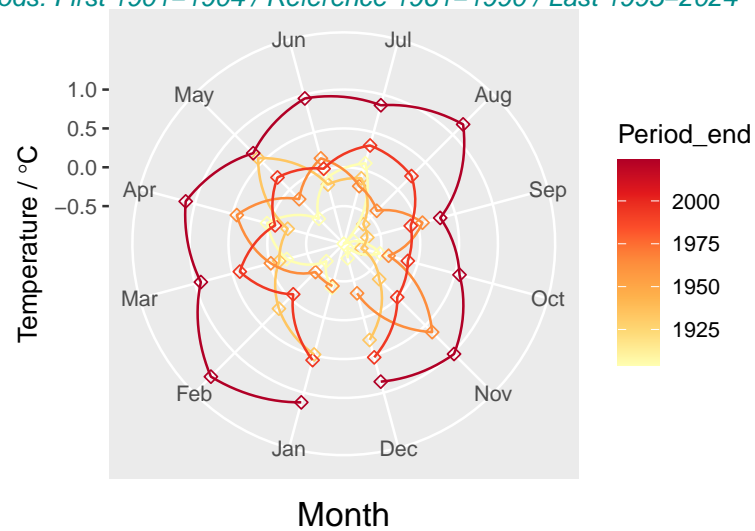


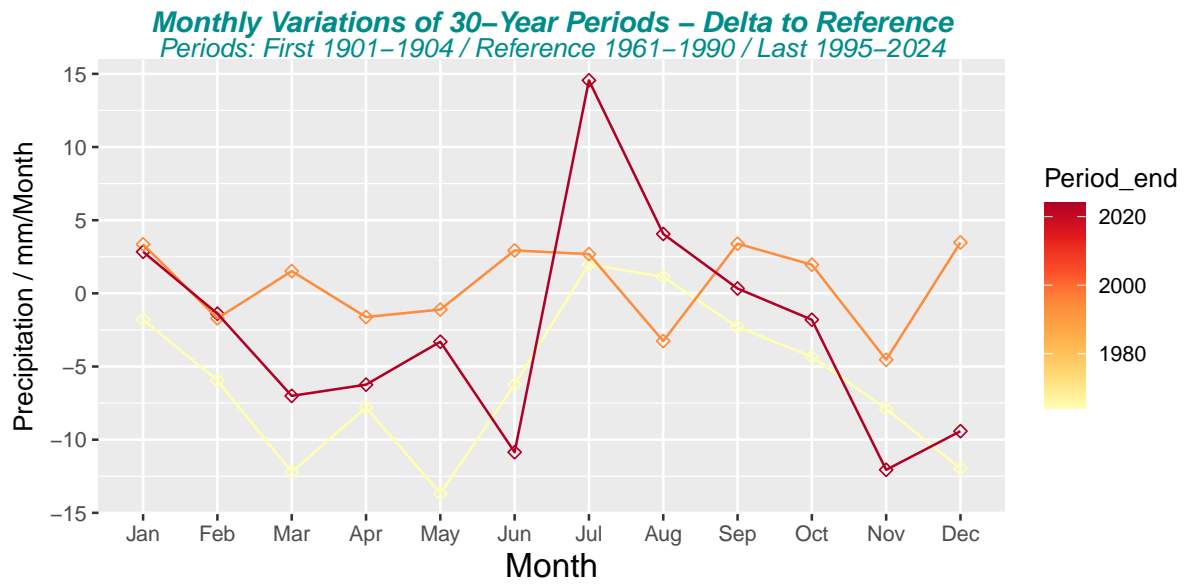


1.2.2 Plot Monthly Delta to Reference Period - Cartesian and Polar Coordinates

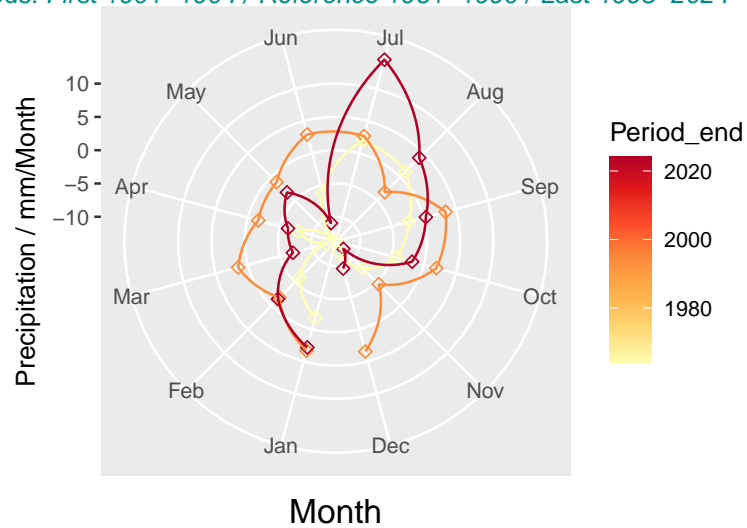


Monthly Variations of 30-Year Periods – Delta to Reference
Periods: First 1901–1904 / Reference 1961–1990 / Last 1995–2024

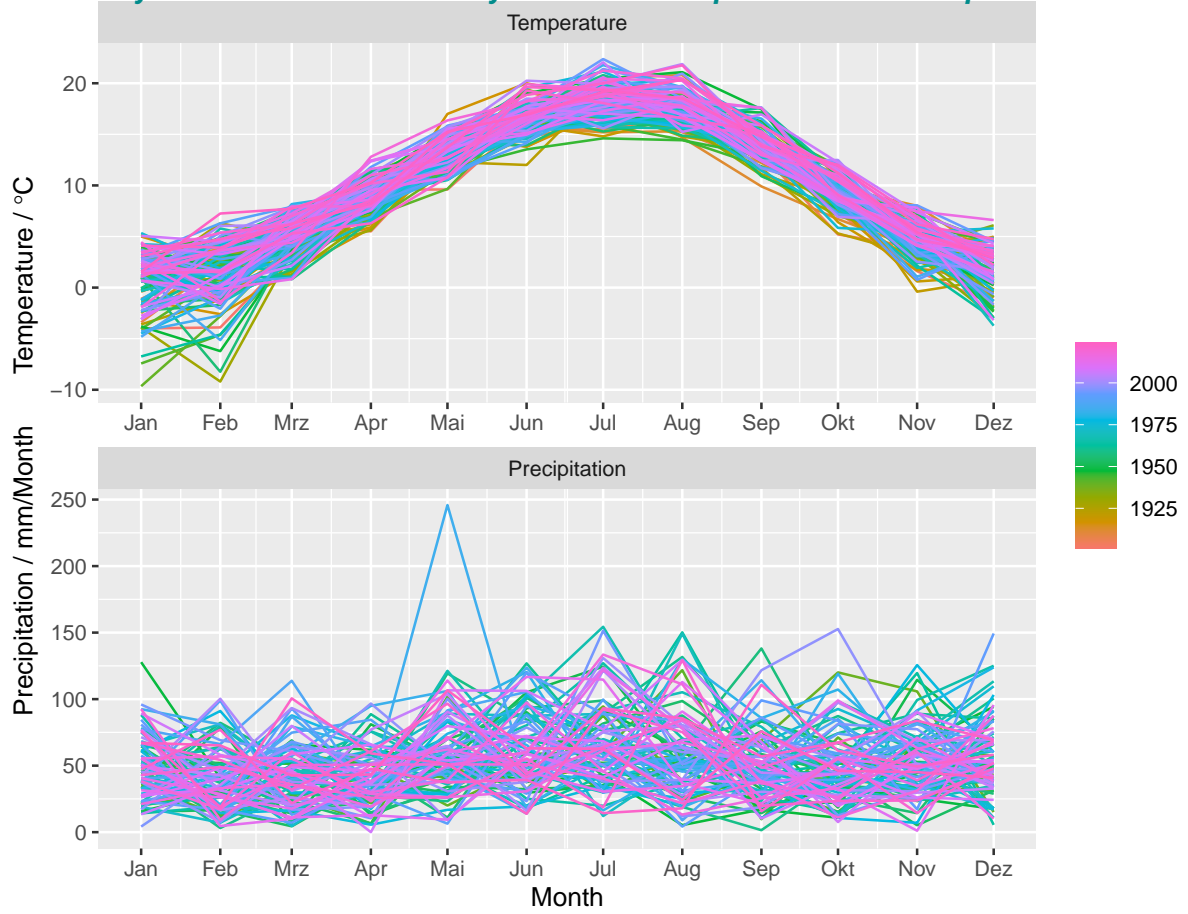




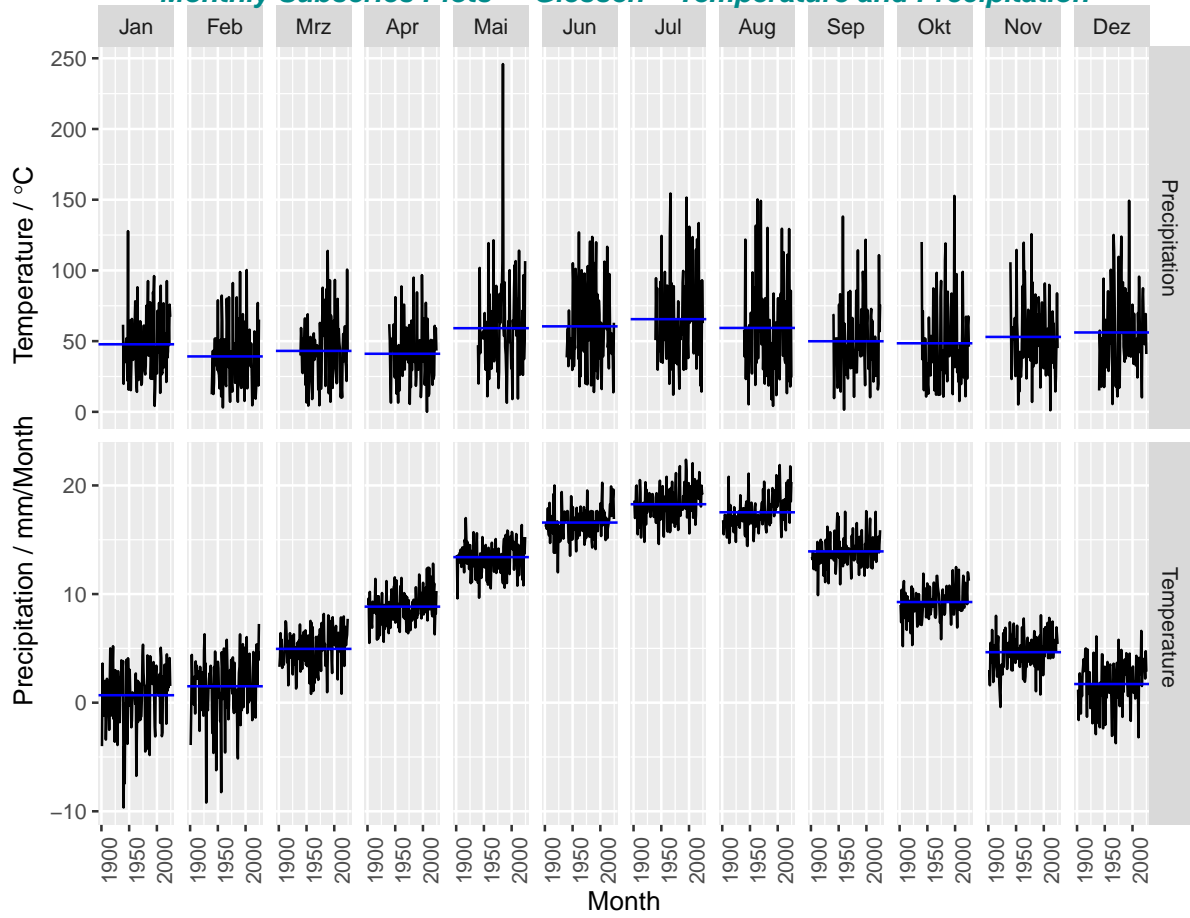
Monthly Variations of 30-Year Periods – Delta to Reference
Periods: First 1901–1904 / Reference 1961–1990 / Last 1995–2024



Yearly Seasonal Plots – Monthly Giessen – Temperature and Precipitation

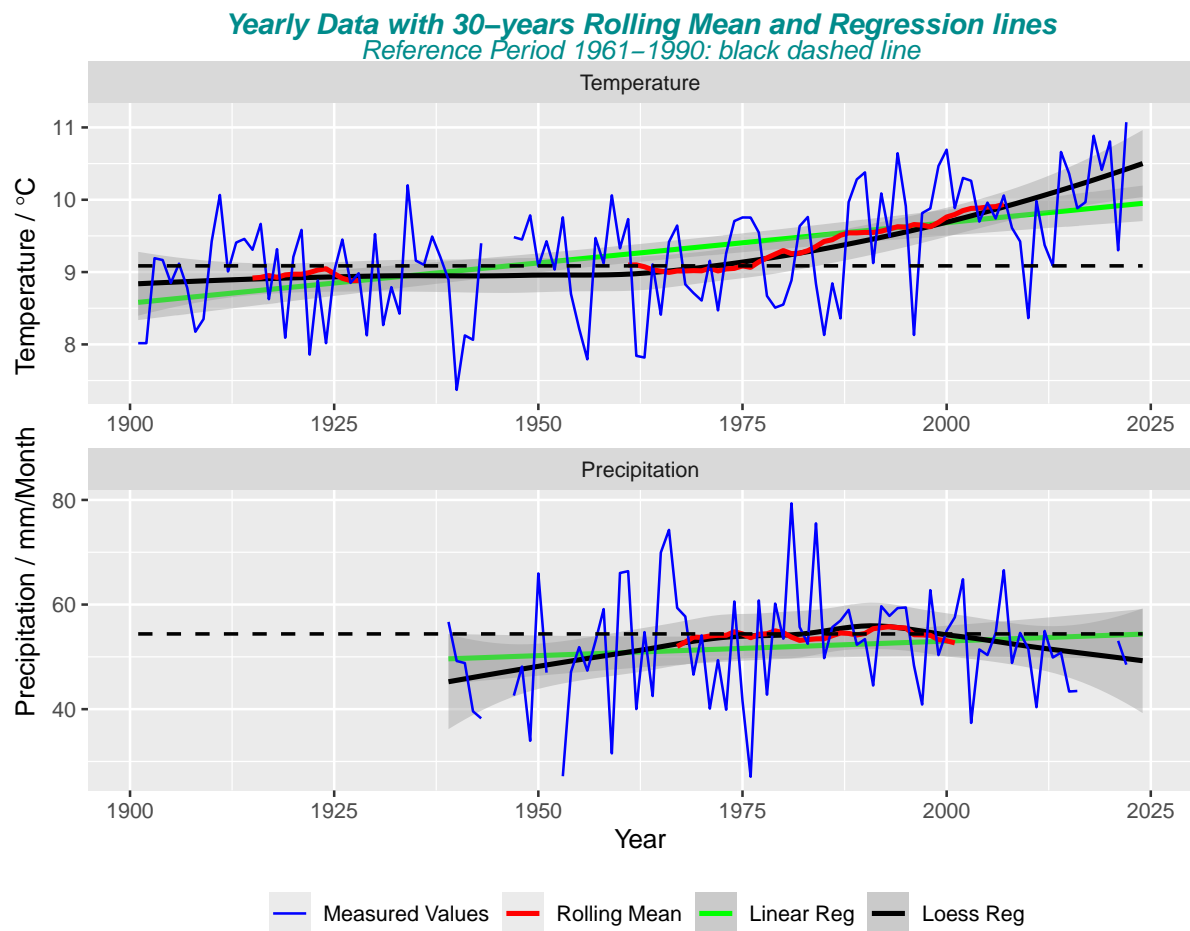


Monthly Subseries Plots – Giessen – Temperature and Precipitation

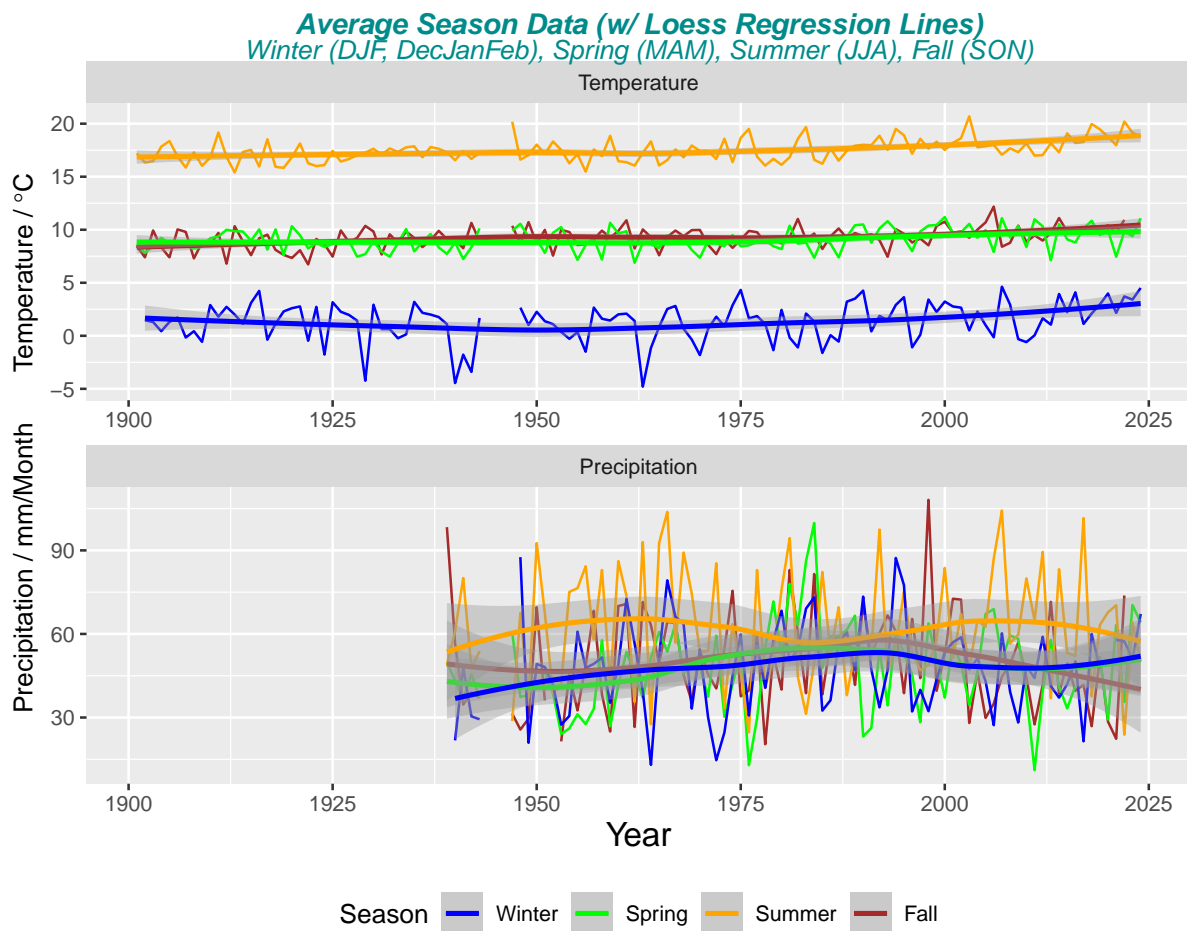


1.3 Yearly Giessen - Temperature and Precipitation

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.

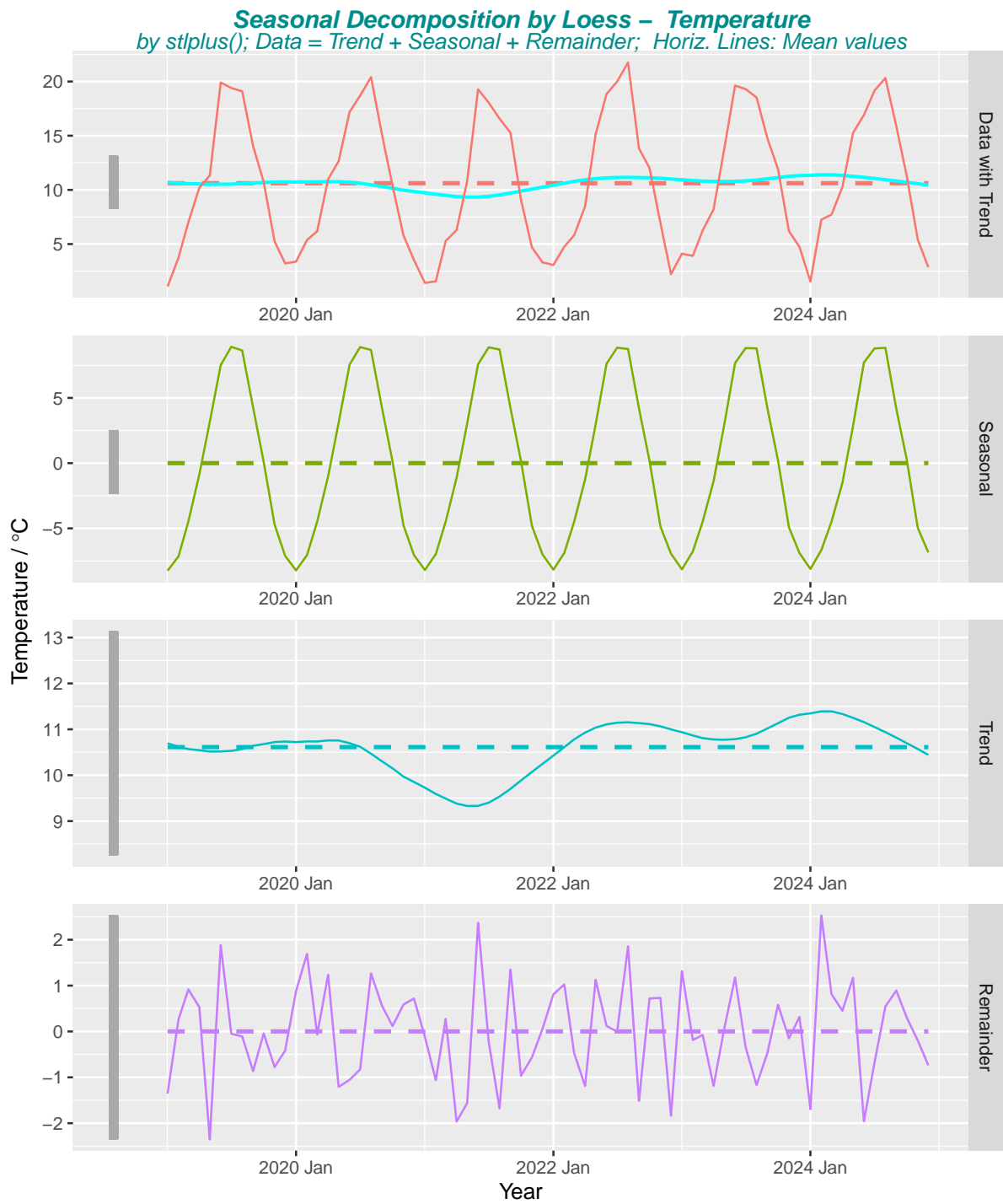
Time series using an

- 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

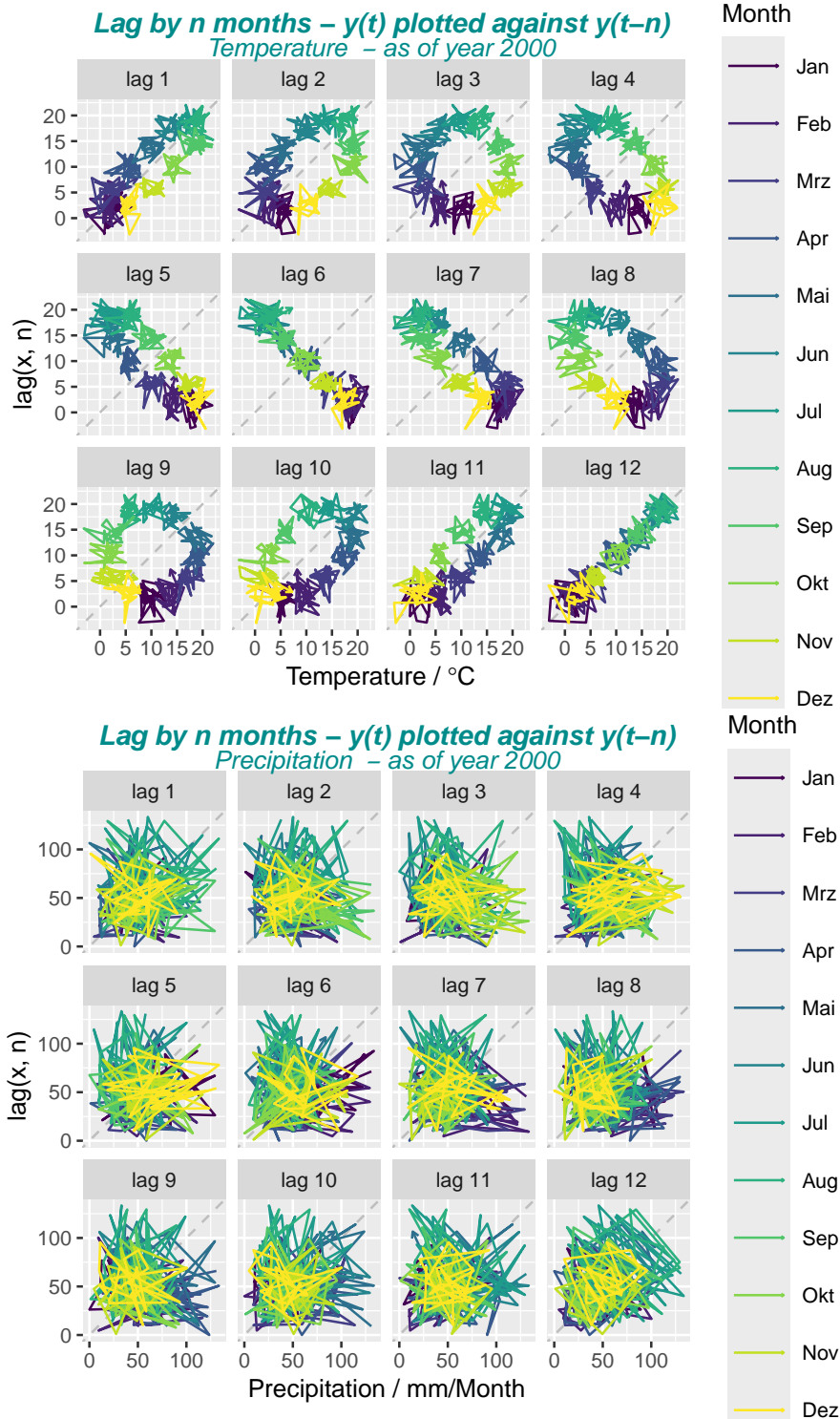
Cyclical components is often grouped into the Trend component

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

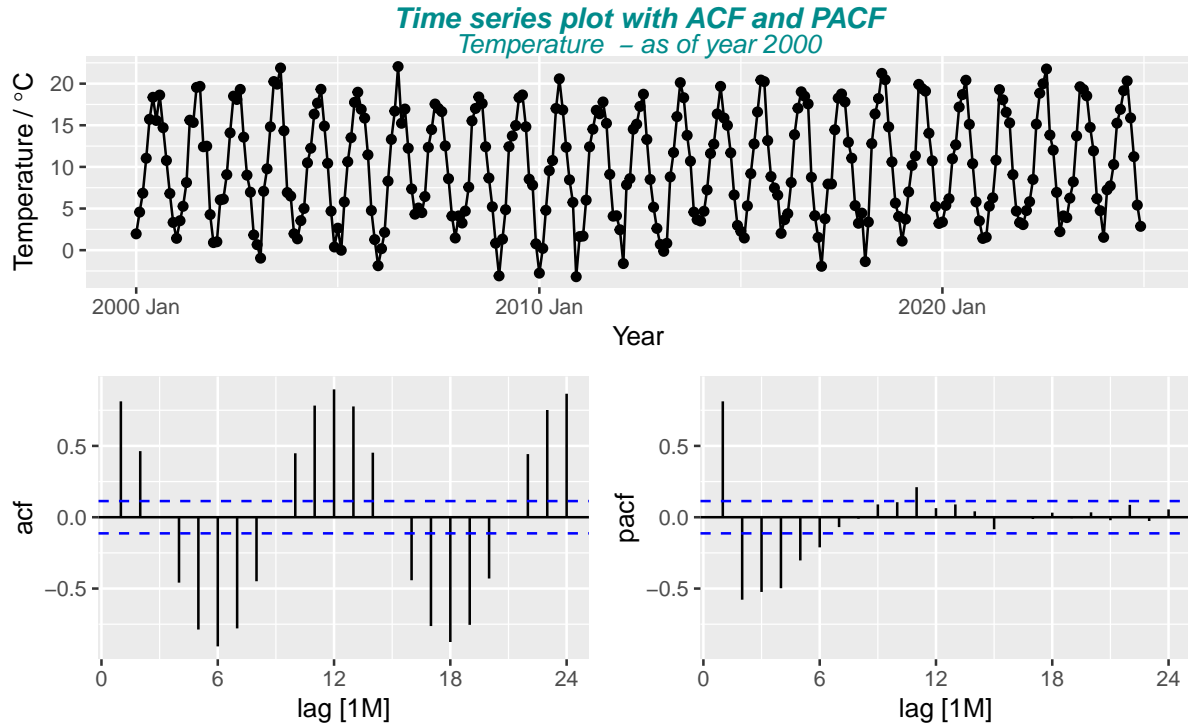
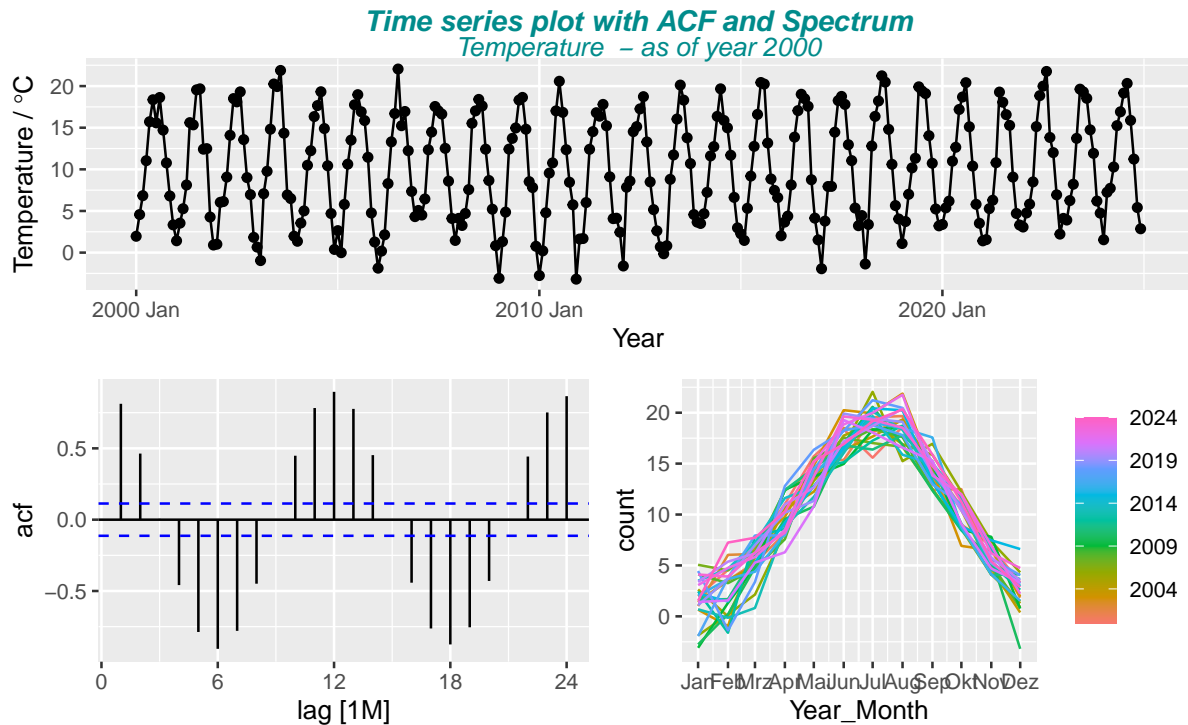
2.2.3 Periodogram - Spectral Density Estimation of a Time Series

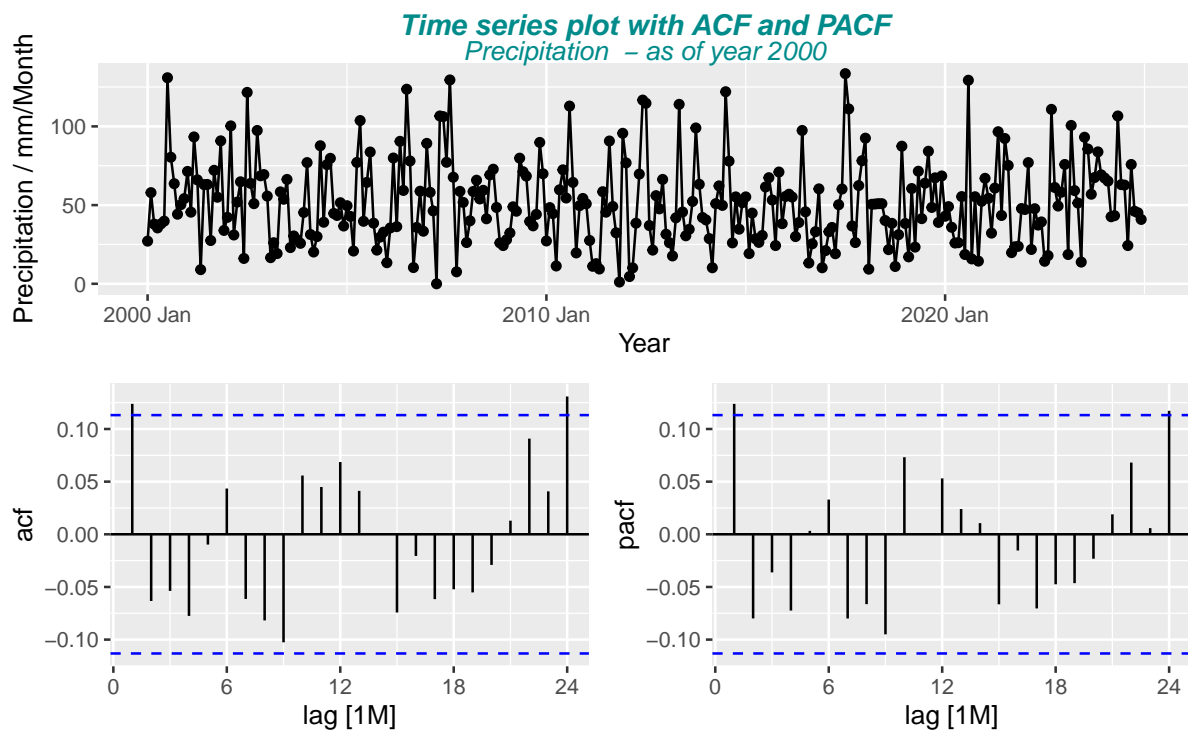
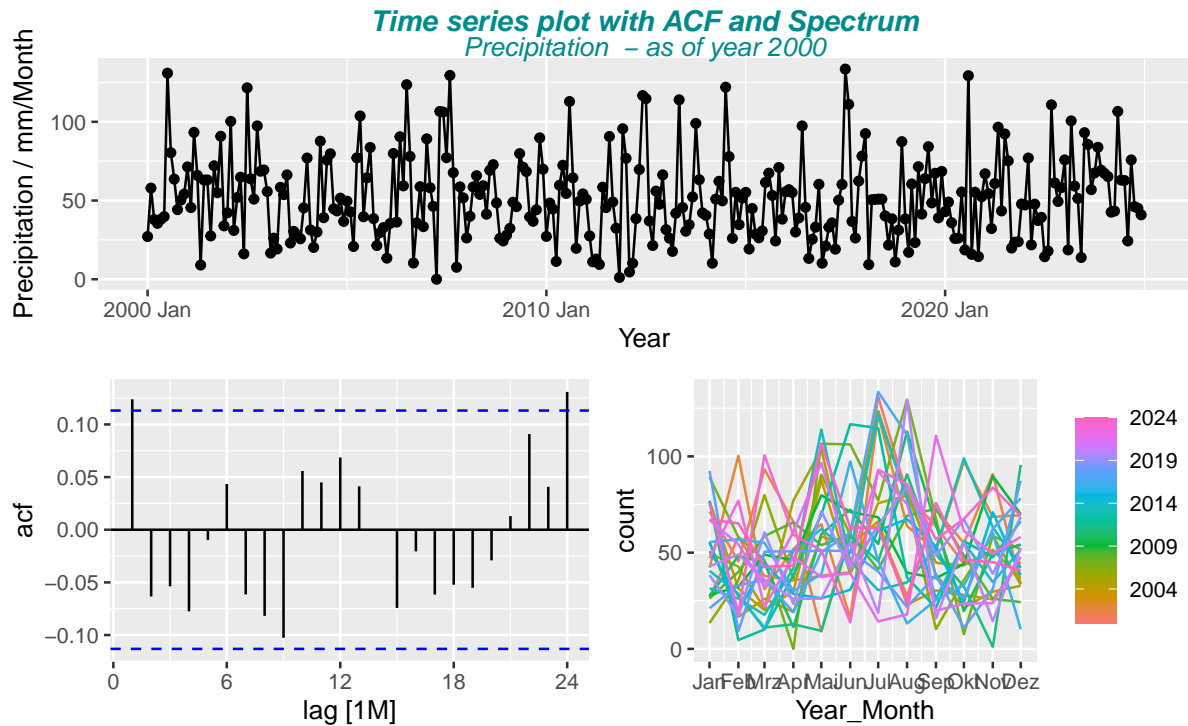
The spectral density characterizes the frequency content of the signal. One purpose of estimating the spectral density is to detect any periodicities in the data, by observing peaks at the frequencies corre-

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.



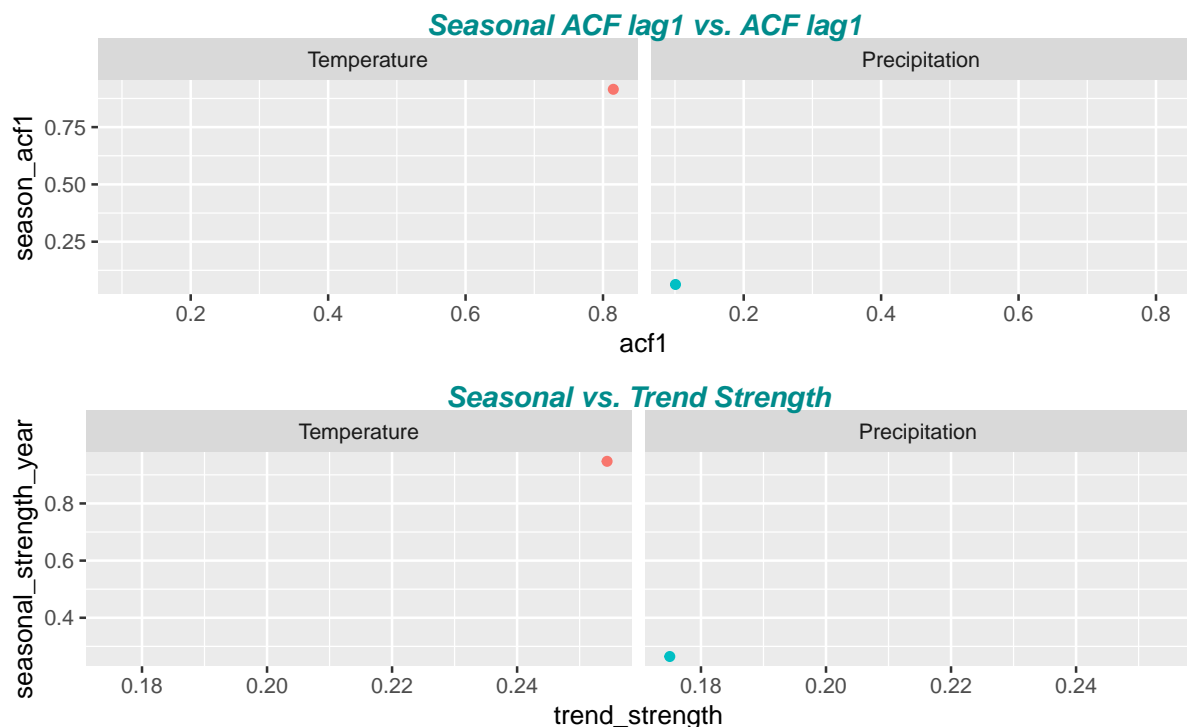


2.2.4 Seasonal vs non Seasonal ACF / Strength (Seasonal/Trend)

- 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~ 0.815 3.55      0.448      1.74      -0.379      0.258      0.915
#> 2 Precip~ 0.101 0.0193    -0.453      0.214     -0.640      0.433      0.0633
#> [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      0.254          0.947          7
#> 2 Precipitation     0.175          0.264          5
#> # 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    0.175
#> 2 Precipitation   0.999
```

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 Giessen - 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
Giessen	Temperature	1901	NA	8.6	17.2	8.5	8.0
Giessen	Temperature	1902	1.5	7.8	16.3	7.4	8.0
Giessen	Temperature	1903	1.3	8.5	16.5	9.9	9.2
Giessen	Temperature	1904	0.4	9.2	17.8	8.3	9.2
Giessen	Temperature	1905	1.3	8.7	18.4	7.4	8.8
Giessen	Temperature	1906	1.7	8.6	16.9	10.0	9.1
Giessen	Temperature	1907	-0.2	8.5	15.9	9.8	8.8
Giessen	Temperature	1908	0.4	8.2	17.3	7.3	8.2
Giessen	Temperature	1909	-0.6	8.4	16.0	8.8	8.3
Giessen	Temperature	1910	2.9	9.2	16.8	8.6	9.4
Giessen	Temperature	2015	2.2	9.1	19.1	9.8	10.4
Giessen	Temperature	2016	4.1	8.8	18.2	10.2	9.9
Giessen	Temperature	2017	1.1	10.1	18.3	9.8	10.0
Giessen	Temperature	2018	2.1	10.8	20.0	10.3	10.9
Giessen	Temperature	2019	3.0	9.5	19.5	10.0	10.4
Giessen	Temperature	2020	4.0	9.9	18.8	10.4	10.8
Giessen	Temperature	2021	2.2	7.5	18.0	9.7	9.3
Giessen	Temperature	2022	3.7	9.8	20.2	10.9	11.1
Giessen	Temperature	2023	3.4	9.4	19.2	NA	NA
Giessen	Temperature	2024	4.5	11.1	18.8	10.8	11.2

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

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Giessen	Precipitation	1901	NA	NA	NA	NA	NA
Giessen	Precipitation	1902	NA	NA	NA	NA	NA
Giessen	Precipitation	1903	NA	NA	NA	NA	NA
Giessen	Precipitation	1904	NA	NA	NA	NA	NA
Giessen	Precipitation	1905	NA	NA	NA	NA	NA
Giessen	Precipitation	1906	NA	NA	NA	NA	NA
Giessen	Precipitation	1907	NA	NA	NA	NA	NA
Giessen	Precipitation	1908	NA	NA	NA	NA	NA
Giessen	Precipitation	1909	NA	NA	NA	NA	NA

City	Measure	Year	Winter_avg	Spring_avg	Summer_avg	Fall_avg	Year_avg
Giessen	Precipitation	1910	NA	NA	NA	NA	NA
Giessen	Precipitation	2015	42.0	33.3	53.2	49.5	43.4
Giessen	Precipitation	2016	50.2	41.3	52.1	39.6	43.5
Giessen	Precipitation	2017	21.5	NA	101.6	41.8	NA
Giessen	Precipitation	2018	60.0	NA	37.6	26.9	NA
Giessen	Precipitation	2019	47.6	51.8	63.2	51.6	52.0
Giessen	Precipitation	2020	NA	29.3	67.8	28.5	NA
Giessen	Precipitation	2021	57.9	63.2	70.3	22.4	53.1
Giessen	Precipitation	2022	57.3	35.6	23.8	73.8	48.5
Giessen	Precipitation	2023	50.9	70.4	64.2	NA	NA
Giessen	Precipitation	2024	67.2	64.2	50.0	55.7	56.9

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

City	Month	Temperature	Precipitation
Giessen	Jan	0.7	47.8
Giessen	Feb	1.5	39.2
Giessen	Mar	5.0	43.1
Giessen	Apr	8.8	41.1
Giessen	May	13.4	59.1
Giessen	Jun	16.6	60.5
Giessen	Jul	18.3	65.5
Giessen	Aug	17.5	59.3
Giessen	Sep	13.9	49.9
Giessen	Oct	9.3	48.5
Giessen	Nov	4.7	53.0
Giessen	Dec	1.7	56.1

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>