Assignment: Project No. 1

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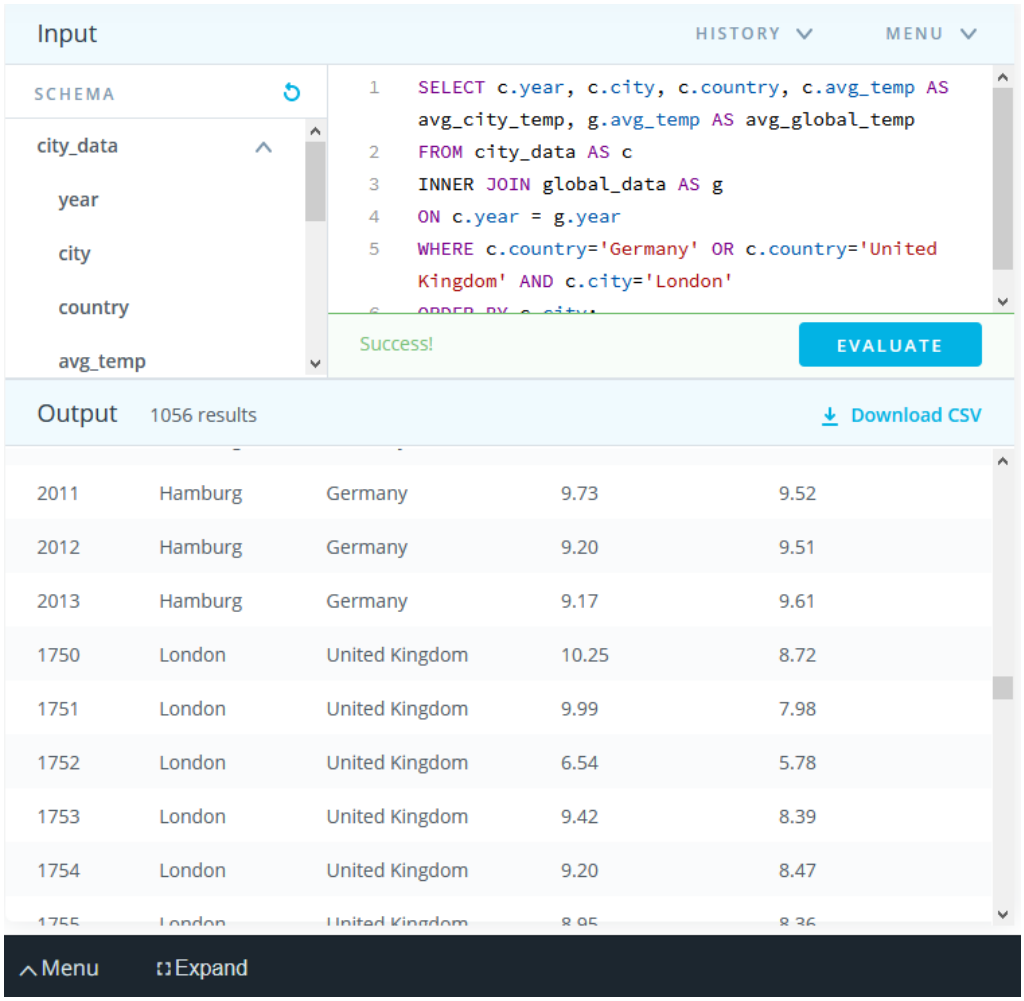
Explore Weather Trends

I live in Frankfurt, Germany. I have analysed weather trends in the nearest German city Munich, and I have compared them with global weather trends. Furthermore, I have included data from the other available German cities in the database, Berlin and Hamburg as well as for London, United Kingdom.

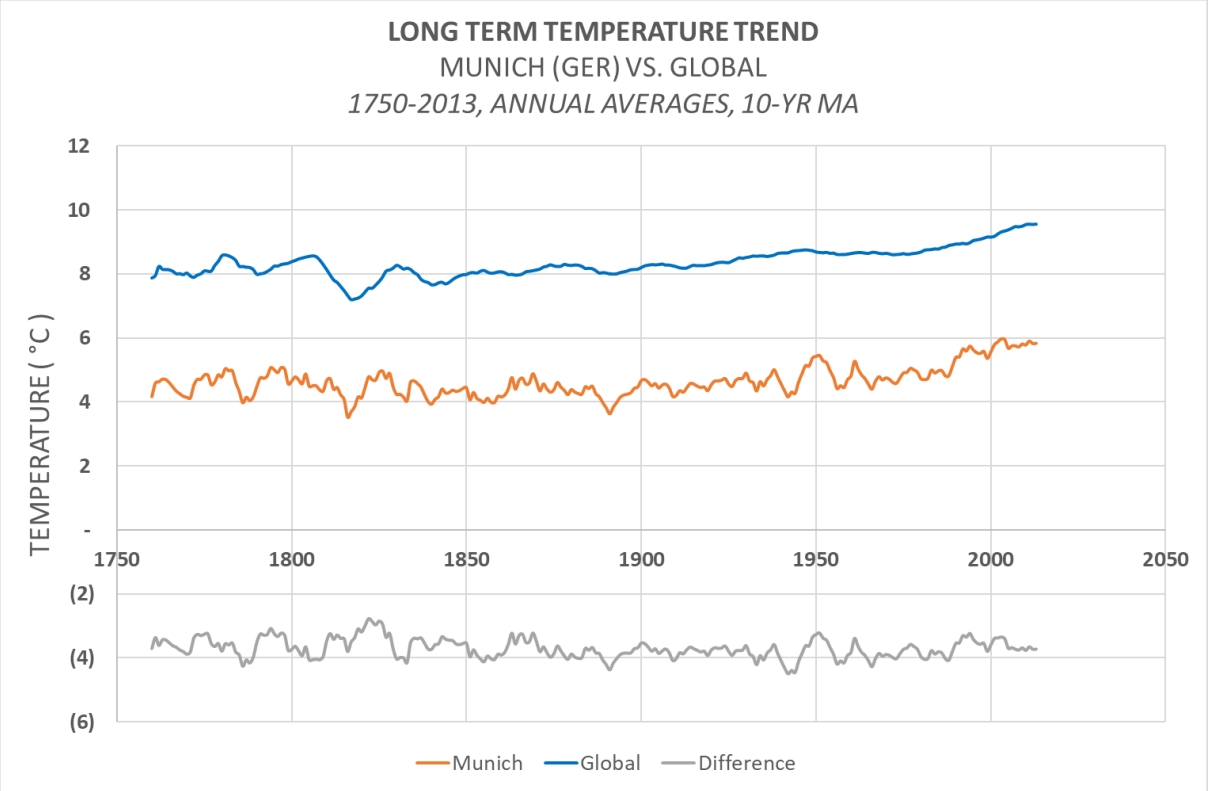
Accessing Data With SQL

The following query extracts both city level data and global data for the entire available timeframe from 1750 until 2013 (264 data points for the average annual temperature in each of the 4 cities and for the global average). The generated CSV-file contains the data for the following analysis.



Create a line chart

I have used MS-Excel to import the CSV-file from the SQL query and to generate a line chart for the annual average temperature in Munich and for the global average. In order to smooth out the lines 10-year **moving averages (MA)** were used. The MS-Excel command AVERAGE was used to calculate the MA[1]. The line 'Difference' shows the deviation of the MA temperature in Munich from the MA of the global average.



Munich: Latitude 48° 8' N, Longitude 11° 34' E

Height above mean sea level: +519 metres

Proximity to sea: approx. 700 km

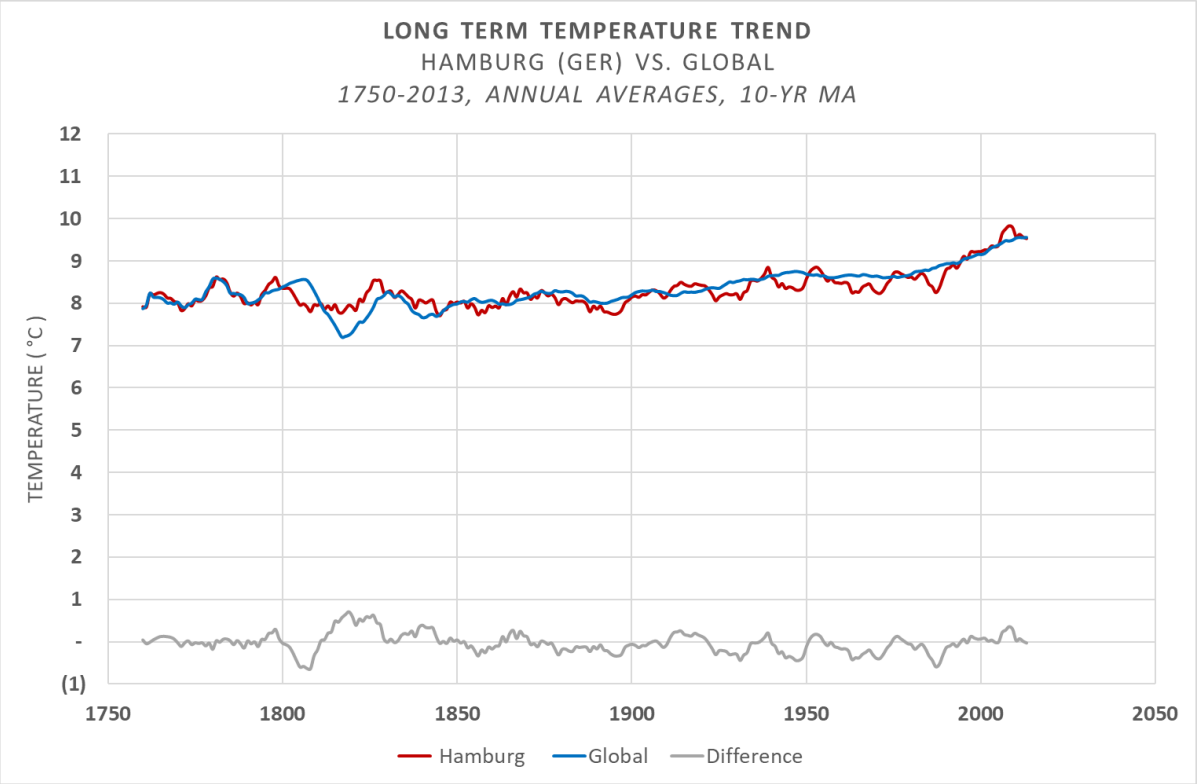
Observations

Both the average annual temperature for Munich and for the global average show an upwards trend. Since the early 1900s both time series started deviating from their previous long term (LT) equilibrium levels of approx. 4 degrees Celsius (°C) for Munich and approx. 8°C for the global

[1] For example, the Munich MA data points for the year 1760 was calculated by AVERAGE (MUNICH TEMP 1751: MUNICH TEMP 1760)

average. Both average temperatures have risen by almost 2°C since then while the temperature difference of Munich to the Global average has remained constant at approx. minus 4°C. Nevertheless, while the global average temperature shows a smooth ascent with a steepening incline in the last 40 years, the time series for the city of Munich is more volatile.

Therefore, I would like to compare weather trends in Munich with other cities near Frankfurt. Does the temperature difference between cities and the global average increase over time, or does it show **mean reversion**?



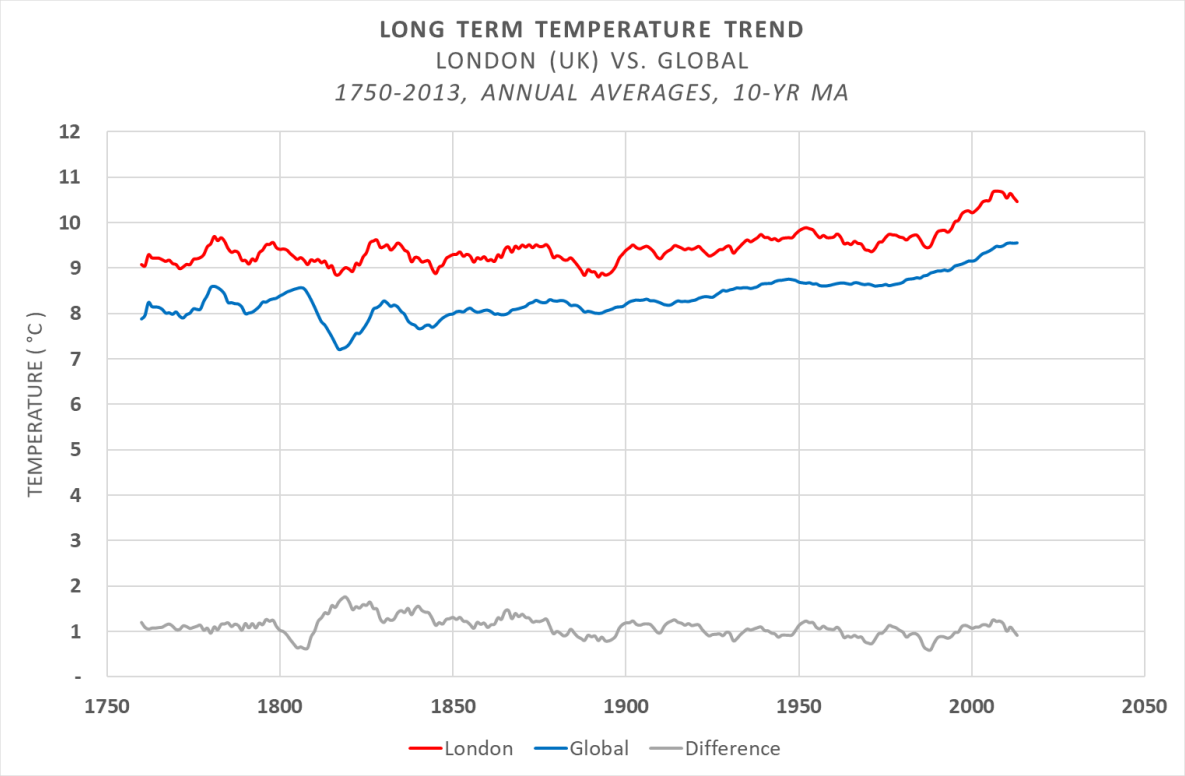
Hamburg: Latitude 53° 33' N, Longitude 10° 0' O

Height above mean sea level: +6 metres

Proximity to sea: approx. 70 km

Hamburg's average temperature closely mimic the average global level, albeit with higher volatility. While Hamburg's annual temperatures have deviated from the global temperature for extended time periods (e.g. in the early 1800s), the temperature difference shows mean reversion as well.

In a similar vein, London weather pattern follow the global trend with on average +1°C higher annual temperatures. Both city's altitudes are at sea level and their geographic location is close to the sea, but London's latitude is 2° or approx. 200km further south.

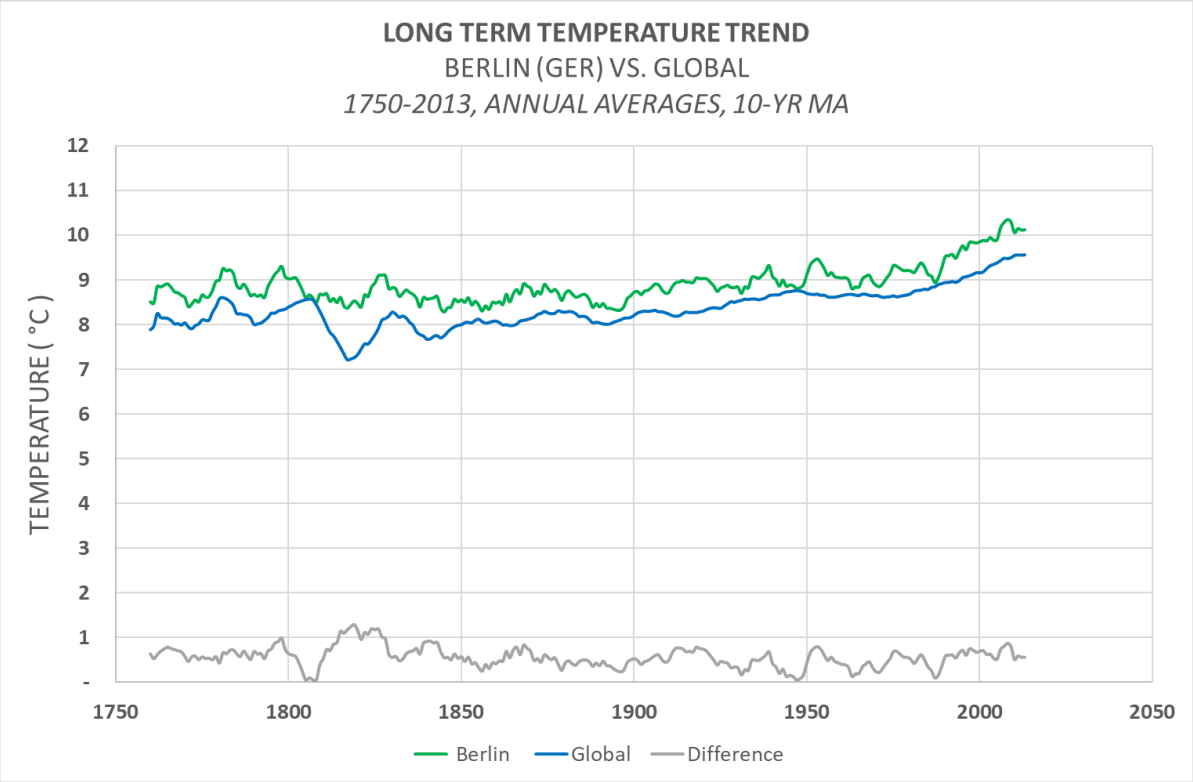


London: Latitude 51° 31′ N, Longitude 0° 7′ W

Height above mean sea level: +11 metres

Proximity to sea: approx. 50 km

London shows similar historical weather trends as Hamburg with stronger deviations from the global trend in the early 1800s. However, in early 1800s global temperatures dropped significantly while temperatures in sea locked Hamburg and London declined only marginally. Interestingly, the volatility of the temperature difference for both cities has declined since global temperatures have started rising in the early 1900s.



Berlin: Latitude 52° 31' N, Longitude 11° 34' E

Height above mean sea level: +34 metres

Proximity to sea: approx. 200 km

Comparing the weather data for those 4 cities reveal common trends. All 4 cities have experienced rising temperatures since the early 1900s. While each city time series is more volatile than the global average, their temperature differences to the global average show **mean reversion** and they remain mostly within a narrow band of +/- 1 degree Celsius. Therefore, rising temperatures are a truly global phenomenon while the temperature difference of cities to the global average are determined by constant factors like geographic position relative to the equator (i.e. latitude), height above sea level and distance to a large body of salty water. Consequently, despite being absent in the Udacity dataset we could guess average temperature trend for Frankfurt based on those geographic constants[2]. Frankfurt is landlocked like Berlin at a similar elevation level, but 180 km further away from the sea. Nevertheless, Frankfurt's latitude is 2° 25′ or approx. 300 km further south than Berlin, leading to higher average temperatures.

[2] In 2018, Frankfurt Westend station reached the highest average temperature ever recorded in Germany since measurement by Deutsche Wetterdienst began in 1882 with an annual average temperature of 12.8°C (Source: DWD Deutscher Wetterdienst).

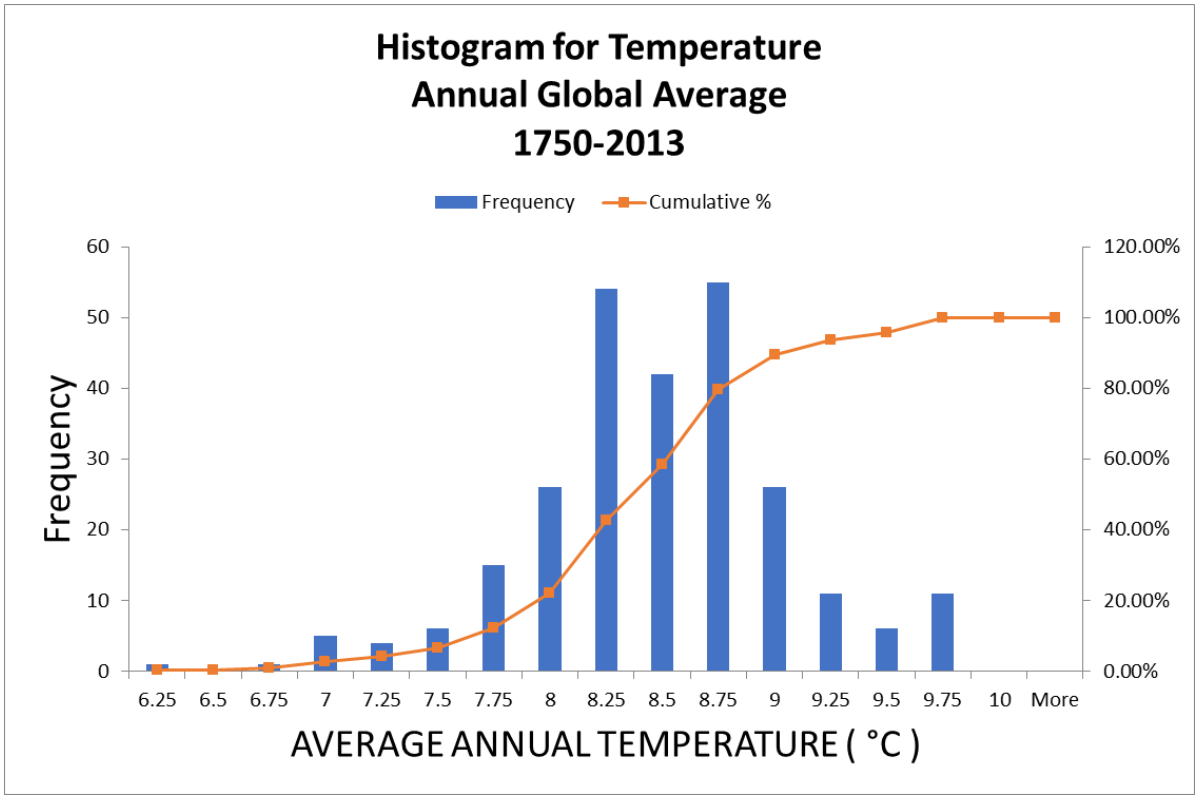
	Mean (°C)	***Difference (°C)***	*Latitude*	*Height (m)*	*Proximity to sea (km)*	*Distance to Frankfurt (Km)*
London	9.5	**1.1**	51° 31' N	11	50	638
Berlin	8.9	**0.6**	52° 31' N	34	200	424
Hamburg	8.3	**0.0**	53° 33' N	6	70	393
Munich	4.6	**-3.7**	48° 08' N	519	700	304
Frankfurt	N.A.	N.A.	50° 06' N	112	380	-
Global	8.4	-	-	-	-	
One degree of latitude approx. 111 km						

The Descriptive Statistics table in MS-Excel reveals some basic characteristics of the weather data time series for individual cities and for the global trend. All the data for the 4 cities show a significantly higher volatility compared to the global average (see table below), which is probably due to the smoothing effect of averaging multiple geographic data points each year in the global data series. For example, Munich's proximity to the Alps and the high altitude of the city (approx. 500 metres above sea level) can contribute to particularly low temperatures in some years (e.g. minimum annual avg. temperature in Munich only 0.53°C). Correspondingly, Munich's annual avg. temperature seldom exceeds 6°C and stays well below the maximum temperatures in Berlin, Hamburg, London and well below the global average.

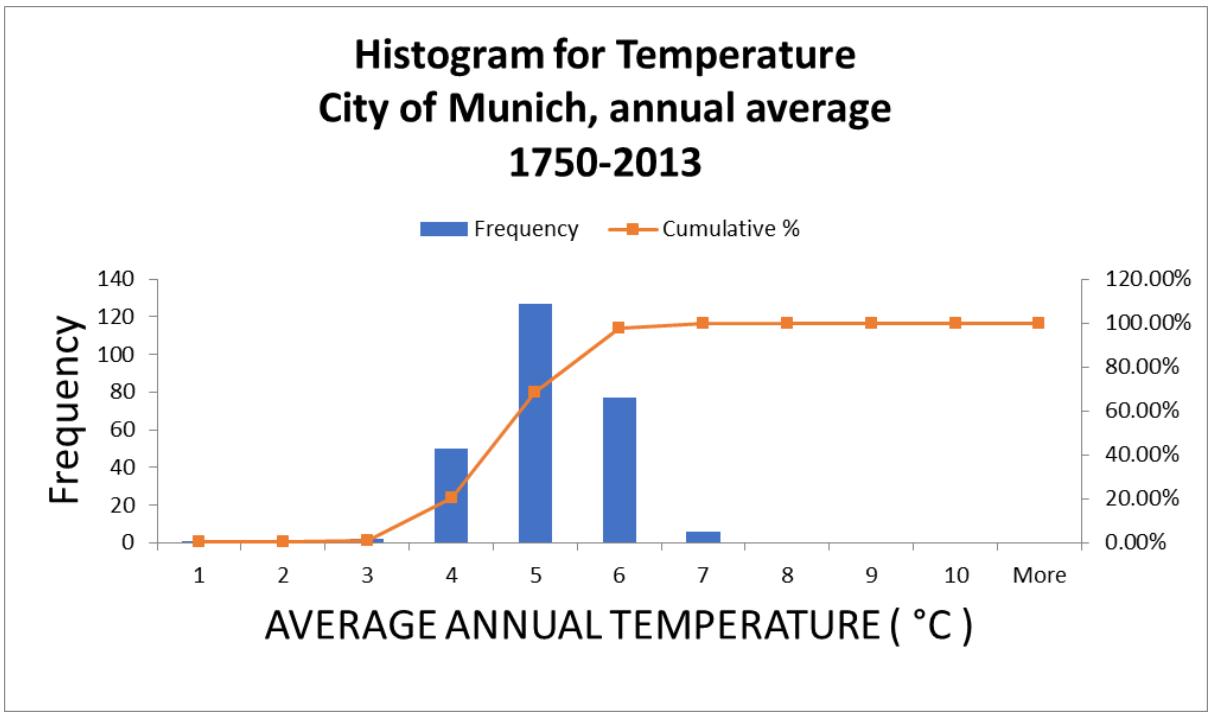
	Munich	*Global*		*Berlin*	*Hamburg*	*London*
Mean	4.64	8.36		8.92	8.33	9.46
Standard Error	0.05	0.04		0.05	0.05	0.04
Median	4.66	8.37		8.94	8.32	9.43
Mode	4.61	7.98		9.15	7.91	9.69
Standard Deviation	0.76	0.58		0.88	0.85	0.67
Sample Variance	0.57	0.33		0.78	0.71	0.45
Kurtosis	2.55	1.66		1.11	0.77	1.08
Skewness	-0.48	-0.44		-0.43	-0.33	-0.22
Range	6.11	3.95		6.12	5.72	4.65
Minimum	0.53	5.78		4.84	4.65	6.54
Maximum	6.64	9.73		10.96	10.37	11.19
Count	264	264		264	264	264
Confidence Level(95.0%)	0.1	0.1		0.1	0.1	0.1

Rising temperature trends show in the **negative skewness** of the weather data. The time series for cities and for the global average show deviations from symmetric normal distributions with more hot years above average than cold years below average[3].

[3] Negative skew commonly indicates that the *tail* is on the left side of the distribution and the mass of the distribution is concentrated on the right of the figure (Source: Wikipedia).



All particularly hot years in Munich with average annual temperatures above 6.0°C have occurred in the last 25 years (hottest year 1994 with 6.6°C).



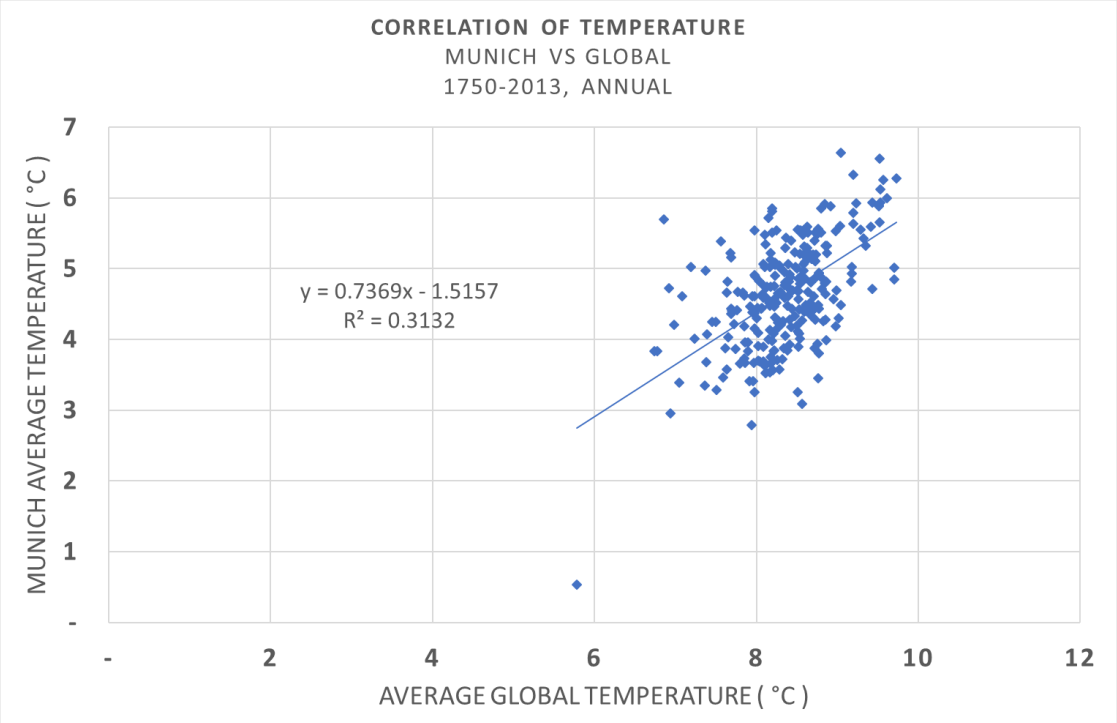
Forecasting Munich weather

The average annual temperature in Munich shows a high correlation of +0.55 to the global trend.

$$(\ Correlation = \frac{Covariance\ (Munich,Global)}{\sqrt{Variance(Munich)} * \sqrt{Variance(Global)}} = \frac{+0.24}{\sqrt{0.57} * \sqrt{V0.33}} \ )$$

Covariance matrix					
	Berlin	*Hamburg*	*London*	*Munich*	*Global*
Berlin	**0.78**				
Hamburg	0.73	**0.71**			
London	0.51	0.52	**0.45**		
Munich	0.60	0.56	0.43	**0.57**	
Global	0.26	0.25	0.22	0.24	**0.33**
1750-2013, annual					

A linear estimate for the average annual temperature in Munich based on the average global temperature in the same year explains approx. 31% of the variation (R^2 = 0.3132). For example, in a record braking year with annual average global temperatures of 10.0°C we would forecast a Munich temperature of 5.9°C. We would expect Munich temperature in the range of +/-1 standard deviation (STD) around this mean estimate with 67% probability and +/-2 STD with 95% confidence.



Example:

global temperature (t)	=	10.0°C
Munich estimate (t)	=	5.9°C
STD (Munich)	=	0.76°C

Munich Forecast **Confidence Intervals**

67% Confidence	=	[5.1°C - 6.7°C]	+/-1 STD
95% Confidence	=	[4.4°C - 7.4°C]	+/-2 STD
99% Confidence	=	[3.6°C - 8.2°C]	+/-3 STD

Alternatively, we could assume that the weather does not change from last year (2013 Munich = 6.0°C and Global = 9.6°C) and we can use the confidence intervals around this point estimates (static expectations).

For longer term forecasts I would start with a linear extrapolation of the temperature trend since the early 1900s with average temperature increases of approx. 1°C every 50 years for both the global trend and for Munich weather. Nevertheless, data **extrapolation** outside previously observed values is less accurate than data interpolation within previously observed ranges. The trend might change from linear increase to exponential increase, or temperatures might drop again over an extended period like in the early 1800s. Nevertheless, I would expect Munich to stay cooler than the global average given its geographic location.

Sources:

https://www.thelocal.de/20181228/berlin-germanys-sunniest-city-in-2018-frankfurt-the-warmest

https://www.fnp.de/frankfurt/frankfurt-waermste-deutschlands-jahr-2018-10921875.html

https://www.distancecalculator.net/

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https://www.luftlinie.org/