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Trend and the Cycle of Fluctuations and Statistical Distribution of Temperature of Berlin, Germany, in the Period 1995-2012

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Data Source

In this research, the data used from freely available data of the DWD Climate Data Centre, the hourly grids of air temperature for Germany (project TRY Advancement) [3]
https://opendata.dwd.de/climate_environment/CDC/grids_germany/hourly/Project_TRY/air_temperature_mean/
The urban area of Berlin city in Germany was selected from these coordinates: 12.87°E, 52.24°N to 13.96°E, 52.78°N.

Materials

Python computer program, and NetCDF4, Matplotlib, Pandas, Numpy, and Scipy modules. The matplotlib basemap toolkit from Cartopy for plotting 2D data on maps in Python, contour plots, bar graphs, boxplots, and line plots. Other tools including mean, median, inter quantile range, histogram, rfft from Numpy, and signal, fftpack, norm, Gaussian, beta, optimize, and leastsq from Scipy [7-12]

Methodology

Determining the main periodicity was the Fast Fourier Transform (FFT) [13], by the fft and ifft tool from the Python Numpy module. Linear regression trend of average annual temperature increase, the least squared error fitting method, harmonic temperature fluctuations to find the main sinusoidal period, and the correlation of the fitted function and original data. Inter Quantile Range (IQR), Histogram, and probability distribution analysis, and the classification of data divided by seasons and daytime. Fitting on distribution probability and sum square error (SSE).

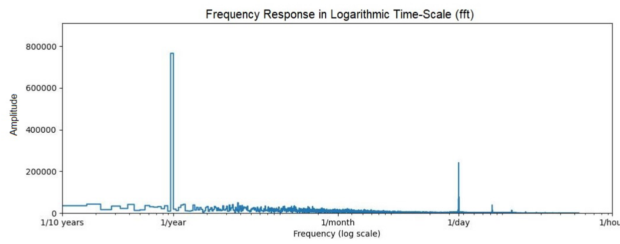

Figure 1. FFT analysis of hourly temperature data for the Berlin city region

Table 1. Statistics for average values of the Berlin region temperature for hourly and daily average data.

Data	mean	max	min	median	variance	Standard deviation
hourly	9.62	36.96	-20.61	9.61	70.05	8.37
daily avg.	9.62	29.42	-16.38	9.95	61.55	7.85

Table 2. Statistical results of IFFT reconstructed data and Residuals for hourly data.

Data	mean	median	correlation coefficient	variance	Standard deviation
IFFT	9.62	9.34	0.867	52.66	7.26
Residuals	0.00	-0.03	0.498	17.38	4.17

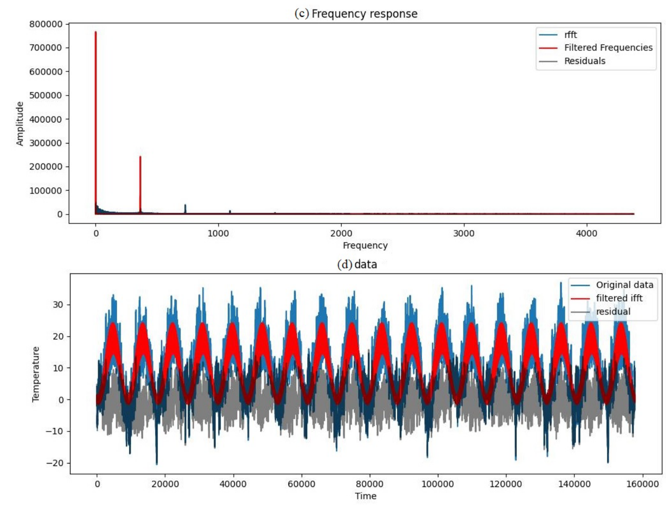

Figure 2. FFT analysis of hourly temperature data for the Berlin city region. (c) Filtered main Frequencies response; (d) Original data, IFFT and Residuals.

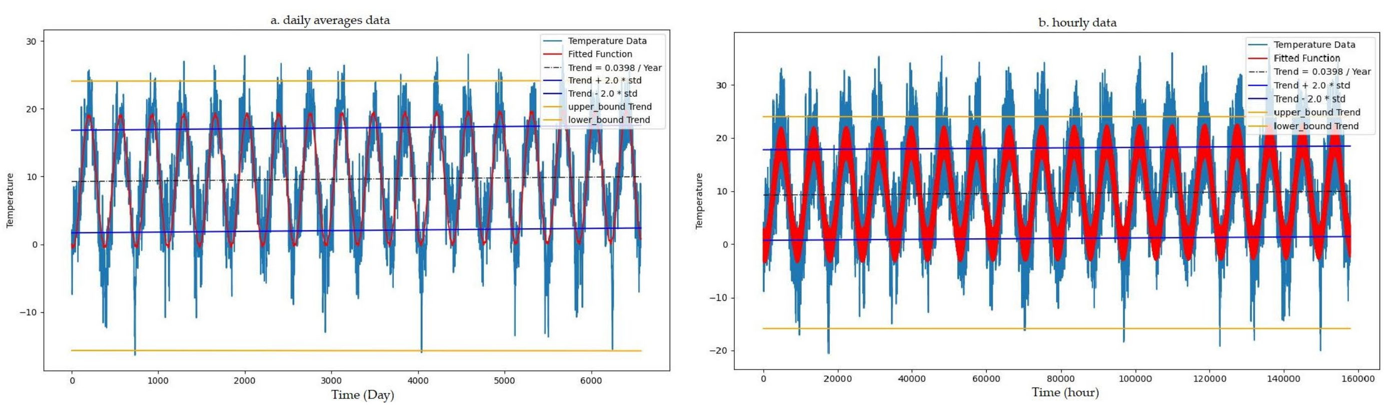

Figure 3. Linear Trend and harmonic function fitted data. (a) daily averages data; (b) hourly data. Fitting equation: $y = a + b \times t + c \times \sin(w_1 \times t + d) + e \times \sin(w_2 \times t + f)$.

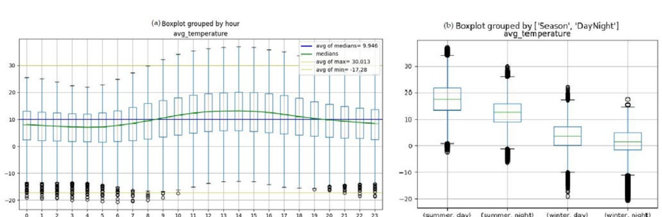

Figure 5. The hourly temperature of Berlin region Boxplot. (a) hour of the day; (b) hourly data grouped by season and daytime

Table 3. Linear regression and harmonic function fitting results.

Data	a	b	c	W1	d	e	W2	f	Correlation C.
hourly	9.26	4.54×10^{-06}	9.70	0.00071	4.43	-3.058	0.2618	0.9036	0.860
daily avg.	9.26	0.00011	-9.70	0.01720	7.58	0.248	0.2606	2.6463	0.876

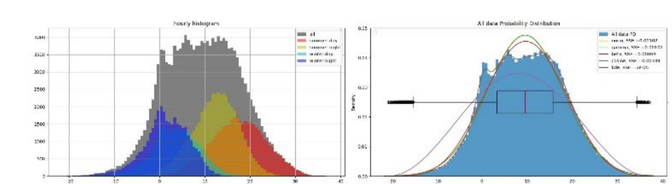

Figure 8. Histogram, Probability distribution and fitting functions, the hourly average temperature of Berlin region, All data.

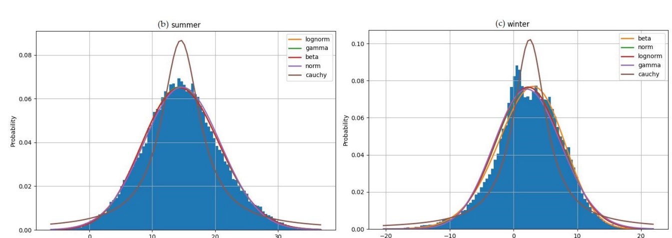

Figure 7. Probability distribution and fitting functions, the hourly average temperature of Berlin region. (a) All data; (b) Summer; (c) Winter

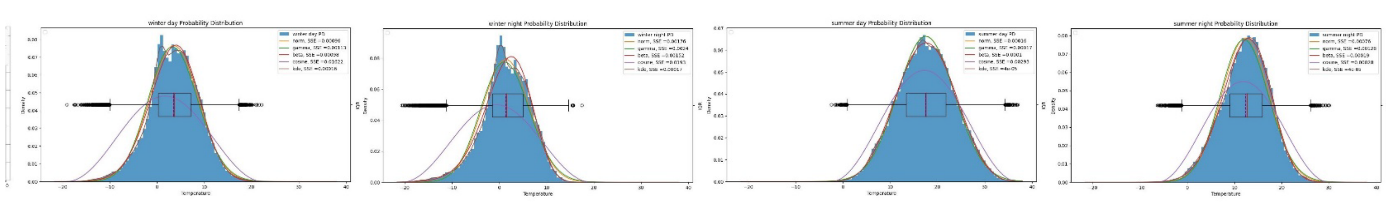

Figure 9. Probability distribution and fitting functions for hourly data by Season and Daytime classification.

Table 4. Statistical results of Probability distribution and fitting functions for hourly data by Season and Daytime classification.

Data	mu	sigma	skewness	kurtosis	Normal SSE	Beta SSE	Q1	Q2	Q3	IQR
All data	9.615	8.370	0.0150	-0.3845	0.00102	0.00069	3.3465	9.6119	15.7281	12.3816
Winter Day	3.554	5.209	-0.1989	0.2625	0.00096	0.00098	0.2765	3.6167	7.1116	6.8351
Winter Night	1.413	5.036	-0.5021	0.5888	0.00176	0.00152	-1.4874	1.5164	4.9810	6.4684
Summer Day	17.571	6.011	-0.0154	-0.3057	0.00016	0.0001	13.3968	17.5554	21.7395	8.3428
Summer Night	12.307	5.066	-0.2331	-0.0703	0.00076	0.00019	9.0489	12.5862	15.8574	6.8085

Conclusions

Without predefinition of season, months numbered 4 to 10 were determined as summer, and hours from 9 to 19 were determined as day hours, by considering medians of data as the benchmark for classification. While the mean temperature in this period is 9.62˚C with a range of -20.61˚C to 36.96˚C, the median difference between the summer and winter months is 12.32˚C, and the ratio of the median difference between days and nights for these seasons is 2.46