TREND AND CYCLE OF FLUCTUATIONS AND STATISTICAL DISTRIBUTION OF TEMPERATURE OF BERLIN, GERMANY, IN THE PERIOD 1990-2022

SAEED RASEKHI, ISIDRO A. PÉREZ, M. ÁNGELES GARCÍA, FATEMEH PAZOKI

Department of Applied Physics, Faculty of Sciences,

University of Valladolid, Valladolid, Spain

e-mail: saeed.rasekhi@uva.es

Abstract

Temperature trends and fluctuations provide key insights into climate change dynamics. This study analyzes historical temperature data for Berlin, Germany, between 1990 and 2022, using the European Meteorological Observations (EMO) Project dataset, which provides gridded temperature data at a 1 arcmin resolution. The daily maximum and minimum temperatures were calculated using spatial averaging over the urban area of Berlin, considering all grid points within the geographical boundary (12.87°E, 52.20°N to 13.96°E, 52.79°N). The study employs Fourier Transform analysis, linear regression modeling, and least squares fitting to examine temperature fluctuations and identify dominant periodic cycles. Statistical analysis classifies April to September as the warm season, with a median temperature difference of 10.3°C (min temp) and 14.2°C (max temp) between warm and cold months. Probability distribution fitting reveals that beta and normal distributions best represent the observed temperature variations. A comparison with the TRY project dataset (1995–2012) indicates an increasing trend: 0.55°C per decade for maximum temperature and 0.30°C per decade for minimum temperature. This work highlights the growing temperature trends in Berlin and supports further studies on urban heat dynamics and climate adaptation.

Key words**:** *Temperature trend; harmonic analysis; distribution functions, probability distribution functions; urban climate.*

Përmbledhje

Tendencat dhe luhatjet e temperaturës ofrojnë njohuri kyçe në dinamikën e ndryshimit të klimës. Ky studim analizon të dhënat historike të temperaturës për Berlinin, Gjermani, përgjatë viteve 1990 dhe 2022, duke përdorur të dhënat e projektit të Vrojtimeve Meteorologjike Evropiane (VME), i cili siguron të dhëna të temperaturës në një rezolucion 1 arcmin. Temperaturat maksimale ditore dhe minimale ditore janë llogaritur duke mesatarizuar në shtrirjen hapësinore të zonës urbane të Berlinit, duke marrë në konsideratë të gjitha pikat e rrjetit në shtrrijen gjeografike (12.87°E, 52.20°N deri në 13.96°E, 52.79°N). Në studim janë përdorur analiza e transformimit Furier, regresi linear dhe metoda e katrorrëve më të vegjël për të ekzaminuar luhatjet e temperaturës dhe për të identifikuar ciklet periodike mbizotëruese. Analiza statistikore klasifikon periudhën nga prilli në shtator, si sezon i ngrohtë, me një ndryshim mesatar të temperaturës prej 10.3°C (temperature miinimale) dhe 14.2° C (temperaturë maksimale) ndërmjet muajve të ngrohtë dhe të ftohtë. Shpërndarja probabilitare tregon se shpërndarjet beta dhe normale përfaqësojnë më së miri ndryshimet e vrojtura të temperaturës. Një krahasim me të dhënat e projektit TRY (1995–2012) tregon për një tendency në rritje prej 0.55°C për dekadë, për temperaturën maksimale dhe rritjen prej 0.30°C në dekadë, për temperaturën minimale. Ky studim nxjerr në pah tendencat në rritje të temperaturës për Berlinin dhe mbështet studime të mëtejshme mbi dinamikën e nxehtësisë urbane dhe përshtatjen klimatike.

Fjalë kyçe: *Trendi i temperaturës, analiza harmonike, funksionet e shpërndarjes, shpërndarja e probabilitetit, klima urbane.*

Introduction

Air temperature, a critical component of meteorological data analysis, exhibits significant variations throughout the annual cycle, influenced by geographical location. Understanding temperature trends is essential for assessing the impacts of climate change and developing effective mitigation strategies. The study of meteorology and the analysis of temperature data have gained substantial importance over the last century, driven by advancements in mathematical, statistical, and data analysis techniques (Wilks, 2020; Weng et al., 2016). This significance is reflected in the diverse methodologies developed to study, analyze, and forecast weather patterns and climate changes, as well as seasonal climate predictions based on historical data

(Goddard et al., 2001). This study focuses on the statistical analysis of historical temperature data for Berlin, Germany, from the European Meteorological Observations (EMO) Project and a comparison with a previous result for the same region with a different dataset in the period of 1995–2012 (Rasekhi et al., 2023).

Methodology

The study uses daily maximum and minimum temperature data from the European Meteorological Observations (EMO) Project, a high-resolution meteorological dataset providing 1 arcmin (~1.85 km) gridded temperature data for Europe (Thiemig et al., 2022) from 1990 to 2022. The dataset provided comprehensive information on daily maximum and minimum temperatures, allowing for detailed analysis of temperature fluctuations over time. The Berlin region is defined within 12.87°E to 13.96°E longitude and 52.20°N to 52.79°N latitude, including a grid of 35 by 65 data points. To obtain representative daily min/max temperature values, we applied spatial averaging across all grid points within Berlin's boundary.

The Fourier Transform method is applied with the fast Fourier tool from the Python computer program to identify dominant periodic cycles. Linear regression analysis is used to determine long-term temperature trends by using the fitting equation: $y = a + b \times t + c \times \sin(w1 \times t + d) + e \times \sin(w2 \times t + f)$.

Interquartile Range (IQR) and Histogram Analysis: Used to classify warm and cold months. Probability Distribution Fitting: Comparing different probability functions (normal, beta, gamma, cosine) to determine the best fit for temperature distributions.

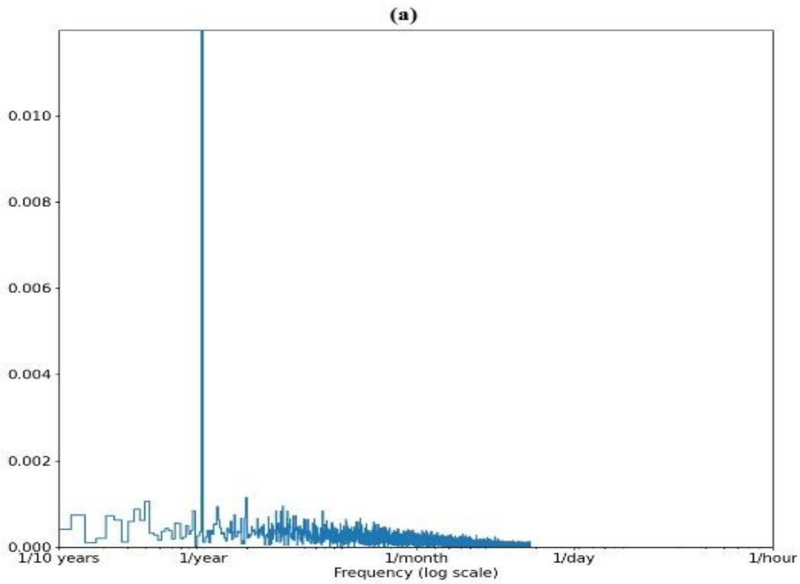
Results

The statistical analysis is presented in **Table 1**. While the average of min and max temperatures are 16.67 ˚C and -5.95 ˚C for the minimum temperature data, these values are 27.45 ˚C and 1.0 ˚C, respectively for the maximum temperature data.

Table 1. Statistical analysis for average values for the daily average minimum and maximum temperature data of the Berlin city region. Units are in °C.

Data	mean	max	min	median	variance	Std
Min temperature	6.53	22.56	-19.95	6.63	46.16	8.37
Max temperature	14.04	37.83	-12.34	14.09	82.01	9.05

The Fourier analysis shows the main yearly frequency for both minimum and maximum temperature data for the selected region in the period, which is presented in Figure 1 (a, b) identifying an annual periodic cycle as the dominant frequency.



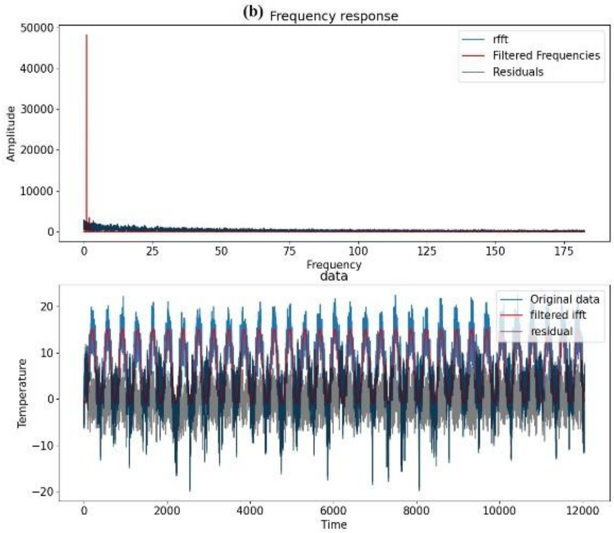
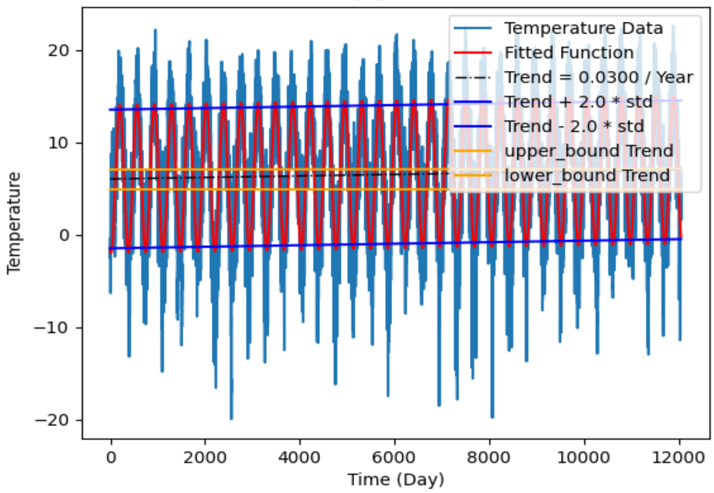


Figure 1. FFT analysis of daily temperature data (a), filtered main frequency response (b, the upper panel); original data, IFFT, and residuals (b, the lower panel)

The harmonic fitting and the trend analysis are demonstrated in Figure 2 (a, b). The correlation coefficient corresponding to the analysis is above 80%.



(b)

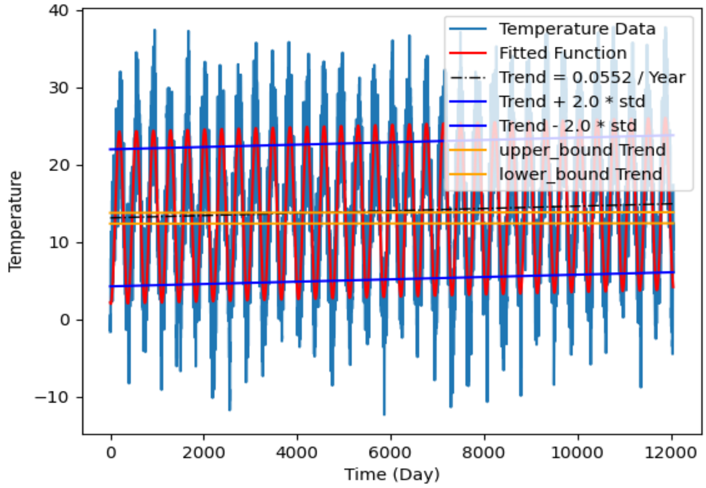


Figure 2. Harmonic fitting trend analysis of minimum temperature (a) and of the maximum temperature (b).

Using median-based classification, April to September were identified as warm months, with a median temperature difference of 10.3°C (min) and 14.2°C (max) between warm and cold months. The median temperature difference between the hot and cold months is 10.27˚C for the minimum temperature and 14.19˚C for the maximum temperature data.

In Figure 3 (a, b) the results of the IQR and Monthly boxplot are presented. The analysis of the minimum temperature data results in 6.67°C for the average of medians, 11.83°C for hot months, and 1.56°C for cold months. For maximum temperature data, the Analysis shows 13.8°C as the average of medians, while the average median temperature of the hot and cold months is 21.06°C and 6.84°C, respectively.

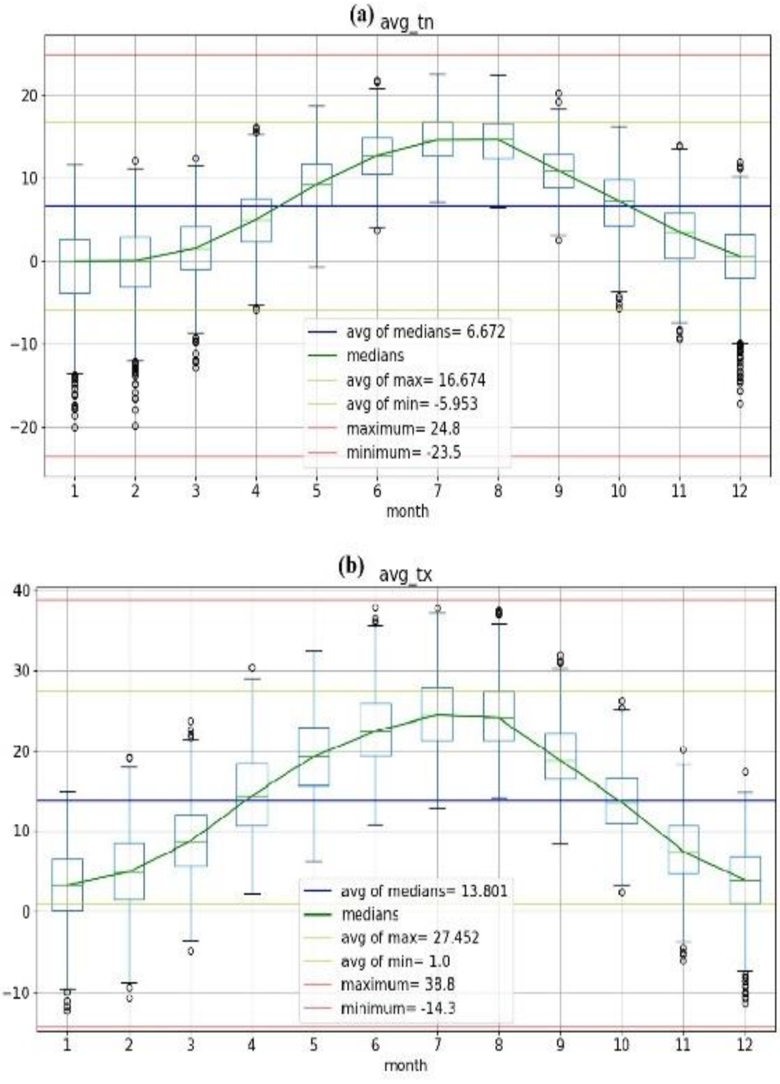
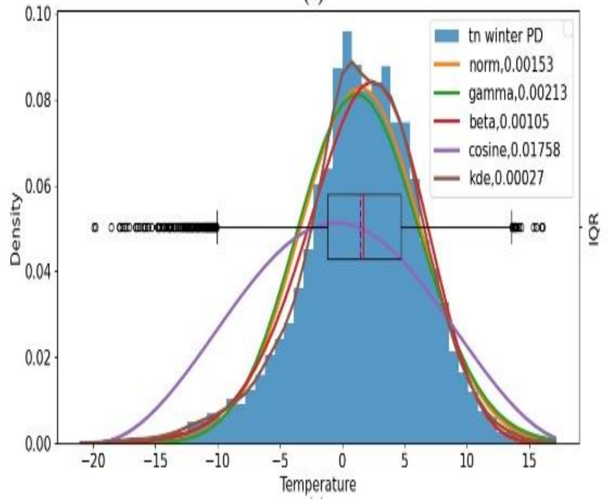


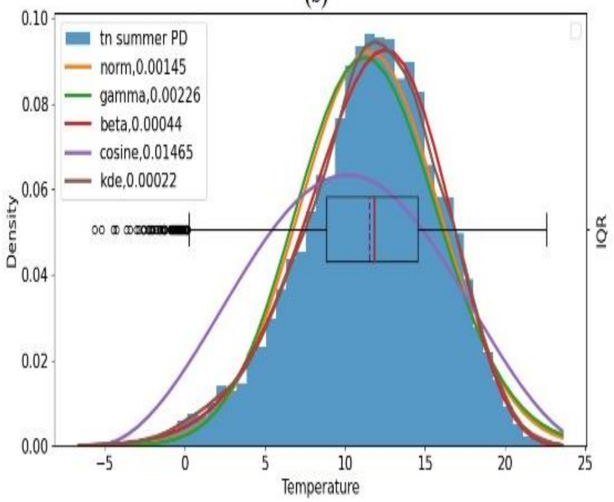
Figure 3. Monthly Boxplot, IQR, and seasonal classification of minimum temperature (a) and maximum temperature (b), (units in °C)

Figure 4 (a, b, c, d) illustrates the histogram and probability distributions, along with Table 2, demonstrating the sum squared errors for distribution functions. The data provided shows the minimum likelihood of the distribution with the cosine function.

(a)


tn winter PD
norm,0.00153
gamma,0.00213
beta,0.00105
cosine,0.01758
kde,0.00027
Density
Temperature
IQR

(b)


tn summer PD
norm,0.00145
gamma,0.00226
beta,0.00044
cosine,0.01465
kde,0.00022
Density
Temperature
IQR

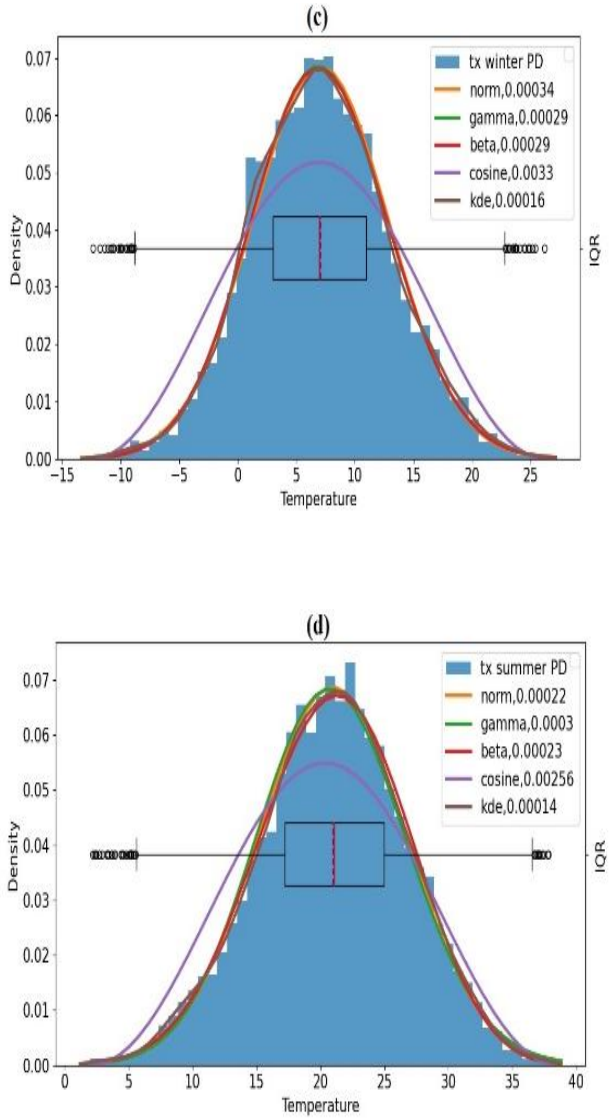


Figure 4. IQR, Histogram, fitting probability distribution and SSE values of minimum temperature for cold months (a) and for hot months (b); and IQR, Histogram, fitting probability distribution and SSE values of maximum temperature for cold months (c) and hot months (d)

Table 2. Sum squared errors of fitting distribution functions for hot and cold months of minimum and maximum temperature data.

	Minimum temperature		Maximum temperature	
Function	Cold months	Hot months	Cold months	Hot months
Normal	0.0015	0.0015	0.0003	0.0002
Gamma	0.0021	0.0023	0.0003	0.0003
Beta	0.0011	0.0004	0.0003	0.0002
Cosine	0.0176	0.0147	0.0033	0.0026

Discussion

Similar research efforts have been undertaken to analyze the temperature trends in the Berlin region employing various approaches (Fenner, 2014), which reported similar intra-urban temperature variability in Berlin. Another study was performed to identify temperature pattern shifts in Europe (Monteiro et al., 2023). Furthermore, (Lemoine-Rodríguez et al., 2022) studied the intra-urban heterogeneity in land surface temperature trends within diverse climate cities. A similar study of the TRY dataset (1995 to 2012) showed an increase in the temperature trend of 0.398 ˚C per 10 years (Rasekhi et al., 2023). Further studies are possible to use different methods for analyzing meteorological time series data such as machine learning and wavelet analysis, and for a statistical study of extreme temperatures and other meteorological variables.

Conclusions

This study analyzed Berlin's temperature trends using a high-resolution dataset (1990–2022) and found a clear warming trend (0.55 °C/decade for maximum temperature and 0.30 °C/decade for minimum temperature). Dominant annual temperature cycles, confirmed via Fourier Transform analysis, and Beta and Normal distribution functions best describe temperature variability with the minimum sum squared error.

While the distribution of minimum temperature data has a wider range of outliers, the maximum temperature data shows a more uniform distribution for both hot and cold months. Although, the maximum temperature data has a smaller gap between the median and the average of the interquartile range, compared with the minimum temperature data for both hot and cold months.

Acknowledgments

This study is conducted as part of a Ph.D. study at the Department of Applied Physics, Science Faculty, University of Valladolid, Spain.

Notes on Contributors

Methodology, Analysis, S. Rasekhi. and I.A. Perez; Investigation S. Rasekhi. and F. Pazoki; Writing original draft preparation, writing review and editing, S. Rasekhi; Validation, supervision, project administration, I.A. Perez. and M.Á. Garcia.

References

Fenner D., Meier F., Scherer D., and Polze A., (2014): "Spatial and temporal air temperature variability in Berlin, Germany, during the years 2001–2010", Urban Climate, vol 10, pp. 308–331.

Goddard L., Mason S. J., Zebiak S., Ropelewski C. F., Basher R. E., and Cane M. A., (2001): "Current approaches to seasonal-to-interannual climate predictions", International Journal of Climatology, vol 21, pp. 1111–1152, DOI: 10.1002/joc.636.

Lemoine-Rodríguez R., Inostroz L., and Zepp H., (2022): "Intraurban heterogeneity of space-time land surface temperature trends in six climate-diverse cities", Science of the Total Environment, vol 804, 150037, DOI: 10.1016/j.scitotenv.2021.150037.

Monteiro M., and Costa M. (2023): "Change point detection by state space modeling of long-term air temperature series in Europe", Stats, vol 6, pp. 113–130, DOI: 10.3390/stats6010007.

Rasekhi S., Perez I. A., Garcia M. A., and Pazoki F., (2023): "Trend and the cycle of fluctuations and statistical distribution of temperature of Berlin, Germany, in the period 1995–2012", Environmental Science Proceedings, vol 27(1), pp. 5, DOI: 10.3390/ecas2023-15704.

Thiemig V., Gomes G. N., Skoien J. O., Ziese M., Rauthe-Schoch A, Rustemerier E., Rehfeldt K, Walawender J. P, Kolbe C. Pichon D., Schweim C. and Salamon P., (2022): "EMO-5: a high-resolution multi-variable gridded meteorological dataset for Europe", Earth System Science Data, Vol 14, DOI: 10.5194/essd-14-3249-2022

Weng Q., Firozjaei M. K., Sedighi A., Kiavarz M., and Alavipanah, S. K., (2018): “Statistical analysis of surface urban heat island intensity variations: A case study of Babol city, Iran”, GIScience & Remote Sensing, vol 56(4), pp. 576–604,
DOI: 10.1080/15481603.2018.1548080

Wilks, D. S., (2020): “Statistical Methods in the Atmospheric Sciences”, 4th ed., Elsevier, New York: Cornell University, DOI: 10.1016/C2017-0-03921-6.