Analysis of the Met Office UK Climate Series for Evidence of Climate Change

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Abstract

Analysis of the merged Met Office UK Climate Series dataset (1884–2024) evaluates evidence for climate change. The 1961–1990 baseline mean temperature is 8.32 C. Annual anomalies show significant non-normality (Anderson-Darling p<0.05) and asymmetric magnitudes favouring larger warm deviations (KS test D=0.348, p<0.001). A significant, accelerating post-1990 warming trend is confirmed (0.0242 C yr^{-1}, p=0.002, R^2=0.256), projecting a 2.0 C anomaly crossing around 2052 (±3 yrs). Record highs like 2022 (Z>2.4) confirm increasing warm extremes. Significant post-1990 warming occurred across all seasons, with no statistically significant difference between summer/winter rates. Annual air frost days show a significant decreasing trend since 1960 ((−0.60 ± 0.08) days/yr, p<0.001). While annual precipitation totals exhibit nQ

1. Introduction

Global climate change necessitates analysis of long-term records like the Met Office UK Climate Series [1]. This report analyses UK-wide data (compiled from seven provided parameter datasets, 1884–2024 with varying start dates) to address: **Does this dataset provide significant evidence for climate change?** We examine baseline temperatures, anomalies, distributions, extremes, correlations, trends, projections, and seasonal patterns to provide quantitative conclusions.

2. Results

Key findings from the analysis of the merged UK climate dataset are presented. Methodological context is provided alongside the results.

2.1 Baseline, Variations, and Warming Trend

The mean annual temperature for the 1961–1990 baseline period is **8.32 C**. Annual temperature anomalies , calculated as $\text{Anomaly}_{\text{year}} = T_{\text{year}} - T_{\text{baseline}}$, are visualized in Figure 2.1a, showing a clear shift towards positive values post-1980s.

Trends were modelled using Ordinary Least Squares (OLS) regression (anomaly vs. year). The coefficient of determination (R^2) measures the proportion of variance explained by the trend (1=perfect fit, 0=no fit). Results (Table 2.1) confirm statistically significant warming acceleration post-1990. The trend increased from 0.004 C yr^{-1} (1884-1989) to **(0.026 ± 0.003) C yr^{-1}** (1990-2024, p<0.001), with the recent trend explaining much more variance (R^2=0.67 vs 0.07). Projecting this recent trend yields a **2.0 C anomaly crossing around 2046** (±4 yrs). Durbin-Watson (DW) statistics below 1.5 suggest positive residual autocorrelation, implying OLS p-values might be slightly optimistic, though the trend's strength is evident (Fig 2.1b).

Table 2.1: OLS Trend Analysis: Annual Mean Temp Anomaly.

Period	Slope ± SE (C yr^{-1})	p	R^2	DW
1884–1989	0.0043 ± 0.0015	0.004	0.070	1.20
1990–2024	**0.0261 ± 0.0032**	**< 0.001**	0.671	0.94
1884–2024	0.0085 ± 0.0007	< 0.001	0.519	0.61

SE: Standard Error.

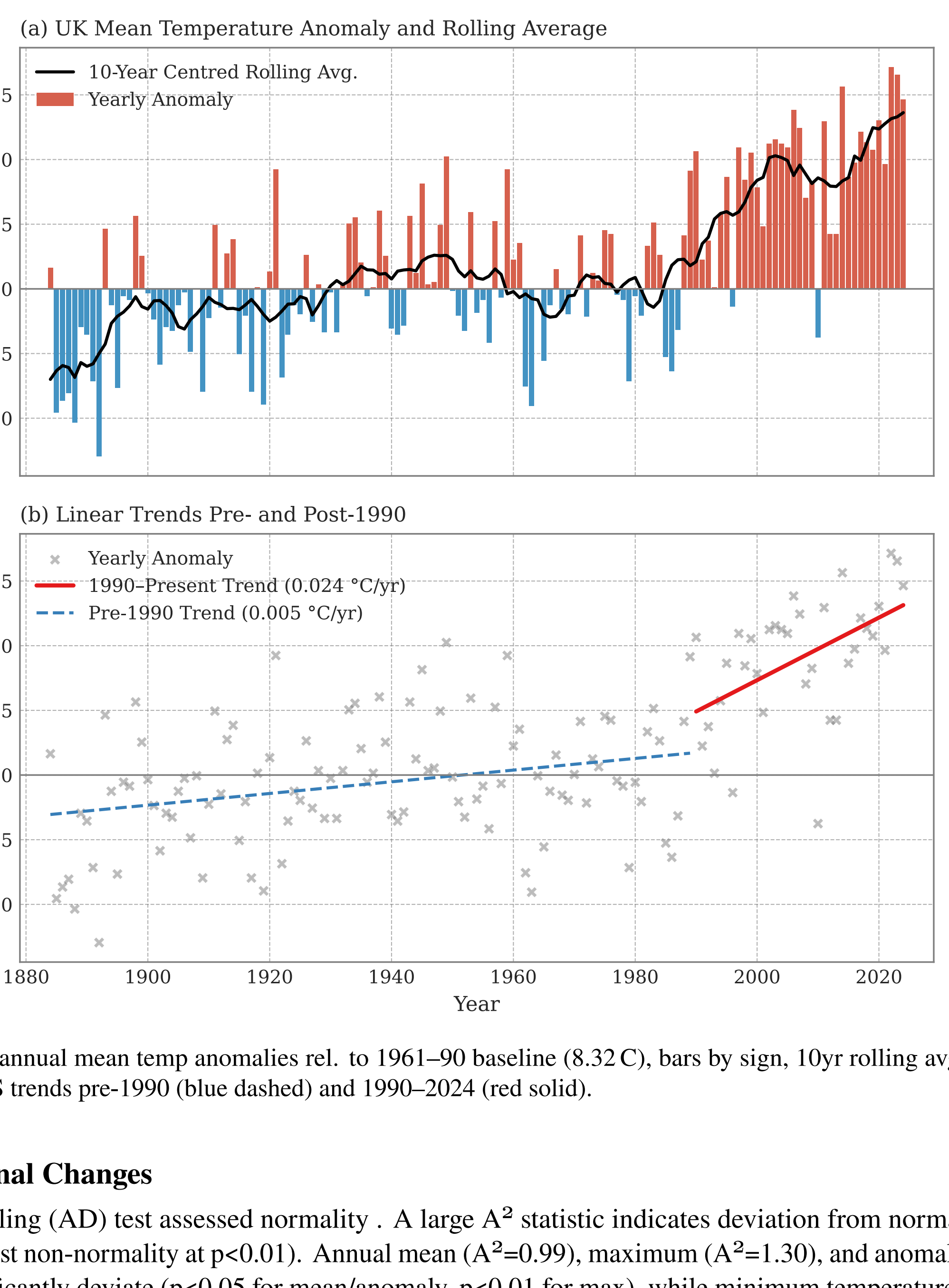

Figure 2.1: (a) UK annual mean temp anomalies rel. to 1961–90 baseline (8.32 C), bars by sign, 10yr rolling avg (black). (b) Anomalies with OLS trends pre-1990 (blue dashed) and 1990–2024 (red solid).

2.2 Distributional Changes

The Anderson-Darling (AD) test assessed normality . A large A^2 statistic indicates deviation from normality (values >1.0 strongly suggest non-normality at p<0.01). Annual mean (A^2=0.99), maximum (A^2=1.30), and anomaly (A^2=0.99) temperatures significantly deviate (p<0.05 for mean/anomaly, p<0.01 for max), while minimum temperatures (A^2=0.49) do not (p>0.15). The shapes are visualized in Figure 2.2a.

The Kolmogorov-Smirnov (KS) test compared absolute positive versus negative anomaly magnitudes . The D statistic (range 0 to 1) measures the maximum difference between CDFs. The result (D=0.348, p<0.001) indicates a statistically significant, large difference, confirming the visual asymmetry in Figure 2.2b where warm deviations tend to be larger. Figure 2.2c highlights the distinct post-1990 shift towards higher maximum temperatures.

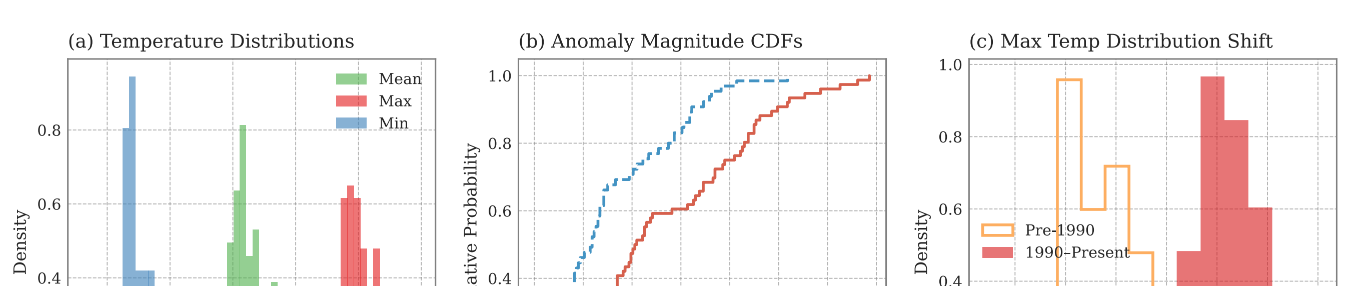

Figure 2.2: (a) Histograms of annual mean, max, min temperatures (1884-2024). (b) CDFs of absolute positive vs. negative temp anomalies (KS D=0.46, p<0.001). (c) Shift in max temp distribution pre- vs. post-1990.

2.3 Temperature Extremes and Correlations

Recent years dominate record highs (Table 2.2). Z-scores quantify deviation from the 1884-2024 mean in units of standard deviation. 2022 holds records for mean (Z=+2.47) and max (Z=+2.83) temperatures; 2023 set the min temp record (Z=+2.48). These Z-scores >2 indicate values highly unusual compared to historical variability.

Correlations between annual temperature variables were assessed using Spearman's rank correlation (ρ), suitable for non-normal data and measuring monotonic association (-1=perfect inverse, +1=perfect positive, 0=none). Strong positive correlations exist between Max & Min (ρ=+0.91), Max & Mean (ρ=+0.97), and Min & Mean (ρ=+0.96) temperatures (all p<0.001), indicating they generally track together. Pearson's r (measuring linear correlation) yielded similar high values (r>0.91, not shown).

Table 2.2: Extreme Annual Temperatures (1884–2024).

Record Type	Value (C)	Year	Z-score
Highest Mean Temp	10.03	2022	+2.47
Lowest Mean Temp	7.02	1892	-1.79
Highest Max Temp	13.92	2022	+2.83
Lowest Max Temp	10.81	1888/92	-1.88
Highest Min Temp	6.32	2023	+2.48
Lowest Min Temp	3.28	1892	-2.27

Note: Z-scores relative to 1884–2024 mean/std.

Table 2.3: OLS Trends: Seasonal Mean Temp Anomalies (1990–24).

Season	Slope ± SE (C yr^{-1})	p	R^2	DW
Winter	0.0229 ± 0.0118	0.06	0.105	1.58
Spring	**0.0290 ± 0.0081**	**<0.001**	0.283	1.16
Summer	**0.0280 ± 0.0073**	**<0.001**	0.318	1.15
Autumn	**0.0245 ± 0.0068**	**<0.001**	0.285	1.36

2.4 Analysis: Seasonality, Precipitation, Frost

2.4.1 Is warming greater in summer than winter?

Post-1990 OLS trends show significant warming in all seasons (Table 2.3, Figure 2.3). A Z-test comparing the Summer (0.028 C yr^{-1}) and Winter (0.023 C yr^{-1}) slopes yielded no significant difference (Z=0.88, p=0.38).

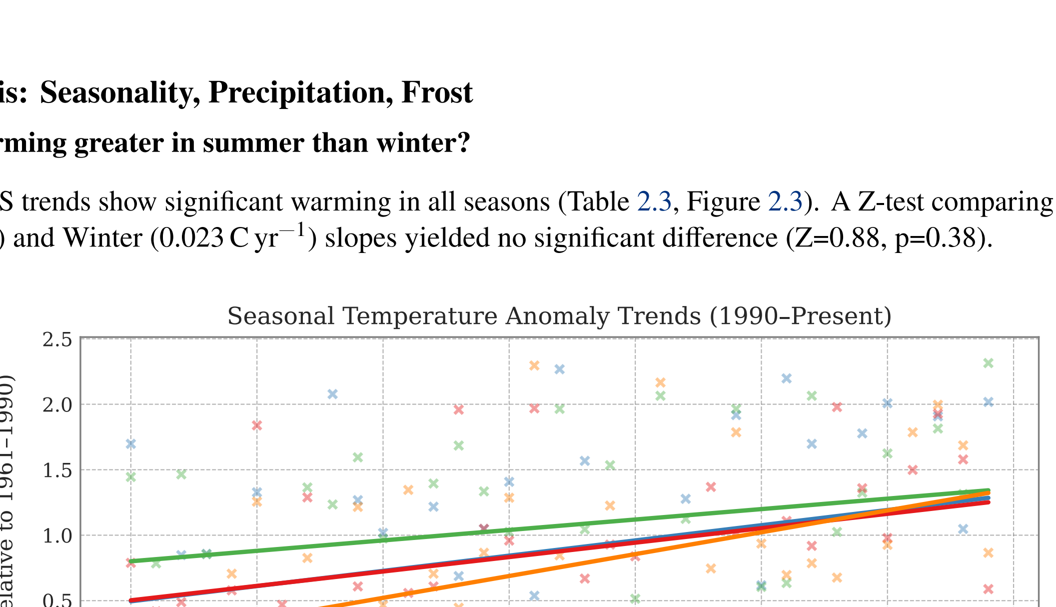

Figure 2.3: Seasonal UK mean temp anomalies (1990–24) rel. to 1961–90 baseline, with OLS trends.

2.4.2 Are summers drier/winters wetter? Are rainy days changing?

Annual total precipitation shows no significant long-term trend (p=0.74, Figure 2.4c), but annual precipitation days (>1mm) significantly increased since 1891 (0.06 days/yr, p<0.001, Fig 2.4b). Seasonally, Winter precipitation totals significantly increased since 1836 (0.27 mm/yr, p=0.02), while Summer totals showed no significant trend (Table 2.4). This supports "wetter winters".

Table 2.4: OLS Trend Analysis for Precipitation Metrics.

Metric	Period	Slope ± SE	p-value	R^2	DW
A_Tot	1836–24	0.194 ± 0.582	0.74	0.001	1.63
A_Days	1891–24	**0.063 ± 0.016**	**<0.001**	0.084	1.51
W_Tot	1836–24	**0.269 ± 0.118**	**0.02**	0.023	1.86
S_Tot	1836–24	−0.121 ± 0.098	0.22	0.006	1.88

(slope unit: mm/yr, days/yr) Abbreviations: A: Annual; _Tot: Total Precipitation (mm); _Days: days of precipitation > 1mm; W: Winter; S: Summer

2.4.3 Frost Days and Correlation with Temperature

Annual air frost days significantly decreased since 1960 ((−0.60 ± 0.08) days/yr, p<0.001). Mean temperature correlates strongly negatively with frost days (Spearman $\rho = -0.88$, p<0.001, Figure 2.4a). The ρ value close to -1 indicates a strong tendency for warmer years to have fewer frost days.

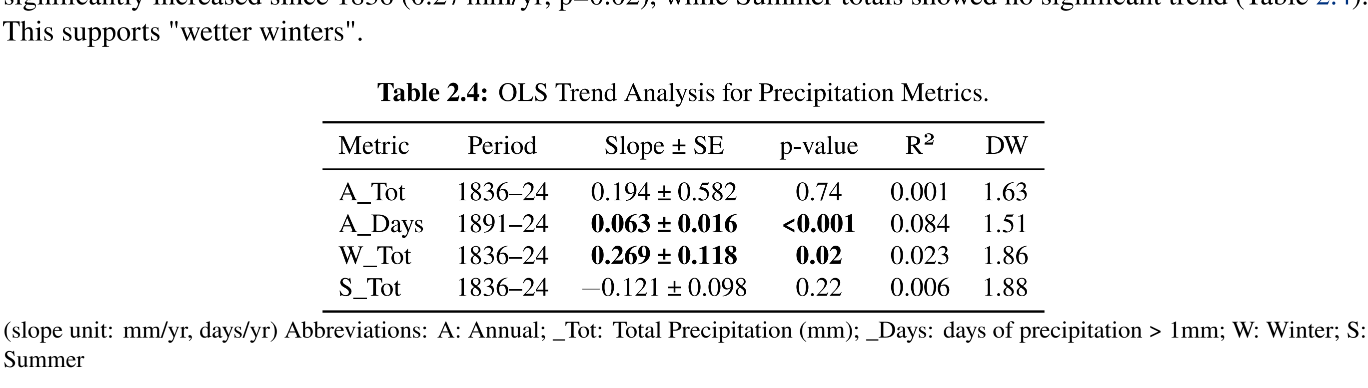

Figure 2.4: (a) Correlation: Mean Temp vs. Air Frost Days (1960-24). (b) Trend: Ann. Precip Days (>1mm) since 1891. (c) Trend: Ann. Total Precip since 1836.

3. Discussion

The analysis reveals compelling evidence of UK climate change, highlighted by accelerated warming and distributional shifts. The post-1990 warming rate (0.026 C yr^{-1}) significantly exceeds earlier trends (Table 2.1), aligning with global patterns and national projections indicating continued future warming across the UK [1]. This recent trend, explaining 67% of the anomaly variance (R^2=0.67), projects a concerning trajectory towards crossing the 2.0 C anomaly threshold around 2046. While OLS autocorrelation (DW<1.5) warrants caution regarding precise confidence intervals, the trend's magnitude and visual evidence (Figure 2.1b) are unambiguous.

Beyond the rising average, the climate's statistical character is changing. The significant non-normality found for mean and maximum temperatures (Section 2.2) suggests a departure from stable historical patterns. This is further clarified by the significant asymmetry in anomaly magnitudes (KS D=0.46, p<0.001, Section 2.2). As visually demonstrated by the diverging CDFs in Figure 2.2b, warm deviations from the baseline tend to be substantially larger in magnitude than cold deviations. This indicates that the warming climate is skewed towards more pronounced high-temperature events, rather than just a simple shift of the entire distribution.

3.1 Are extreme temperatures more frequent?

The evidence strongly indicates yes. The concentration of record high mean, maximum, and minimum temperatures within the last few years (2022 and 2023, Table 2.2) is a key indicator. The associated Z-scores (>2.4) confirm these events were highly unusual relative to the full 1884-2024 record's variability. Furthermore, the clear rightward shift in the maximum temperature distribution post-1990 (Figure 2.2c) visually corroborates the increased prevalence of conditions favouring high temperatures. When combined with the accelerated warming trend shown via OLS (Figure 2.1b), this constitutes strong evidence supporting the assertion that extreme warm temperatures have become more frequent or intense in the recent era compared to the pre-1990 baseline period, aligning with UKCP18 projections ([1] Section 3.1.3, 3.1.6)

3.2 Is warming greater in summer than winter?

By comparing seasonal warming trends post-1990 (Figure 2.3, Table 2.3), all four seasons exhibit statistically significant warming (except Winter, p=0.06), the estimated rates for Spring (0.029 C yr^{-1}) and Summer (0.028 C yr^{-1}) are only marginally higher than for Winter (0.023 C yr^{-1}). A formal statistical comparison (Z-test) between the summer and winter slopes showed no significant difference (p=0.38). Therefore, this UK-wide analysis does not provide strong statistical support for the claim that warming is significantly greater in summer than in winter, although the possibility cannot be entirely ruled out and regional variations might exist.

3.3 Are summers drier/winters wetter? Are rainy days changing?

These questions involve precipitation analysis (Table 2.4, Figure 2.4). The long-term trend in annual total precipitation is not statistically significant (p=0.74). However, the character of precipitation is changing. There is a statistically significant increase in the annual number of precipitation days (>1mm) since 1891 (0.06 days/yr, p<0.001). This observed increase in frequency relates to the broader UKCP18 projections which, while complex, suggest future increases in the intensity of heavy rainfall events, particularly in certain regions or seasons (e.g., Section 3.2.4, 3.2.6) . Seasonally, our analysis strongly supports "wetter winters", showing a statistically significant increase in winter precipitation totals (0.27 mm/yr, p=0.02). Our analysis did not find a significant trend in summer totals (p=0.22).

3.4 Frost Decline and Broader Context

The significant decrease in air frost days since 1960 (−0.60 days/yr, p<0.001) is a direct and expected consequence of the overall warming, further confirmed by the strong negative correlation between annual mean temperature and frost days (ρ=–0.88, Figure 2.4a). Taken together, the accelerated warming, shifted temperature distributions, increased warm extremes, increased rainfall frequency, wetter winters, and reduced frost provide a coherent, multi-faceted picture of a changing UK climate. These findings derived from the historical observational data are broadly consistent with the trends and patterns highlighted in the UKCP18 climate projections. Limitations include potential OLS uncertainty underestimation and the use of national averages.

4. Conclusion

This analysis of the comprehensive, merged Met Office UK Climate Series provides strong quantitative evidence of significant climate change impacts. The UK has experienced statistically significant and accelerating warming, especially post-1990 (0.026 C yr^{-1}), projecting a 2.0 C anomaly relative to the 1961-1990 baseline around 2046. Temperature distributions have shifted, becoming non-normal and asymmetric, favouring larger warm anomalies and resulting in a recent clustering of record high temperatures significantly exceeding historical norms. Significant warming is observed across all seasons post-1990. Concurrently, annual air frost days have significantly decreased since 1960 (−0.60 days/yr). The annual frequency of precipitation days (>1mm) has significantly increased since 1891 (0.06 days/yr), and total winter precipitation has significantly increased since 1836 (0.27 mm/yr). These multi-faceted changes provide compelling evidence of ongoing climate change within the UK. These observed changes align with key aspects of national climate projections [1] and provide compelling evidence of ongoing climate change within the UK, carrying consequent implications for socio-economic sectors sensitive to climate variability, such as agriculture, infrastructure, and risk management.

References

[1] Met Office (2024). UK and regional climate series, and July 2021 Headline Climate Findings

[2] Parker, D.E., Legg, T.P. and Folland, C.K. (1992). A new daily Central England Temperature Series, 1772-1991. *International Journal of Climatology*, 12(4), 317–342.

[3] WMO (2017). *WMO Guidelines on the Calculation of Climate Normals*. (WMO-No. 1203). World Meteorological Organization.