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Investigating the Link Between Human Activities and the Climate System: Long-Term Climate Trends in the United Kingdom

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Abstract. Climate change has emerged as one of the most pressing global challenges, with regional impacts showing significant variability. The United Kingdom, located in a temperate oceanic climate zone, has experienced notable shifts in temperature and precipitation over recent decades. This study investigates long-term climate trends in the UK, focusing on temperature changes and precipitation extremes. Using secondary data from NOAA reanalysis products (NCEP/NCAR) and observational datasets covering 1948–2023, the research applies quantitative statistical methods and spatiotemporal comparison to examine variability, long-term trends, and extreme events. Data processing included area-weighted aggregation, time-series analysis, and extreme value extraction. The results indicate a clear warming trend, with reduced extreme cold events and more frequent summer heat extremes. Precipitation shows strong variability, with a marked increase in extreme rainfall since the 1980s. The findings highlight the combined influence of anthropogenic drivers and natural variability, emphasizing that while long-term linear changes are modest, hydrological extremes have intensified. These results provide valuable scientific evidence for policy-making in climate adaptation and mitigation.

Keywords: Climate change, United Kingdom, Precipitation variability

1. Introduction

Since the beginning of the 21st century, climate research has increasingly focused on global climate change and its environmental and socio-economic impacts. The IPCC Sixth Assessment Report (AR6) indicates that the climate system is undergoing unprecedented millennial-scale changes, with human activities—particularly greenhouse gas emissions—being the primary driver [1]. However, significant uncertainties remain at regional scales, especially regarding extreme precipitation events and socio-economic vulnerability. Existing studies mostly focus on global or continental trends, often overlooking local topography and land-use effects.

In this context, this study addresses the following research questions: How have climate patterns in the United Kingdom evolved over the past seventy years? What is the relationship between human activities and local climate? Under future climate scenarios, what adaptation policies should the UK government implement? To answer these questions, this research employs secondary data

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analysis using long-term observational and reanalysis datasets from NOAA, including CDRs, Climate Data Online, and NCEP/NCAR Reanalysis products [2]. Quantitative statistical analysis and spatiotemporal comparisons are conducted to examine trends in precipitation, temperature, and extreme events, as well as their driving factors. This study aims to fill gaps in regional climate research for the UK and provide scientific insights to improve regional climate projections, mitigate human impacts, and inform government decision-making.

2. Climate system and human impacts

The climate system is composed of five interacting components: the atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere. The atmosphere regulates key elements such as temperature, precipitation, and wind. The hydrosphere includes oceans, lakes, rivers, and groundwater, with the oceans playing a critical role in heat storage and transport (e.g., ocean currents) [3]. The cryosphere —glaciers, ice sheets, sea ice, snow, and permafrost—strongly influences Earth's albedo and the energy balance. The lithosphere, including landforms and soils, affects circulation and is altered by land use and cover changes such as deforestation and urbanization. The biosphere comprises organisms and ecosystems that contribute to feedbacks through processes such as photosynthesis and the carbon cycle. Together, these five subsystems shape global and regional climate variability.

Human activities are the dominant drivers of modern climate change. Greenhouse gas emissions from fossil fuel use, agriculture, and waste management strengthen the greenhouse effect, while aerosols contribute both cooling through solar reflection and complex cloud impacts. Land-use changes, such as deforestation and urbanization, reduce carbon sink capacity and intensify the urban heat island effect. Human-driven change also triggers feedbacks: positive mechanisms like the ice–albedo effect, water vapor retention, and carbon cycle interactions amplify warming, while negative ones, including longwave radiation and vegetation uptake, provide only partial offset [4]. According to the IPCC AR6 report, human activities are unequivocally the main cause of current warming trends, and the imbalance between positive and negative feedbacks ensures continued global warming [2].

3. Data and methods

3.1. Data sources and processing

The datasets used in this study were obtained from the NOAA Physical Sciences Laboratory (PSL) Climate Data Portal. The spatial domain was restricted to the United Kingdom (49°–60°N, 8°W–2°E), with a temporal coverage from 1948 to 2025. Two variables were selected: precipitation rate (mm) and near-surface air temperature (°C).

Both datasets were downloaded as annual mean time series aggregated from monthly records, each containing 78 annual values to ensure comparability. The values represent area-weighted means across the UK domain, thereby minimizing grid-size bias at higher latitudes. Precipitation and near-surface air temperature were both treated as monolevel variables. To preserve seasonal variability, data were aggregated by month, yielding twelve mean values per year and enabling refined analysis of intra-annual patterns alongside long-term climatic trends. Area weight grids = Yes was selected to correct for biases arising from smaller high-latitude grid cells [5].

The output format was set to raw data values, providing complete time series for trend testing, extreme climate index calculation, and spatiotemporal comparative analysis. These processed datasets form a robust foundation for investigating regional climate variability and change.

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3.2. Analytical methods and uncertainty assessment

This study applies quantitative statistical analysis and spatio-temporal comparative methods to identify long-term trends, periodicity, and extreme events in the United Kingdom. Time series analysis is used to detect linear or nonlinear trends, with further assessment of oscillation patterns. Extreme indices are derived by extracting maximum monthly precipitation, annual extreme high-temperature months and extreme low-temperature months, which are then visualized through line plots. Causality and correlation analysis are conducted by integrating human activity indicators to distinguish the anthropogenic from natural drivers.

The identified trends and spatial contrasts are interpreted by linking anthropogenic drivers (e.g., greenhouse gas emissions, land-use change) with natural climate factors (e.g., North Atlantic Oscillation). This integrated attribution approach provides insight into the mechanisms shaping observed regional climate changes.

Uncertainties are acknowledged at several levels. NOAA reanalysis and observational datasets may contain measurement errors, limited resolution, and gaps in early records. Methodological choices, including statistical techniques and threshold definitions for extremes, involve some subjectivity. Internal variability (e.g., ENSO, NAO) can obscure or amplify signals, while the trajectory of anthropogenic forcing remains scenario-dependent [6]. Furthermore, the UK's complex topography may lead to heterogeneous local responses. Despite these limitations, the results provide essential evidence for understanding regional climate variability and provide a valuable reference for adaptation and mitigation policy.

4. UK long-term climate trends

4.1. Overview of the climate characteristics in the United Kingdom

The United Kingdom lies within the temperate oceanic climate zone, strongly influenced by the Atlantic Ocean and prevailing westerlies. The climate is generally mild but variable, with precipitation distributed relatively evenly throughout the year yet showing clear regional contrasts. Due to the North Atlantic Current, winters are milder than those at similar latitudes, while summers are relatively cool [7]. Precipitation exhibits a west–east gradient due to topography, and strong winds and high humidity occur year-round. Interannual and decadal variability is further modulated by the North Atlantic Oscillation (NAO) [8].

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4.2. Features of temperature and precipitation variability

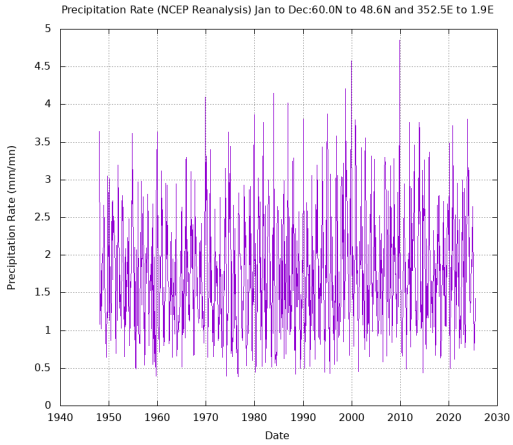

Figure 1. Monthly precipitation rate over the United Kingdom (1948-2023)

Figure 1 presents the monthly precipitation rate (mm/month) in the United Kingdom from 1948 to 2023. The time series exhibit strong fluctuations characteristic of maritime climates, with no clear linear trend but marked nonlinear variability. Two phases can be distinguished: relatively moderate variability during 1948-1980, followed by intensified fluctuations and more frequent extremes after 1980. Several months in the 1990s and 2000s exceeded 4.0 mm/mn, suggesting an increase in extreme precipitation events in recent decades. Seasonal and interannual variability is also evident, with substantial differences in magnitude between years. Extreme value analysis further reveals that while the long-term signal shows only a slight upward tendency, high interannual variability obscures any significant trend.

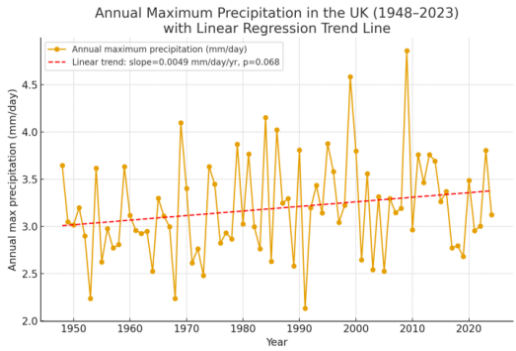

Figure 2. Annual maximum precipitation rate (mm/day) in the UK (1948–2023) with linear trend

Strong interannual variability is observed, with some years exceeding 5.0 mm/day. A slight upward trend (+0.0049 mm/day per year) is detected, but it is not statistically significant ($p = 0.068$).

Figure 2 presents the annual maximum precipitation rate (mm/day) from 1948 to 2023. Interannual variability is pronounced, with several years exceeding 4.5 mm/day. The long regression shows a weak upward trend (+0.0049 mm/day per year), which is not statistically significant ($p = 0.068$). Similarly, the Mann-Kendall test reveals only a weak positive tendency. Despite the absence of a robust linear trend, the frequency of extreme high-precipitation years has increased since the 1990s, suggesting intensifying hydrological extremes likely linked to both NAO variability and anthropogenic forcing.

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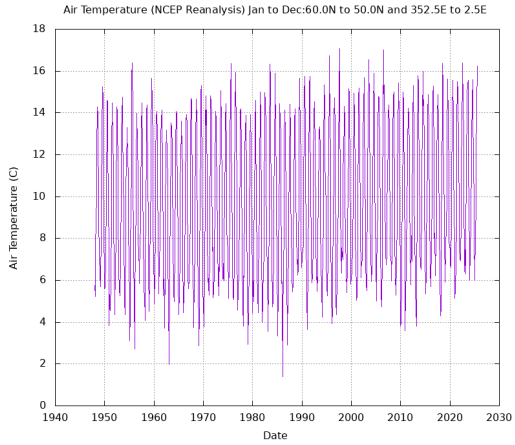

Figure 3. Monthly air temperature (°C) in the UK, 1948–2023

Figure 3 presents the monthly near-surface air temperature (°C) for 1948-2023. The series shows pronounced seasonal variability, with annual amplitudes of about 10°C between winter minima and summer maxima. Since the 1980s, a long-term warming trend has emerged: winter minimum values have gradually increased, indicating a reduction in the frequency of extremely cold years, while summer peaks have intensified, with several exceeding 16°C. These changes suggest that extreme heat events are becoming more frequent and intense. Overall, the UK has experienced significant warming in recent decades, consistent with global climate change and modulated by regional climate drivers such as the NAO.

5. Linkages between human activities and climate change in the UK

The results of this study indicate pronounced climatic changes in the United Kingdom over the past seven decades. A significant warming trend is evident: extreme cold events in winter have declined, while extreme heat events in summer have become increasingly frequent. The frequency of extreme precipitation events has also risen markedly since the 1980s. These changes cannot be fully attributed to natural variability, such as the NAO, but instead point to the cumulative effects of anthropogenic drivers, particularly greenhouse gas (GHG) emissions and land-use changes.

5.1. Industrialization, energy use, and GHG emissions

Industrialization and energy consumption are the primary forces behind contemporary climate change. Since the Industrial Revolution, coal, oil, and natural gas have replaced biomass energy, leading to massive GHG emissions that are enhanced the atmospheric greenhouse effect. According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), fossil fuel combustion and industrial processes account for the largest share of global GHG emissions since 1850, driving persistent warming and intensifying extremes.

The UK, as one of the earliest industrialized nations, exemplifies this trajectory: heavy coal use historically contributed to marked regional warming and increasing extreme precipitation [9]. While recent years have seen a shift toward renewables and low-carbon energy, the cumulative impact of past emissions continues to exert influence on the climate system. Therefore, future climate strategies must prioritize restructuring the energy system and expanding the role of clean energy, which remain essential tasks in mitigating climate change and enhancing resilience [10].

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5.2. Urbanization, land-use change, and regional climate effects

Urbanization and land-use change significantly alter local climates in the UK. Expanding cities and impermeable surfaces have intensified the urban heat island (UHI) effect, consistent with the observed decline in extreme cold events and rise in summer heat extremes [11]. Moreover, urbanization amplifies energy consumption and waste heat emissions, reinforcing warming through a "climate–energy" feedback loop.

Land-use change, including agricultural intensification and suburban expansion, has reduced forest and grassland cover, weakening evapotranspiration and carbon sequestration [11]. These shifts have modified regional hydrology and contributed to the recent increase in extreme precipitation events. Such evidence underscores how human-induced land transformations interact with broader climate drivers to amplify climate risks.

6. Conclusion

This study analyzed long-term climate changes in the United Kingdom from 1948 to 2023 using NOAA reanalysis datasets and observational records. The findings reveal clear signals of regional climate change: a general warming trend marked by fewer extreme cold events, more frequent and intense extreme heat events, and an increase in the frequency of extreme precipitation since the 1980s. Several years in the 1990s and 2000s recorded annual maximum rainfall rates exceeding 5.0 mm/day. These results suggest that the UK climate has shifted from a traditionally "mild and wet" pattern toward one characterized by warming and greater hydrological extremes. Such changes reflect the combined effects of natural climate variability, such as the AO, and anthropogenic drivers, including industrialization, energy use, urbanization, and land-use change.

Policy responses must therefore be multi-faceted. Accelerating the transition from fossil fuels to renewables such as wind and solar energy remains essential for reducing GHGs at the source. At the same time, urban planning and land-use policies should incorporate climate adaptation measures. Increasing green infrastructure, restoring wetlands, and expanding forest cover can mitigate urban heat island effects, enhance local water cycles, and improve carbon sequestration capacity. Strengthening monitoring and early warning systems for floods, heatwaves, and other extremes is also critical to improve infrastructure resilience and reduce risks to society and the economy.

Future research should prioritize high-resolution modeling to capture spatial and temporal patterns of climate extremes more accurately, while also fostering interdisciplinary collaboration across climate science, economics, sociology, and public health. Understanding how human activities interact with natural drivers, such as the coupled impacts of urbanization and NAO on precipitation extremes, will be vital to reducing uncertainty in projections.

In conclusion, the UK's climate trajectory highlights both its regional vulnerability and its alignment with global warming trends. Addressing these challenges will require a dual approach of scientific innovation and policy action, enabling the UK to pursue mitigation and adaptation strategies in parallel.

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