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TRACKING CLIMATE EXTREMES IN THE UNITED KINGDOM: THE UNITED KINGDOM ACTUARIAL CLIMATE INDEX

ANÁLISIS DE LOS EXTREMOS CLIMÁTICOS EN EL REINO UNIDO: EL ÍNDICE ACTUARIAL DEL CLIMA DEL REINO UNIDO

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ABSTRACT

The Actuaries Climate Index (ACI), jointly developed by a consortium of North American actuarial bodies, is a climate monitoring metric designed to track long-term changes in extreme weather and sea level conditions across the United States and Canada. Rather than focusing on average climate conditions, the ACI quantifies changes in the frequency of extreme events (including high and low temperatures, heavy precipitation, prolonged droughts, high winds, and coastal sea level changes) which are critical drivers of climate risk for society and the insurance sector.

In this paper, we construct the ACI for the United Kingdom, analyse its trends, identify the weather-related variables that contribute most to the index, and compare our results with the Australian Actuaries Climate Index (AACI). Our findings highlight the sensitivity of climate risk assessments to the selection of underlying variables, suggesting that the design and interpretation of composite climate indices should be carefully tailored to their intended application and regional context.

Keywords: extreme weather events; climate risk; climate indices; United Kingdom.

RESUMEN

El Índice Climático Actuarial (*Actuaries Climate Index*, ACI), desarrollado conjuntamente por un consorcio de organizaciones actuariales norteamericanas, es un indicador diseñado para analizar los cambios a largo plazo en los fenómenos meteorológicos extremos y en el nivel del mar en Estados Unidos y Canadá. En lugar de centrarse en las condiciones climáticas medias, el ACI cuantifica los cambios en la frecuencia de los eventos extremos, incluidas las temperaturas máximas y mínimas extremas, las precipitaciones intensas, las sequías prolongadas, los vientos fuertes y las variaciones del nivel del mar en las zonas costeras, que constituyen factores determinantes del riesgo climático para la sociedad y el sector asegurador.

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En este artículo, construimos el ACI para el Reino Unido, analizamos su evolución, identificamos las variables meteorológicas que más contribuyen al índice y comparamos nuestros resultados con los del Índice Climático Actuarial de Australia (*Australian Actuaries Climate Index*, AACI). Nuestros resultados muestran que el ACI puede variar considerablemente en función de las variables seleccionadas para su construcción, lo que pone de manifiesto la importancia de tener en cuenta las características climáticas de cada región a la hora de elaborar estos índices.

Palabras clave: eventos meteorológicos extremos; riesgo climático; índices climáticos; Reino Unido.

1. INTRODUCTION

Climate change is increasing the frequency and severity of many climate-related hazards worldwide. The IPCC Sixth Assessment Report (AR6) reports that global surface temperature in 2011–2020 was 1.09°C higher than in 1850–1900, and that this warming has already led to more frequent and intense hot extremes and heatwaves, along with fewer cold extremes. AR6 also reports that heavy precipitation has intensified in many regions, while drought, flooding, tropical cyclones, and compound events such as heat-drought combinations and coastal flooding are becoming more important climate risks (IPCC, 2021). As these hazards continue to evolve, there is a growing need for indicators that can consistently track climate extremes and support climate risk assessment over time.

The Actuaries Climate Index (ACI; American Academy of Actuaries et al., 2018), launched in November 2016, is a climate monitoring metric designed to track long term changes in extreme weather and sea level conditions across Canada and the continental United States. It was jointly developed by a consortium of North American actuarial bodies: the Society of Actuaries (SOA), the Canadian Institute of Actuaries (CIA), the Casualty Actuarial Society (CAS), and the American Academy of Actuaries (AAA). The collaboration was coordinated through a dedicated Climate Change Committee, with support from climate science partners who provided data and helped develop the methodology. Rather than focusing on mean climate conditions, the ACI specifically quantifies changes in the frequency of extreme events, such as unusually high or low temperatures, heavy precipitation, prolonged drought, high winds, and changes in coastal sea level.

The index serves as an objective, transparent, and educational tool, informing actuaries, policymakers, researchers, and the public about changes in the prevalence of extreme climate events. These changes are increasingly relevant for risk assessment, financial modelling, and adaptation planning. By summarising multiple climate extremes into a single consistent metric, the ACI provides a framework for comparing climate risk across regions.

Several studies have explored the applicability of the ACI methodology in Europe. For example, Zhou et al. (2023) developed an actuarial climate index for the Iberian Peninsula based on the North American ACI framework, Garrido et al. (2026) for France, and Rogo et al. (2025) for Italy. These developments highlight the adaptability of the ACI methodology and provide a basis for constructing a comparable index for the UK.

A related measure, the Actuaries Climate Risk Index (ACRI; American Academy of Actuaries, 2020), was later introduced to assess the economic risks associated with climate-related hazards by linking climate indicators with financial loss data.

Following the development of the ACI, the Australian Actuaries Climate Index (AACI; Actuaries Institute, 2025) was first launched in 2018 to monitor changes in the frequency of extreme weather conditions and sea levels in Australia. Although the AACI was inspired by the ACI, its methodology differs due to the use of different climate variables, thresholds, and reference periods reflecting regional climate characteristics; these differences are discussed in Section 6.

The aim of this paper is to construct the ACI for the UK (UKACI) and explore historical trends

in extreme weather-related events. The remainder of the paper is structured as follows. Section 2 describes changes in the UK climate. The ACI framework and the data used in this study are outlined in Sections 3 and 4, respectively. Section 5 analyses the weather-related variables included in the ACI and presents the calculation of the index for the UK. In Section 6, we present a sensitivity analysis of the UKACI and compare it with the methodology of the AACI. Finally, Section 7 concludes with a discussion and final remarks.

2. CHANGES IN THE UK CLIMATE

The United Kingdom has a mild climate, largely influenced by the nearby Atlantic Ocean and prevailing westerly winds. As a result, temperatures are generally moderate compared with other regions at similar latitudes. The long-term average annual temperature for the UK is approximately 9–10°C, although this varies across regions due to latitude, elevation, and proximity to the coast (Kendon et al., 2025).

The United Kingdom has experienced significant climatic changes over recent decades. Observational records indicate that the UK climate has become warmer and wetter compared with much of the twentieth century (Kendon et al., 2025). Notably, the ten warmest years on record in the UK have all occurred since 2002 (Fung & Lowe, 2023; Kendon et al., 2025), highlighting the strong warming trend observed in recent decades. According to the Met Office, the UK's average temperature has increased by approximately 0.9°C since the period 1961–1990, with the most rapid warming observed since the 1990s. This warming has contributed to an increased frequency of extreme high temperature events and heatwaves, particularly in southern England. Climate projections suggest that temperatures will continue to increase throughout the twenty-first century, with particularly pronounced warming during summer months (Met Office, 2022).

Changes in precipitation patterns have also been documented. Historical records indicate that five of the ten wettest years in the UK since 1836 have occurred since 1998, suggesting an increase in wet extremes in recent decades (Kendon et al., 2025). More recently, during the period 2010–2019, UK summers mean annual precipitation has increased by approximately 11%, while mean winter precipitation has increased by around 4% in terms of total rainfall amount (millimetres) compared with the 1981–2010 baseline (Kendon et al., 2022). These changes are broadly consistent with climate projections that anticipate wetter winters and an increased frequency of heavy rainfall events.

Rainfall patterns across the UK exhibit substantial spatial variability. Although climate change affects the entire country, the distribution of precipitation is highly heterogeneous, reflecting the influence of atmospheric circulation patterns and topographical features. In particular, rainfall amounts tend to be higher along the western coasts, with especially high levels observed in western Scotland, while eastern regions are generally drier.

Overall, the available evidence indicates that extreme weather events, including heavy rainfall and heatwaves, are becoming more frequent or more intense in the UK. These developments highlight the need for robust indicators capable of systematically monitoring changes in climate-related extremes and their potential implications for economic and financial risk.

These climatic changes increase the severity of climate-related physical risks affecting the UK. Perils such as flooding, storms, heatwaves, and droughts are becoming more damaging under changing climatic conditions. These perils can damage buildings and transport networks, disrupt business activity, threaten food security, and increase pressure on public health systems (Kendon et al., 2025; Met Office, 2026). In other words, climate change is not only changing the climate baseline but also worsening the very events that drive physical losses.

3. ACTUARIES CLIMATE INDEX (ACI) FRAMEWORK

The Actuaries Climate Index (ACI) consists of six components, see Table 1, designed to capture changes in different types of climate extremes, including temperature, precipitation,

wind, drought, and sea level. Each component is presented as a monthly time series beginning in 1961 and is derived from data collected from a large network of meteorological and coastal tide stations across the United States and Canada (American Academy of Actuaries et al., 2018).

All measurements are evaluated relative to a 30-year reference period from 1961 to 1990, and the ACI is expressed in terms of anomalies from this baseline.

Component	Description
Warm temperature	Frequency of daily maximum and minimum temperatures above the 90th percentile.
Cool temperature	Frequency of daily maximum and minimum temperatures below the 10th percentile.
Precipitation	Maximum five-day precipitation in month.
Drought	Maximum consecutive dry days in year.
Wind Speed	Frequency of daily wind speed above the 90th percentile.
Sea Level	Change in sea level.

Table 1. Components of the Actuaries Climate Index

Warm temperature (T90)
This component represents unusually warm temperature events. An increase in the frequency of very warm days is a key indicator of climate warming and reflects a shift in the upper tail of the temperature distribution. It is calculated using both daily maximum temperature (TX) and daily minimum temperature (TN). Since the daily maximum typically occurs during the afternoon and the daily minimum around dawn, TX and TN are commonly interpreted as proxies for daytime and nighttime conditions, respectively.

Warm temperature events are defined as temperatures exceeding the 90th percentile threshold for each calendar day, estimated from a 30-year reference period. The percentile calculation is smoothed using a five-day moving window centred on each calendar day.

For daytime and nighttime temperatures separately, the number of values above the threshold is counted and converted into the percentage of warm days (TX90p) and warm nights (TN90p) for each month.

From the reference period, 12 monthly reference means, $\mu_{ref}(j)$, and 12 standard deviations, $\sigma_{ref}(j)$, are calculated, where j represents the calendar month (j= January, February, ..., December).

Standardised anomalies are then computed as

$$TX90p_{std}(j,k) = \frac{TX90p(j,k) - \mu_{ref}TX90p(j)}{\sigma_{ref}TX90p(j)}$$

and

$$TN90p_{std}(j,k) = \frac{TN90p(j,k) - \mu_{ref}TN90p(j)}{\sigma_{ref}TN90p(j)}$$

where j denotes the calendar month and k denotes the year (k= 1961, 1962, ..., 2024).

Because warm days and warm nights tend to occur simultaneously, the final warm temperature anomaly (T90) is defined as the average of the two standardised indices:

$$T90_{std}(j,k) = \frac{1}{2}(TX90p_{std}(j,k) + TN90p_{std}(j,k)).$$

Cool temperature (T10)

In contrast to warm temperature events, the cool temperature component represents unusually cold temperature conditions. A decreasing frequency of very cold days indicates a shift in the lower tail of the temperature distribution.

Cool temperature events are defined as temperatures falling below the 10th percentile threshold for each calendar day. The percentile calculation is smoothed using a five-day moving window centred on each calendar day and estimated from a 30-year reference.

The methodology is similar to the warm temperatures calculation, except that the cool temperature threshold is defined using the 10th percentile. Thus, the cool days (TX10p) and cool nights (TN10p) standardised anomalies are calculated as

$$TX10p_{std}(j,k) = \frac{TX10p(j,k) - \mu_{ref}TX10p(j)}{\sigma_{ref}TX10p(j)}$$

and

$$TN10p_{std}(j,k) = \frac{TN10p(j,k) - \mu_{ref}TN10p(j)}{\sigma_{ref}TN10p(j)}$$

where *j* denotes the calendar month and *k* denotes the year (*k*= 1961, 1962, ..., 2024).

The final cool temperature anomaly (T10) is defined as

$$T10_{std}(j,k) = \frac{1}{2}(TX10p_{std}(j,k) + TN10p_{std}(j,k)).$$

Precipitation (P)
The precipitation component represents the extreme rainfall and is based on the maximum five-day precipitation (Rx5day) index. The Rx5day is defined as the highest accumulated precipitation over any consecutive five-day period within a given month.

Monthly Rx5day anomalies are standardised relative to the reference period using the corresponding monthly mean, $\mu_{ref}(j)$, and standard deviation, $\sigma_{ref}(j)$:

$$Rx5day_{std}(j,k) = \frac{Rx5day(j,k) - \mu_{ref}Rx5day(j)}{\sigma_{ref}Rx5day(j)}$$

where *j* denotes the calendar month (*j*= January, February, ..., December) and *k* denotes the year (*k*= 1961, 1962, ..., 2024).

Drought (D)
The drought component represents dry conditions and is quantified using the Consecutive Dry Days (CDD) index. A dry day is defined as a day with daily precipitation less than 1 mm. For each year, the longest dry spell is identified as the annual Maximum Consecutive Dry Days (MaxCDD).

The annual MaxCDD mean, μ_{ref}, and standard deviation, σ_{ref}, are calculated from the reference period and used as baseline statistics.

Monthly MaxCDD are obtained by linear interpolation

$$MaxCDD(12,k) = MaxCDD(k)$$

and

$$MaxCDD(j,k) = \frac{12-j}{12}(MaxCDD(12,k-1)) + \frac{j}{12}(MaxCDD(12,k))$$

where *j* denotes the calendar month (*j*= January, February, ..., December) and *k* denotes the year (*k*= 1961, 1962, ..., 2024).

Standardised drought anomalies are then calculated as

$$MaxCDD_{std}(j,k) = \frac{MaxCDD(j,k) - \mu_{ref}MaxCDD}{\sigma_{ref}MaxCDD}.$$

Wind speed (W)
Extreme wind conditions are represented using wind power (WP), calculated from daily mean wind speed as

$$WP = \frac{1}{2}\rho w^3$$

where w is the daily mean wind speed and ρ is the air density (1.23 kg/m^3).

Extreme wind events are defined as wind power values exceeding the 90th percentile threshold. The threshold is estimated for each calendar day using a 30-year reference period as

$$WP_{ref}(i,j) = \mu_{WP}(i,j,k) + 1.28\sigma_{WP}(i,j,k)$$

where i denotes the calendar day (i= 1, 2,..., 30, 31), j denotes the calendar month (j= January, February, ..., December), and k denotes the year within the reference period.

For each month, the number of days with wind power exceeding the threshold is counted and converted into the percentage of extreme wind (WP90).

Monthly WP90 anomalies are standardised relative to the reference period using the corresponding monthly mean, $\mu_{ref}(j)$, and standard deviation, $\sigma_{ref}(j)$:

$$WP90_{std}(j,k) = \frac{WP90(j,k) - \mu_{ref}WP90(j)}{\sigma_{ref}WP90(j)}$$

where j denotes the calendar month (j= January, February, ..., December) and k denotes the year (k= 1961, 1962, ..., 2024).

Sea level (S)
The sea level component represents changes in sea level derived from hourly tide-gauge observations at coastal stations. Monthly mean sea level (S) values are calculated from the hourly records.

Monthly sea level anomalies are then standardised relative to the reference period using the corresponding monthly mean, $\mu_{ref}(j)$, and standard deviation, $\sigma_{ref}(j)$:

$$S_{std}(j,k) = \frac{S(j,k) - \mu_{ref}S(j)}{\sigma_{ref}S(j)}$$

where j denotes the calendar month (j= January, February, ..., December) and k denotes the year (k= 1961, 1962, ..., 2024).

4. DATA AND IMPLEMENTATION

This paper is based on station-based observational data spanning 1961–2024 and represents six climate components of the ACI.

Temperature and precipitation data are obtained from the Global Historical Climatology Network Daily (GHCNd; NOAA National Centers for Environmental Information, 2025), providing daily observations from land-based stations. Wind speed data are sourced from the

Met Office Integrated Data Archive (Met Office, 2012), where hourly observations are aggregated to daily means and used to calculate wind power. Lastly, the sea level data are obtained from the Permanent Service for Mean Sea Level (PSMSL, 2026; Holgate et al., 2013), providing monthly mean values from coastal tide-gauge stations.

To ensure data quality, only stations with less than 50% missing observations over the study period are retained. Remaining missing values are not infilled and are excluded from calculations. Monthly averages are computed using available stations only; consequently, the number of contributing stations varies over time.

After applying these criteria, the final dataset consists of 98 temperature stations, 106 precipitation stations, 125 wind stations, and 20 tide-gauge stations distributed across the United Kingdom.

The UK Actuarial Climate Index (UKACI) is constructed to represent the overall state of climate extremes in the United Kingdom. Monthly observations are first aggregated across all available stations to obtain national-level time series for each climate component. The UKACI is then computed from these aggregated series as the arithmetic mean of the six components, with equal weighting, following the formulation of the North American Actuaries Climate Index (ACI)[1]. The cool temperature component (T10) enters with a negative sign to reflect its inverse relationship with warm temperature extremes.

The UKACI is defined as follows:

$$UKACI(j,k) = \frac{1}{6}(T90_{std}(j,k) - T10_{std}(j,k) + Rx5day_{std}(j,k) + MaxCDD_{std}(j,k) + WP90_{std}(j,k) + S_{std}(j,k)).$$

5. RESULTS

This section first presents the individual components of the UKACI. It then constructs the aggregated UKACI series over the study period and examines its overall evolution and main trends.

5.1. Component Indices

Figures 1–8 display standardised monthly anomalies (light blue vertical bars) together with their five-year moving average (solid black line); the dotted vertical line marks the end of the 1961–1990 reference period. The indices are reported at monthly rather than seasonal resolution, as the monthly series is the elementary unit at which the ACI is computed.

Figures 1 and 2 show the evolution of the warm temperature component (T90), together with its sub-components for warm days (TX90p; Figure 2a) and warm nights (TN90p; Figure 2b).

The warm temperature index (T90) exhibits a clear upward trend from the mid-1980s to the end of the study period, indicating an increasing frequency of extreme warm events. The rise in warm nights (TN90p) appears more pronounced than that of warm days (TX90p), with anomalies reaching maxima of 2.2 and 1.7, respectively, by the end of the study period. This suggests that nighttime temperatures are increasing faster than daytime temperatures.

[1] The North American ACI is computed at the regional level, and the sea level component is omitted in its two land-locked regions. Since the UKACI is constructed as a single national index, sea level is included in the composite for the country as a whole, in line with the Iberian and French implementations.

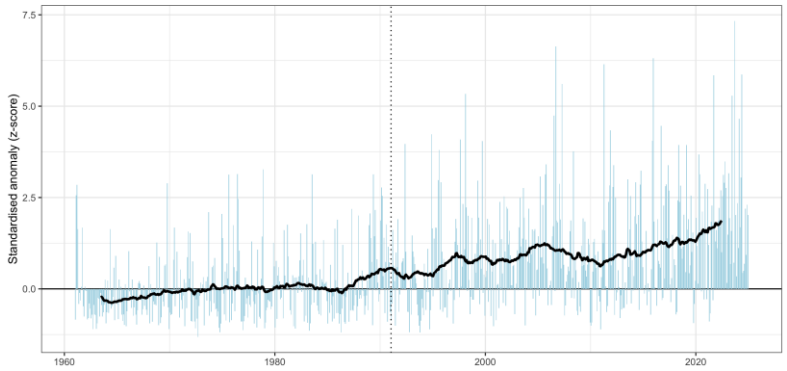
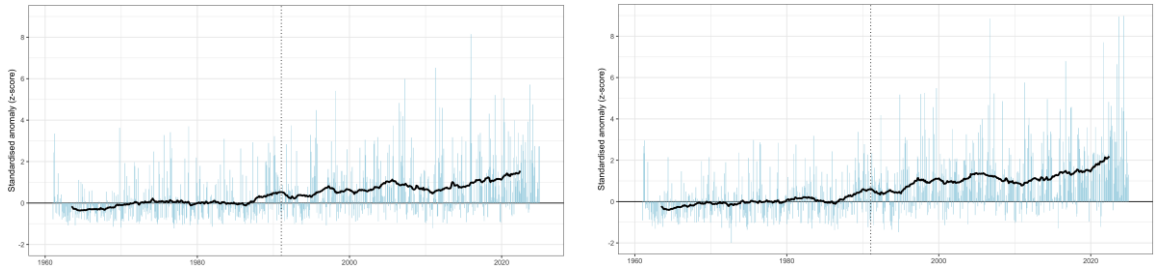


Figure 1. Standardised monthly anomalies of the T90 warm temperature index.



(a) TX90p (warm days) (b) TN90p (warm nights)

Figure 2. Standardised monthly anomalies of warm temperature indices: TX90p (warm days) and TN90p (warm nights).

In contrast, Figures 3 and 4 show that the cool temperature index (T10) displays a downward trend, consistent with a decline in cold extremes. Both cool days (TX10p) and cool nights (TN10p) decrease over time, with a slightly stronger decline in cool days (TX10p). By the end of the study period, anomalies reach approximately -1.8 for cool days and -1.7 for cool nights. This contrasts with the warm index components, where changes in nighttime temperatures are more pronounced than those in daytime temperatures.

The strong upward trend in the warm temperature index (T90), together with the decline in the cool temperature index (T10), reflects a systematic shift in the temperature distribution. This is consistent with observational evidence that climate change has increased both the frequency and intensity of temperature extremes in the UK (IPCC, 2021; Kendon et al., 2025).

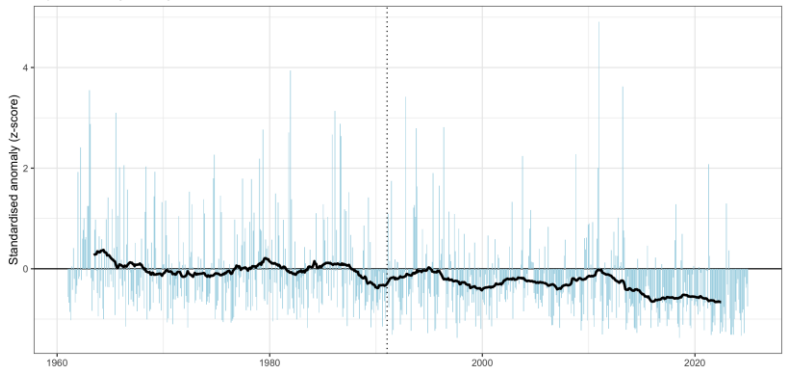
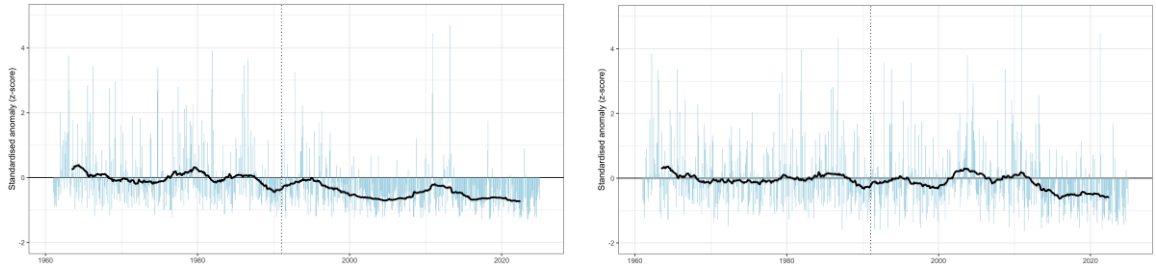


Figure 3. Standardised monthly anomalies of the T10 cool temperature index.



(a) TX10p (cool days) (b) TN10p (cool nights)

Figure 4. Standardised monthly anomalies of cool temperature indices: TX10p (cool days) and TN10p (cool nights).

Figures 5 and 6 show the precipitation (RX5day) and drought (MaxCDD) indices. Both exhibit substantial year-to-year variability, with no clear long-term trend over the study period. The precipitation index component (RX5day) fluctuates around zero, although positive anomalies appear more frequently in recent decades. In contrast, the drought index component (MaxCDD) shows more persistent negative anomalies during the late 1990s and early 2000s.

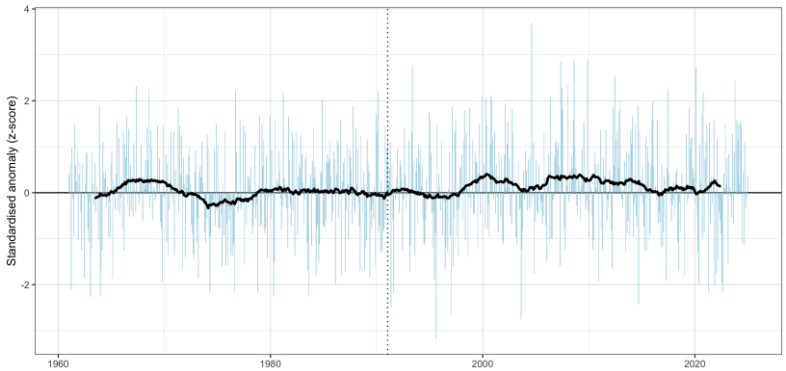


Figure 5. Standardised monthly anomalies of the RX5day index (maximum five-day precipitation).

The absence of a monotonic trend does not imply that precipitation and drought are unaffected by climate change. Rather, their responses appear more complex than those of temperature-related indices. As discussed in Section 2, recent studies suggest that climate change is increasing the intensity and frequency of heavy rainfall events in the UK, particularly during autumn and winter storms, while also increasing drought risk. This reflects a shift towards more variable and extreme hydrological conditions (IPCC, 2021; Manning et al., 2024).

This dual behaviour helps explain why neither the precipitation nor drought index exhibits a simple linear trend. Instead, the results are consistent with a climate system in which both wet and dry extremes are becoming more pronounced over time.

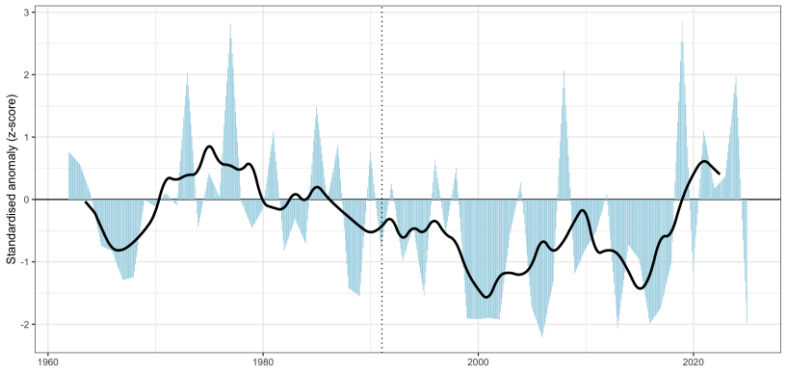


Figure 6. Standardised monthly anomalies of the MaxCDD index (consecutive dry days).

Next, Figure 7 shows wind power anomalies, which show no clear long-term trend but shift towards predominantly negative values from around the 1980s onwards. This pattern is consistent with previous studies, which generally find weaker and less robust changes in wind extremes compared to temperature and precipitation (American Academy of Actuaries et al., 2018; Zhou et al., 2023; Garrido et al., 2026).

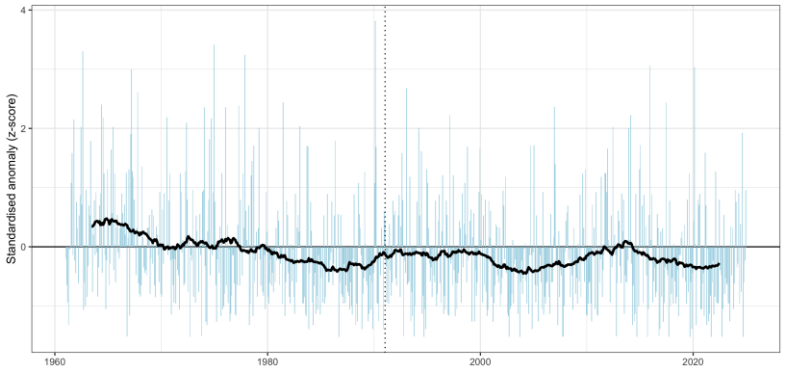


Figure 7. Standardised monthly anomalies of wind power.

Unlike temperature extremes, wind-related changes are influenced by complex atmospheric circulation patterns and tend to show greater variability over time. Previous studies in the UK have also found no compelling long-term trend in storminess (Kendon et al., 2025), while projections of future winter windstorm changes remain uncertain (Met Office, 2022).

Finally, Figure 8 depicts the sea level anomalies, which exhibit the strongest and most persistent upward trend among all components. The increase becomes more pronounced after the reference period, reaching a maximum anomaly of approximately 3.5 by the end of the study period.

Sea level rise reflects both global and regional processes. At the global scale, it is primarily driven by the thermal expansion of warming oceans and the melting of land-based ice sheets and glaciers (IPCC, 2021), with groundwater depletion, which ultimately drains into the ocean, also contributing to rising sea levels (Kuang et al., 2024). In the UK, this signal is further influenced by regional geological processes, particularly glacial isostatic adjustment. As a result, northern parts of the UK are gradually rising, while southern regions are subsiding (Palmer et al., 2018).

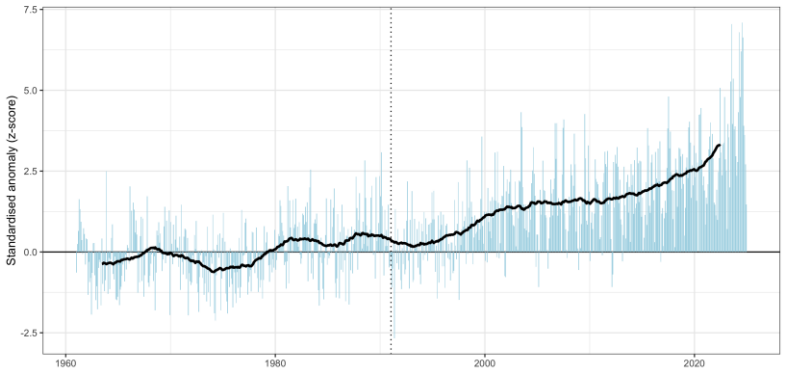


Figure 8. Standardised monthly anomalies of sea level.

Observed data show that mean sea level around the UK has risen by approximately 12–16 cm since 1900, with an acceleration in recent decades (Marine Climate Change Impacts Partnership, 2020). This aligns with the strong upward trend observed in the sea level component of the index. The dominance of this component indicates that sea level rise is a key driver of long-term climate risk, particularly through its contribution to increasing coastal flooding and erosion (Climate Change Committee, 2025).

5.2. The UK Actuarial Climate Index (UKACI)

Figure 9 shows the five-year moving averages of the six components together with the UKACI. The composite index exhibits a clear upward trend, particularly from the 1990s onwards, indicating a rise in the frequency of climate extreme events relative to the reference period.

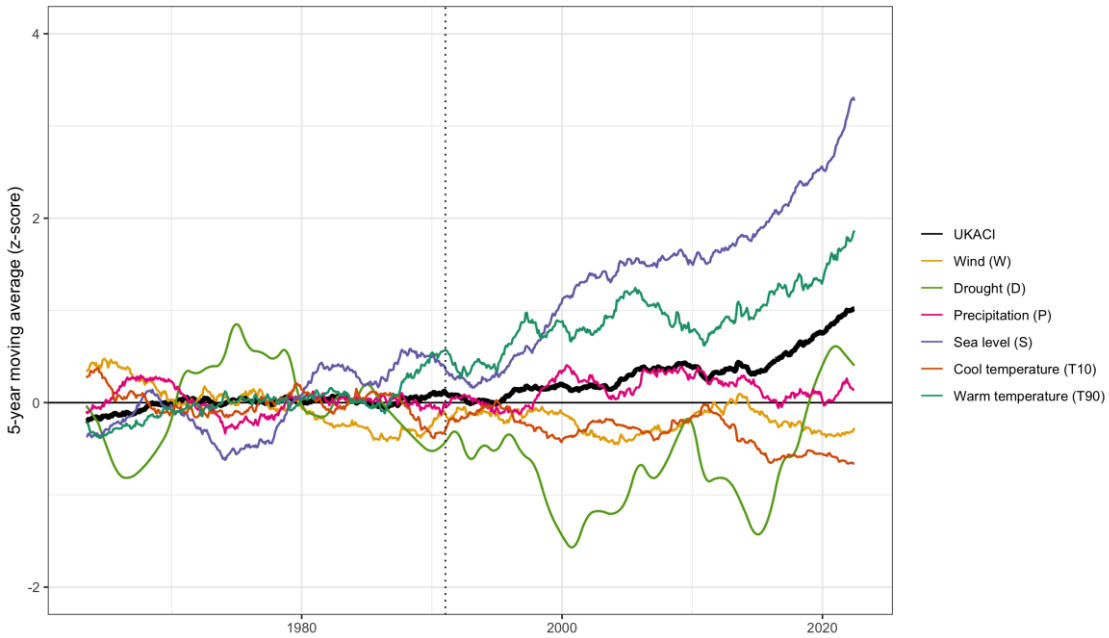


Figure 9. Five-year moving averages of components used in the UKACI.

The increase in the UKACI is mainly driven by the strong and persistent increases in the warm temperature (T90) and sea level (S) components. Among all components, sea level exhibits the largest increase, rising much more rapidly than the others and reaching values of more than 3 by the end of the study period. This is almost twice the magnitude of the warm temperature component, which reaches approximately 1.8 over the same period.

In contrast, precipitation (P), drought (D), and wind (W) fluctuate around zero over time and contribute less consistently to the overall index. The cool temperature component (T10) shows a persistent decline, reflecting the reduction in cold extremes, but its contribution is smaller in magnitude than the increases in warm temperature and sea level.

Figure 10 presents the Pearson correlation coefficients between the standardised monthly series of the six components, computed over the full 1961-2024 period. As expected, the warm and cool temperature indices (T90 and T10) show a moderate negative correlation of -0.47. Sea level (S), on the other hand, is positively correlated with warm temperature (T90), with a correlation coefficient of 0.38, consistent with their similar long-term upward trends.

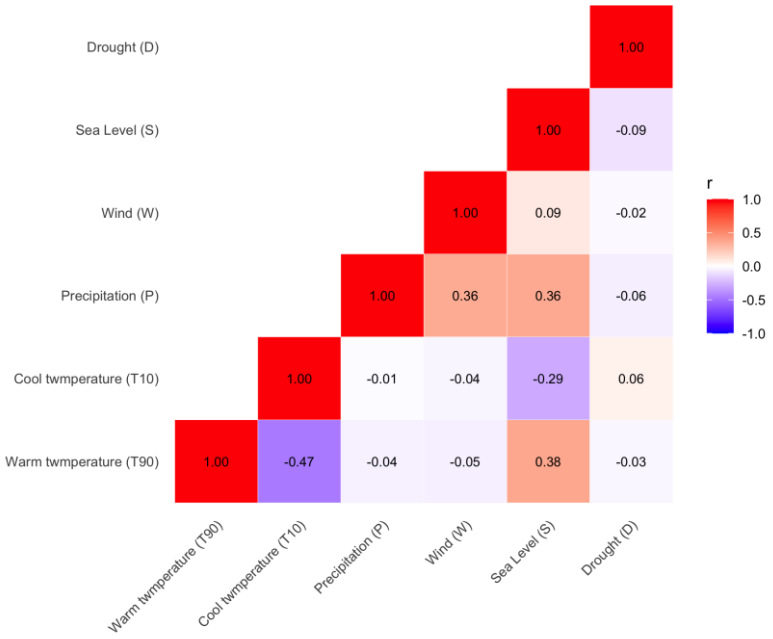


Figure 10. Correlation heatmap of the six components (Pearson correlations of the standardised monthly series, 1961-2024).

These relationships are also evident in the five-year moving averages shown in Figure 9, where warm temperature and sea level both increase substantially over time, while the cool temperature index declines. In contrast, the other component pairs exhibit only weak correlations, generally close to zero, indicating that they vary more independently over time.

The UKACI is comparable to previous ACI implementations, including those developed for North America, France, and the Iberian Peninsula. The main difference lies in the underlying data source, as previous studies typically use gridded datasets derived from station observations or reanalysis products[2], while the present study relies on station-based observations. Gridded datasets provide spatially continuous coverage, whereas station data represent localised measurements. The resulting index shows broadly similar patterns to those reported in previous studies, particularly in the relative importance of temperature and sea-level-related components.

6. SENSITIVITY ANALYSIS

This section assesses the robustness of the UKACI to alternative index constructions, including principal component analysis (PCA), the Australian Actuaries Climate Index (AACI) formulation, and a combined AACI–PCA approach.

6.1. Principal Component Analysis: The PCA-based index

[2] The North American ACI is based on GHCNDEX, a gridded dataset from GHCN-Daily station observations (American Academy of Actuaries et al., 2018). The Iberian and French indices are both computed from the ERA5-Land reanalysis (Zhou et al., 2023; Garrido et al., 2026).

Principal component analysis (PCA) is applied to the six standardised components to identify the dominant mode of variability.[3]

The corresponding loadings (Table 2) show that the first principal component is mainly driven by sea level and warm temperature, with loadings of 0.78415 and 0.53029, respectively. Smaller negative contributions are associated with cool temperature and drought. Precipitation also contributes positively to the first principal component, although its loading is substantially smaller at 0.17023. By contrast, wind has an almost negligible loading of 0.00897. This pattern indicates that the dominant mode of variability is closely associated with warming and sea level rise, while wind has very little influence on the index, consistent with the behaviour observed in the individual component indices.

Component	Loading
Warm Temperature	0.53029
Cool Temperature	-0.22747
Precipitation	0.17023
Drought	-0.15199
Wind Speed	0.00897
Sea Level	0.78415

Table 2. Loadings of the first principal component

Figure 11 compares the UKACI with the PCA-based index derived from the first principal component. The results show that the PCA-based index closely follows the temporal pattern of the UKACI, while exhibiting a larger difference and stronger contrast between the earlier and later parts of the dataset. In the first part of the study period, the PCA-based index remains substantially below zero, whereas the UKACI stays much closer to zero. After the reference period (i.e., after 1991), however, the PCA-based index rises more rapidly and reaches a value of approximately 1.6 by the end of the study period, whereas the UKACI reaches around 1.0.

This reflects the weighting structure of PCA, which gives greater influence to components with strong long-term trends and high variance, particularly sea level and warm temperature. As a result, the PCA-based index emphasises the dominant long-term climate signal more strongly than the equal-weight UKACI. Despite these differences in magnitude, the two indices exhibit a similar long-term upward trend and temporal evolution.

[3] Since the six components are time series, functional principal component analysis (FPCA) would be the natural framework for characterising their dominant modes of temporal variation (Ramsay and Silverman 2002; Shang 2014). In this paper, however, PCA serves a more limited purpose: it provides a data-driven alternative to the equal weights of the composite index by exploiting the cross-sectional covariance among the six standardised components.

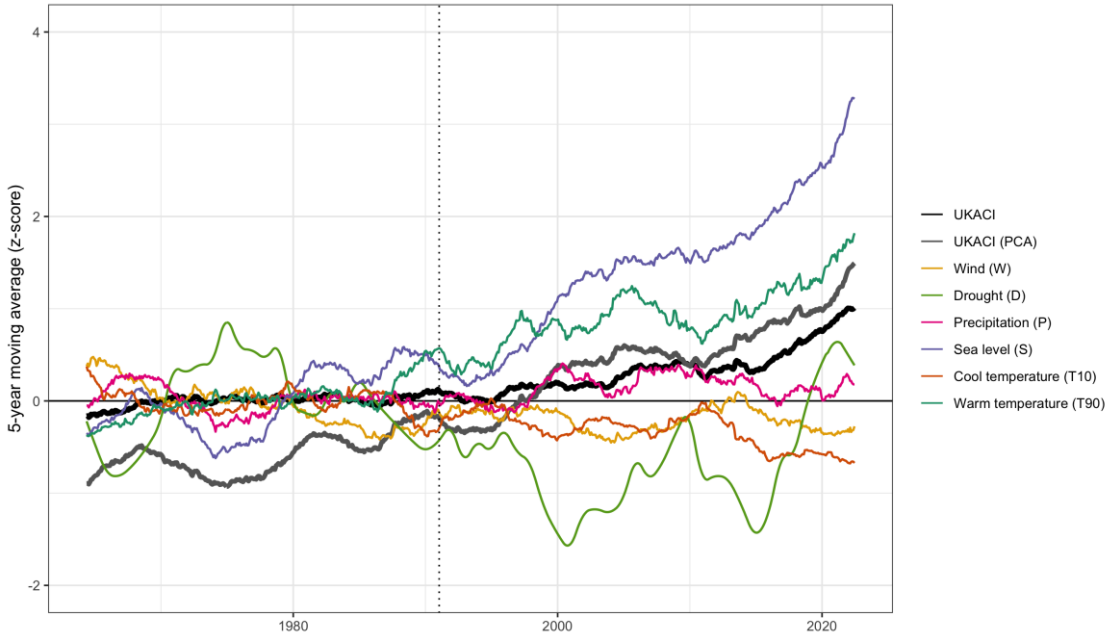


Figure 11. Five-year moving averages of the PCA-based UKACI and its components.

6.2. Alternative Formulation Based on the AACI

An alternative index is constructed following the methodology of the Australian Actuaries Climate Index (AACI; Actuaries Institute, 2025)[4], which modifies the definitions of several components to better capture more severe climate events, as shown in Table 3.

Component	Description
Warm temperature	Frequency of daily maximum and minimum temperatures above the 99th percentile.
Precipitation	Frequency of rainfall over five consecutive days above the 99th percentile.
Wind Speed	Frequency of daily wind gusts above the 99th percentile.
Sea Level	Change in sea level.

Table 3. Components of Australian Actuaries Climate Index

Unlike the North America Actuaries Climate Index (ACI), the AACI excludes drought and cool temperature components[5]

$$UKAACI = \frac{1}{4}(T99_{std} + Rx5day_{std} + W99_{std} + S_{std}).$$

Figure 12 shows the index constructed using the AACI approach. The index exhibits a much stronger and more persistent upward trend than the UKACI, beginning in the 1980s and accelerating after the reference period. By the end of the study period, the UKAACI reaches a value of approximately 2.4, compared with around 1.0 for the UKACI.

[4] Unlike the AACI, whose reference period begins in 1981, the UKAACI is computed over the same 1961-2024 study period and with the same 1961-1990 reference period as the UKACI, so that the two indices are directly comparable.
[5] We use the current version of the AACI (v2.0), which is based on four components. In the earlier 2018 framework (v1.0), cool temperature and consecutive dry days were included in the composite calculation, whereas wind speed was excluded. Further details on these modifications are provided in Actuaries Institute (2025).

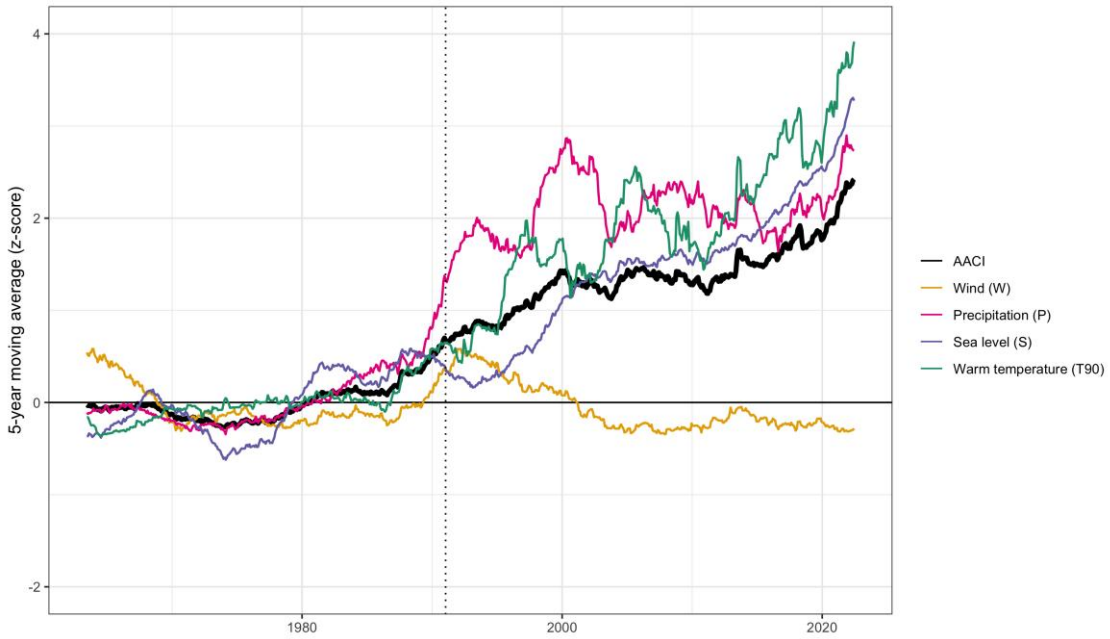


Figure 12. Five-year moving averages of the UKAACI and its components.

This reflects the sensitivity of the index to the choice of variables and definitions. In particular, the warm temperature component plays a more dominant role in the UKAACI, reaching values close to 4 by the end of the study period. Precipitation also contributes more strongly than in the UKACI, with a marked increase after the 1990s and sustained positive anomalies thereafter. By contrast, sea level still shows a strong upward trend, but its relative influence is smaller than in the UKACI because the temperature and precipitation components increase more rapidly and exhibit much larger short-term fluctuations.

Another important difference is that the AACI approach excludes the cool temperature and drought components. As a result, there are fewer components offsetting the upward trends in warm temperature, precipitation, and sea level, leading to a steeper increase in the overall index.

The stronger role of precipitation is partly related to the change in definition. In the AACI formulation, precipitation is measured as the frequency of extreme events rather than the maximum five-day accumulation. This makes the index more sensitive to repeated high-intensity rainfall events and leads to larger positive anomalies over time.

6.3. AACI with Principal Component Analysis

We also consider a combined approach in which principal component analysis is applied to the modified set of variables used in the AACI formulation. The loadings (Table 4) indicate that warm temperature is the dominant driver, followed by precipitation and sea level, with loadings of 0.76326, 0.53413, and 0.36344, respectively. Wind remains negligible, with loading close to zero.

Component	Loading
Warm Temperature	0.76326
Precipitation	0.53413
Wind Gusts	0.00633
Sea Level	0.36344

Table 4. Loadings of the first principal component

As shown in Figure 13, the first principal component, i.e. the PCA-based UKAACI composite index, exhibits a marked upward trend over the study period, particularly after the reference period.

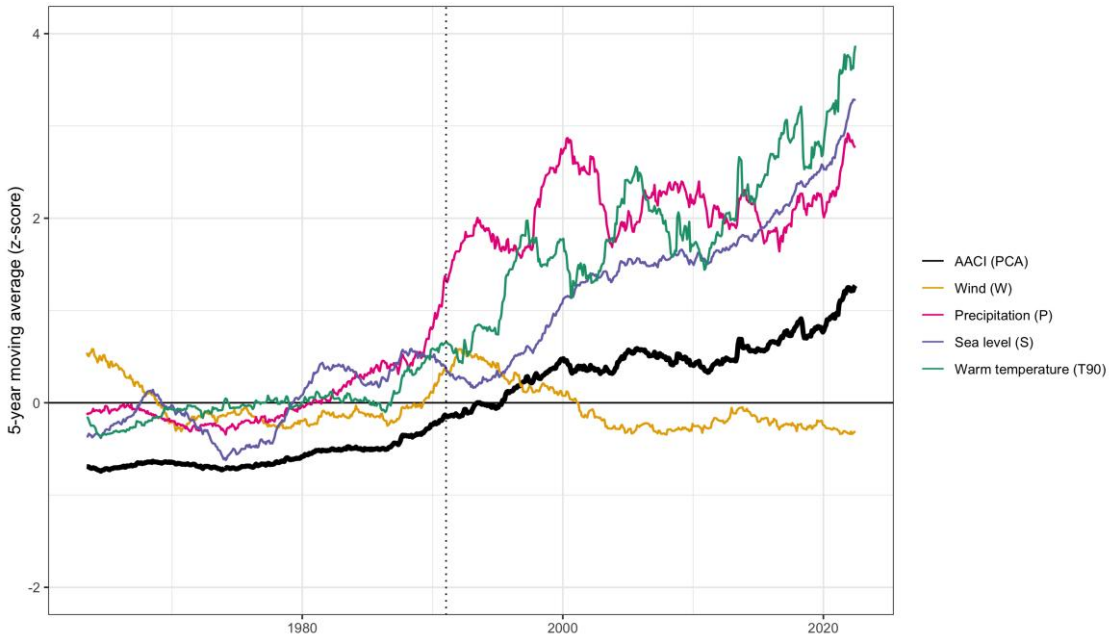


Figure 13. Five-year moving averages of the PCA-based UKAACI and its components.

A comparison between the UKAACI and its PCA-based counterpart (Figure 14) shows that the PCA-based index follows a very similar temporal pattern to the UKAACI but remains consistently lower throughout the study period. This suggests that PCA preserves the overall evolution of the UKAACI, while changing the scale of the index through a different weighting structure.

Overall, all alternative formulations produce a consistent upward trend. Changes in methodology affect the magnitude of the index and the relative importance of individual components, but not its overall evolution. This indicates that the increase in climate extremes is robust to the choice of index construction. However, the contribution of individual components depends strongly on how extremes are defined and weighted.

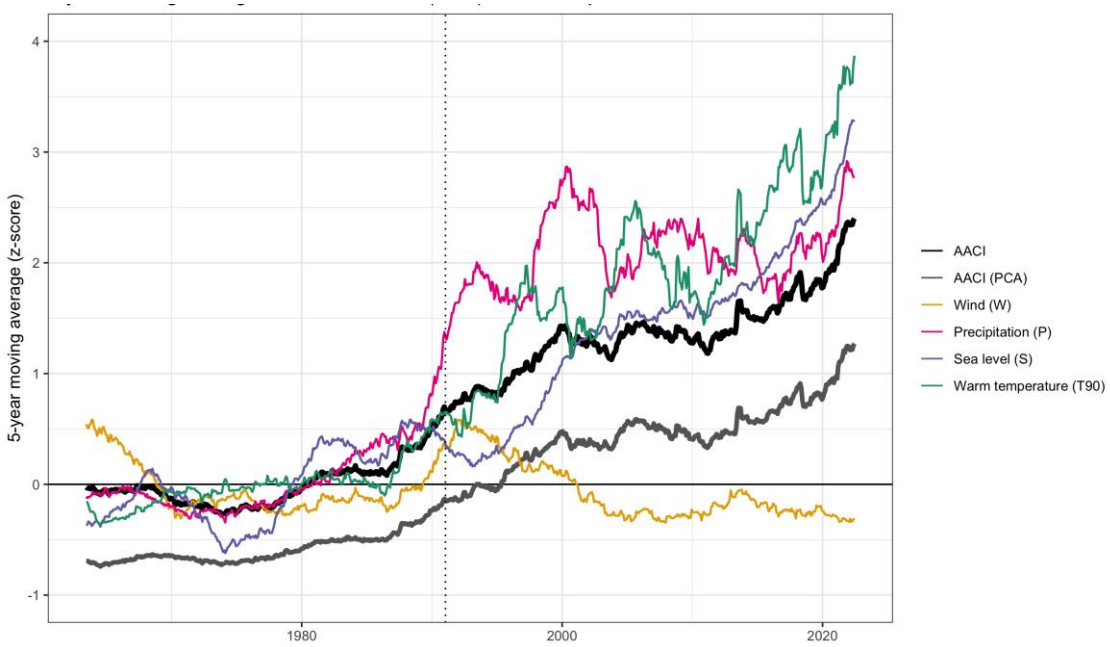


Figure 14. Five-year moving averages of the UKAACI and the PCA-based UKAACI.

7. CONCLUSION

This paper develops the United Kingdom Actuarial Climate Index (UKACI) using station-based observations from 1961 to 2024 within the methodological framework of the North American Actuaries Climate Index (ACI). Sensitivity analyses based on principal component analysis (PCA), the Australian Actuaries Climate Index (AACI), and a combined AACI–PCA approach are also conducted to assess the robustness of the index to alternative constructions.

The results show a clear upward trend in the UKACI over the study period, largely driven by warm temperature and sea-level-related components, while precipitation, drought, and wind exhibit greater variability and weaker long-term trends. Although alternative index formulations produce differences in magnitude and component contributions, the overall upward trend remains consistent across methodologies.

The sensitivity analysis highlights that the representation of climate extremes depends importantly on the choice of variables, thresholds, and weighting schemes. In particular, the AACI formulation places greater emphasis on severe tail events through the use of 99th percentile thresholds and modified definitions of precipitation and wind extremes, leading to larger index magnitudes and a stronger role for temperature and precipitation. Similarly, PCA-based approaches assign greater weight to components with higher variability, particularly sea level and warm temperature.

These findings suggest that the ACI framework captures a robust underlying signal of increasing climate extremes in the United Kingdom. However, the contribution of individual components and the interpretation of the index depend on how climate extremes are defined and aggregated. Different formulations therefore emphasise different dimensions of climate risk, with some approaches capturing broader changes across the distribution of extremes and others focusing more strongly on rare, high-impact events.

8. REFERENCES

Actuaries Institute. (2025). *Australian Actuaries Climate Index*. https://www.actuaries.asn.au/climate-index

American Academy of Actuaries. (2020). *Actuaries Climate Risk Index: Preliminary findings.* https://actuary.org/wp-content/uploads/2024/09/ACRI.pdf

American Academy of Actuaries, Canadian Institute of Actuaries, Casualty Actuarial Society, & Society of Actuaries. (2018). *Actuaries Climate Index development and design*. https://actuariesclimateindex.org/wp-content/uploads/2019/05/ACI.DevDes.2.20.pdf

Climate Change Committee. (2025). *Progress in adapting to climate change: 2025 report to Parliament*. https://www.theccc.org.uk/wp-content/uploads/2025/04/Progress-in-adapting-to-climate-change-2025-1.pdf

Fung, F., & Lowe, J. A. (2023). State of the past and future UK climate. In *Health effects of climate change (HECC) in the UK: 2023 report* (Chapter 1). UK Health Security Agency. https://assets.publishing.service.gov.uk/media/657043059462260721c569a6/HECC-report-2023-chapter-1-climate-projections.pdf

Garrido, J., Milhaud, X., & Olympio, A. (2026). A survey of actuarial climate indices: a new index for France and its insurance applications. *Annals of Actuarial Science*, 1–38. https://doi.org/10.1017/S1748499526100414

Holgate, S. J., Matthews, A., Woodworth, P. L., Rickards, L. J., Tamisiea, M. E., Bradshaw, E., Foden, P. R., Gordon, K. M., Jevrejeva, S., & Pugh, J. (2013). New data systems and products at the Permanent Service for Mean Sea Level. *Journal of Coastal Research*, *29*(3), 493–504. https://doi.org/10.2112/JCOASTRES-D-12-00175.1

Intergovernmental Panel on Climate Change. (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157896

Kendon, M., Doherty, A., Hollis, D., Carlisle, E., Packman, S., Jevrejeva, S., Matthews, A., Williams, J., Garforth, J., & Sparks, T. (2025). State of the UK climate in 2024. *International Journal of Climatology*, *45*(S1), Article e70010. https://doi.org/10.1002/joc.70010

Kendon, M., McCarthy, M., Jevrejeva, S., Matthews, A., Sparks, T., Garforth, J., & Kennedy, J. (2022). State of the UK climate in 2021. *International Journal of Climatology*, *42*(S1), 1–80. https://doi.org/10.1002/joc.7787

Kuang, X., Liu, J., Scanlon, B. R., Jiao, J. J., Jasechko, S., Lancia, M., Biskaborn, B. K., Wada, Y., Li, H., Zeng, Z., Guo, Z., Yao, Y., Gleeson, T., Nicot, J.-P., Luo, X., Zou, Y., & Zheng, C. (2024). The changing nature of groundwater in the global water cycle. *Science*, *383*(6686), Article eadf0630. https://doi.org/10.1126/science.adf0630

Manning, C., Kendon, E. J., Fowler, H. J., Catto, J. L., Chan, S. C., & Sansom, P. G. (2024). Compound wind and rainfall extremes: Drivers and future changes over the UK and Ireland. *Weather and Climate Extremes*, *44*, Article 100673. https://doi.org/10.1016/j.wace.2024.100673

Marine Climate Change Impacts Partnership. (2020). *Marine climate change impacts: Report card 2020*. https://www.mccip.org.uk/sites/default/files/2021-07/mccip-report-card-2020_webversion.pdf

Met Office. (2012). *Met Office Integrated Data Archive System (MIDAS) land and marine surface stations data (1853–current)* [Data set]. NCAS British Atmospheric Data Centre. https://catalogue.ceda.ac.uk/uuid/220a65615218d5c9cc9e4785a3234bd0

Met Office. (2022). *UK Climate Projections: Headline findings (Version 4.0).* https://www.metoffice.gov.uk/api/assets/file/ukcp18_headline_findings_v4_aug22pdf?prefix=assets

Met Office. (2026). *Effects of climate change*. Retrieved April 20, 2026, from https://weather.metoffice.gov.uk/climate-change/effects-of-climate-change

NOAA National Centers for Environmental Information. (2025). *Global Historical Climatology Network daily (GHCN-Daily) (version 3)* [Data set]. Retrieved April 20, 2026, from https://www.ncei.noaa.gov/products/land-based-station/global-historical-climatology-network-daily

Palmer, M., Howard, T., Tinker, J., Lowe, J., Bricheno, L., Calvert, D., Edwards, T., Gregory, J., Harris, G., Krijnen, J., Pickering, M., Roberts, C., & Wolf, J. (2018). *UKCP18 marine report*. Met Office Hadley Centre. https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/UKCP18-Marine-report.pdf

Permanent Service for Mean Sea Level. (2026). *Tide gauge data* [Data set]. Retrieved April 20, 2026, from https://www.psmsl.org/data/obtaining/

Ramsay, J. O., & Silverman, B. W. (2002). *Applied functional data analysis: Methods and case studies*. Springer. https://doi.org/10.1007/b98886

Rogo, B., Garrido, J., & Demartis, S. (2025). The Italian Actuarial Climate Index: A National Implementation Within the Emerging European Framework. *Risks*, *13*(10), Article 192. https://doi.org/10.3390/risks13100192

Shang, H. L. (2014). A survey of functional principal component analysis. *AStA Advances in Statistical Analysis*, *98*(2), 121–142. https://doi.org/10.1007/s10182-013-0213-1

Zhou, N., Vilar-Zanón, J.-L., Garrido, J., & Heras Martínez, A. J. (2023). On the definition of an actuarial climate index for the Iberian Peninsula. *Anales del Instituto de Actuarios Españoles*, (29), 37–59. https://doi.org/10.26360/2023_3