WASITUS Rapid Attribution Study:

Record-breaking May temperatures would not have been possible without human caused climate change

Author list: *Claire Bergin, Lionel Swan, Ciarán Kelly, Paul Moore*
Review author list: *Peter Thorne, Clair Barnes*
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Record-breaking May temperatures would not have been possible without human caused climate change

Authors
Claire Bergin*, ICARUS Climate Research Centre, Maynooth University, Maynooth, Ireland*
Lionel Swan*, ICARUS Climate Research Centre, Maynooth University, Maynooth, Ireland*
Ciarán Kelly*, Met Éireann, Glasnevin, Dublin 9, Ireland*
Paul Moore*, Met Éireann, Glasnevin, Dublin 9, Ireland*

Review Authors
Peter Thorne*, ICARUS Climate Research Centre, Maynooth University, Maynooth, Ireland*
Clair Barnes, *Centre for Environmental Policy, Imperial College London, UK*

Main findings

- As reported by Met Éireann in the May Climate Statement: Last month saw the national May maximum temperature record exceeded by more than 2°C. An intense area of high pressure combined with an unseasonably hot tropical airmass brought exceptionally high temperatures between Monday 25th and Wednesday 27th. The previous May national record high temperature of 28.4°C set in Ardfert, Co Kerry in 1997, was surpassed at a series of locations on Monday, May 25th, before a greater number of stations reached temperatures in excess of 30.6°C on Tuesday, May 26th.
- The record-breaking single day May temperatures, when many May station records were broken, were found to not be possible without human induced climate change.
- Under the current climate (1.3°C warmer than pre-industrial), this single day extreme is expected to occur once every 60 years, and is projected to occur once every 20 years in a climate 3°C warmer than pre-industrial levels.
- These record-breaking temperatures have become 1.1°C warmer compared to if they had occurred in a pre-industrial world. Temperatures are expected to increase by a further 0.1°C, 0.5°C and 1.1°C under a climate where warming has reached 1.5°C, 2°C and 3°C.
- The five-day mean temperatures have become nearly twice as likely today (1-in-5 years) compared to a pre-industrial climate (1-in-9 years) and are expected to further increase in likelihood under future warming. The temperatures themselves have become 1.4°C warmer today compared to a pre-industrial climate and are projected to increase by a further 1.1°C under a climate where warming has reached 3°C.
- The nighttime temperatures experienced were a 1-in-8 year event under a pre-industrial climate and have become nearly three times more likely (1-in-3 year event) under today's climate. Under a climate where warming has reached 3°C, the likelihood of these

temperatures occurring becomes a 1-in-1-to-2 year event, meaning experiencing these uncomfortable nighttime temperatures will be the new norm.

- Nighttime temperatures were also found to have increased in intensity by 1.3°C compared to a pre-industrial world. These temperatures are projected to increase by a further 0.1°C, 0.4°C and 1.1°C under a climate where warming has reached 1.5°C, 2°C and 3°C.

1 Introduction

Ireland experienced an unusually early spell of heat from Saturday 23rd to Wednesday 27th of May 2026. Temperatures began to rise over the weekend of the 23rd and 24th of May 2026 due to an intense heat dome forming over west and central Europe. The heat reached its peak between Monday to Wednesday (the 25th to 27th) with multiple synoptic stations breaking their May temperature records across the country, particularly in the south and east. The highest temperatures in Ireland were predominantly found across Leinster and Munster. The hottest day varied across stations over this period but averaged across Leinster and Munster the Met Éireann gridded product showed the 27th as the hottest single day (and it is this day analysed in the 1-day analysis herein).

The high temperatures occurred when an intense high pressure system stacked through the atmosphere at upper and lower levels, known as a heat dome, developed over western and central Europe and pushed north over Ireland on Sunday 24th May 2026. A very warm airmass advected northwards over Ireland at the surface at the same time. The heat dome sat in place over western Europe for several days with Ireland in the northwest quadrant. It broke down over Ireland on Thursday 28th, allowing a cooler Atlantic airmass to move in from the west, but continued over the UK, France and the Iberian Peninsula for several more days.

When high pressure develops at upper and lower levels and stays over the same areas for several days, it leads to sinking air right through the layers of the troposphere. This air compresses and warms the lower layers of the atmosphere, with the heat building day on day. The heat began building over Ireland on Sunday 24th, peaking on Tuesday 26th and Wednesday 27th before an Atlantic airmass broke through on the 28th. Although it's unusual for Ireland to see such an intense high pressure system over the country, especially in May, many of our hottest spells in the past have come from similar meteorological circumstances. Figure 1.1 shows the synoptic situation when temperatures were building at 12 UTC on Sunday May 24th and at 06 UTC on the morning of May 26th.

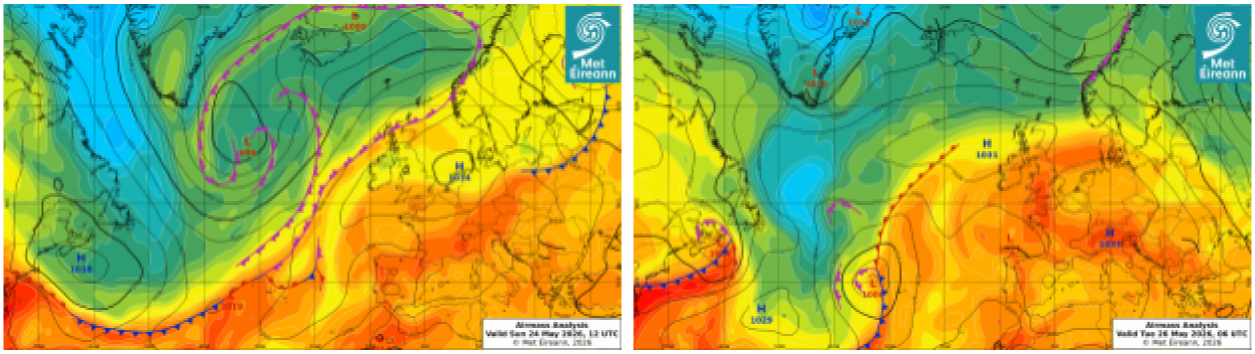

Fig 1.1: Left: Sunday 24th May 2026 at 12 UTC, heat dome building over Europe and pushing towards Ireland. Right: Tuesday 26th May at 06 UTC, heat sitting over south and east of Ireland. From Met Éireann synoptic analyses. Contours are isobars of equal pressure. Colours denote airmass temperatures with yellows oranges and reds denoting hotter temperatures

On Monday 25th May, daytime maximum air temperatures were already well above normal for late May. Shannon Airport, Oak Park and Gurteen were all more than 12°C warmer than the long-term average for daily maximum temperature. This was the first major peak of the heat and the day the previous Irish May maximum temperature record was first provisionally broken. Daily maximum temperature anomalies at selected stations on Monday 25th of May can be seen in Figure 1.2.

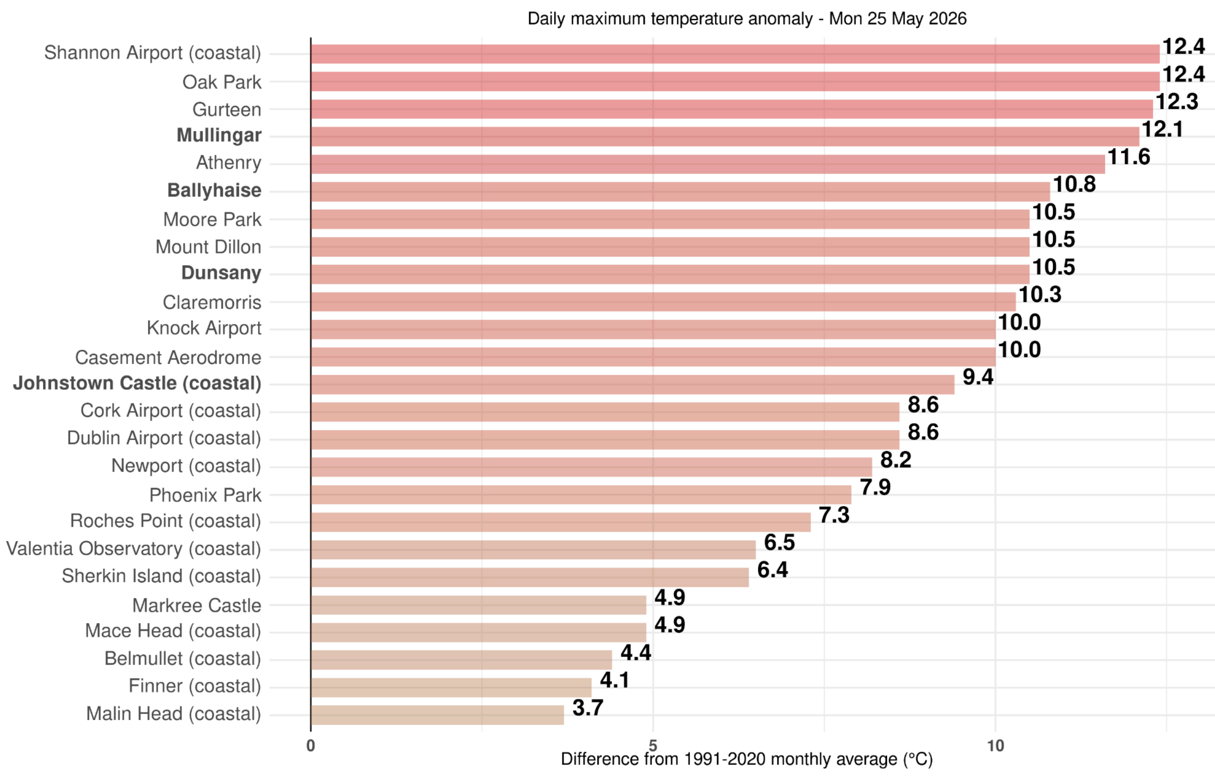

Figure 1.2: Daily maximum temperature anomaly on Monday 25th May 2026 relative to the 1991 - 2020 long-term average. Several stations recorded maximum temperatures more than 10°C above average, indicating the rapid build-up of heat before the peak of the event. Bold station names indicate stations that set new May daily maximum air temperatures recorded on that day.

The previous May high temperature stood at 28.4°C at Ardfert in Co. Kerry on May 31st 1997. On Monday 25th, the record was broken, with 28.6°C recorded at Shannon Airport. Three Automated Climate Stations also exceeded the old record: Killarney (Muckross House) 29.1°C, Clonmel WWTP 29.1°C, and Glengarriff (Ilnacullin) 29.2°C. Limerick Junction equalled the previous record with 28.4°C (all provisional, subject to review).

Met Éireann issued a status yellow high temperature warning for eight counties across Munster and Leinster (Kerry, Limerick, Clare, Tipperary, Galway, Kilkenny, Laois and Offaly), which came into effect at midday on Tuesday 26th and remained in place until 6pm on Wednesday 27th. Maximum daytime temperatures were expected to exceed 27°C and nighttime minima were expected to stay above 15°C.

Tuesday 26th May was the peak of the event. Maximum temperature anomalies exceeded 10°C at many stations. The largest anomalies among the synoptic network were recorded at Shannon Airport, Gurteen, Oak Park and Athenry. Daily maximum temperature anomalies at selected stations on Tuesday 26th are shown in Figure 1.3.

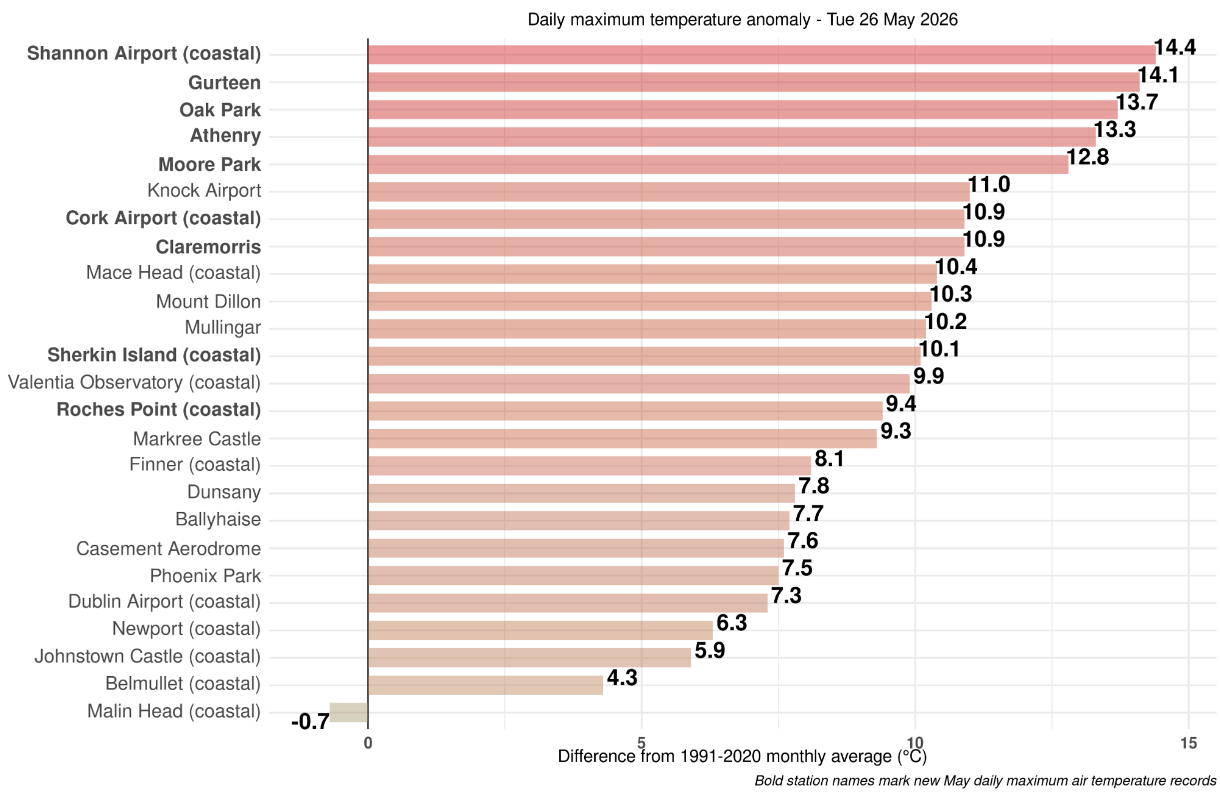

Figure 1.3: Daily maximum temperature anomaly on Tuesday 26th May 2026 relative to the 1991 - 2020 long-term average. This was the peak day of the heat event with widespread anomalies above 10°C. Bold station names indicate stations that set new May daily maximum air temperatures recorded on that day.

On Tuesday 26th, the record was provisionally broken again with 29.7°C recorded at Oak Park. Before the end of the day the original May high temperature record was provisionally broken by

2°C when Shannon Airport recorded 30.6°C. This was the first time temperatures in excess of 30°C were recorded in Ireland during the month of May since records began in 1900.

The heat was widespread, with 22 stations in the automatic climate station network exceeding the previous May record of 28.4°C on the 26th. Eight stations, recorded temperatures above 30°C. Seven stations reached or exceeded the synoptic station Shannon Airport value of 30.6°C, including Abbeyfeale water waste treatment plant (WWTP) and Clonmel WWTP, both with 30.9°C, Castleisland WWTP, Kilkenny (Greenshill), and Durrow with 30.8°C, and Killarney (Muckross House) and Fethard (Parsonshill) with 30.7°C. Subject to data validation, the new national maximum temperature record for May is therefore expected to come from one of these stations rather than Shannon Airport.

On Thursday 27th of May, a further eight stations provisionally exceeded their previous May records: Dooks Golf Club, Dingle WWTP, Clareville WWTP, Glengarriff (Ilnacullin), Inagh (Mount Callan), Killarney (Muckross House), Adare Manor and Cloone Lake. The highest value on 27th May was 29.6°C at Dooks Golf Club.

Nighttime temperatures experienced were also much higher than normal with these anomalies from the night of Tuesday 26th of May, used for our nighttime analysis (Tn1x) discussed in section 1.3, shown in Figure 1.4.

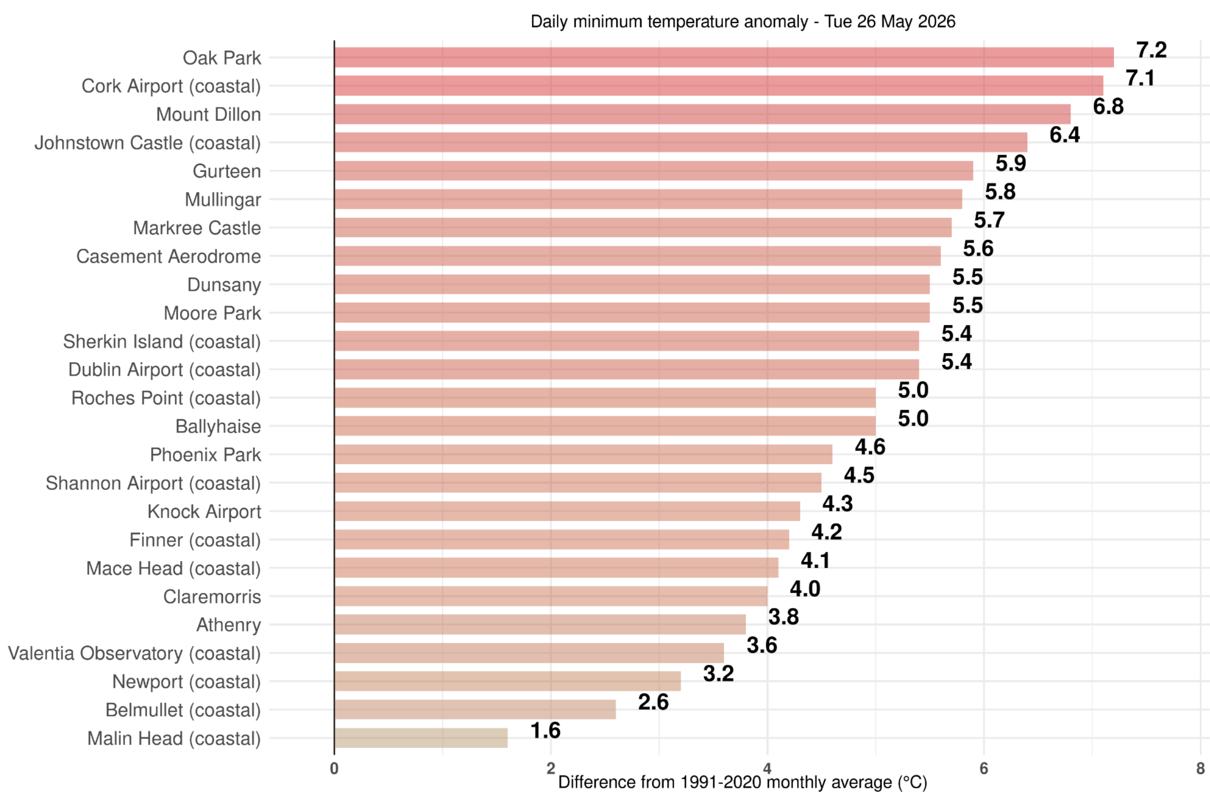

Fig 1.4: Daily minimum temperature anomaly on Tuesday 26th May 2026 relative to the 1991 - 2020 long-term average. Minimum temperatures were also well above average, indicating limited overnight cooling during the peak of the heat event.

1.1 Warmest May temperatures on record

While May in Ireland is typically the sunniest month of the year, mean temperatures tend to stay between 10°C and 12°C across the country, with highs failing to reach 25°C in the last four years (2021-2025). In the historical record, temperatures prior to this year (2026) had never reached 30°C during the month of May, emphasising the extremity of this event. As such this is the first time a 'Hot Day' (Air temperatures > 30.0°C, met.ie) has ever been recorded in the month of May in Ireland.

The magnitude by which the previous May national temperature record (28.4°C) was broken is virtually unprecedented in Irish records. In a stable climate, extreme temperature records in Ireland would be expected to be broken by fractions of a degree, however in this instance, the national May record was broken by over 2°C. This record increase was much larger than when the July national temperature record of 32.3°C was broken by 0.7°C in July 2022 (33.0°C). It should be noted that during the May 2026 event, individual station records were broken by as much as 4.3°C as observed at the synoptic station in Gurteen, Co Tipperary on the 26th May.

A previous attribution study by the WASITUS team found that the extreme temperatures experienced on the 11th and 12th July 2025 had been made warmer and more likely to occur due to human induced climate change. While this extreme occurred during the heart of the summer, the event and temperatures are relatively similar to those experienced at the end of May 2026.

On a broader scale, several attribution studies have been performed by WWA linking early season (April and May) extreme temperatures to human induced climate change in Iceland, Greenland, Saudi Arabia, Central Asia and South Asia. Findings suggest temperatures that would historically occur only during the summer months are now becoming more and more likely to occur earlier in the year, during April and May.

1.2 Effect of early heat on Irish waters

The unusually high temperatures were not just confined to land. Inland Fisheries Ireland implemented their warm water protocol to protect fish species across several fisheries when water temperatures began to reach 20°C. Species such as the Atlantic salmon and brown trout begin to suffer from heat stress when water temperatures exceed 18°C. However, other species like Carp require water temperatures to be 18°C or higher to begin spawning, a threshold that isn't met every year during the month of May.

Figure 1.5 highlights how temperatures at four independent fresh water bodies around Ireland had reached or exceeded 18°C towards the end of May. Three of the four gauges recorded their highest May temperature since 2015, with temperature anomalies ranging from +2.3°C to +3.7°C above the 2015-2025 mean. This is particularly notable given that the first half of May was dominated by anomalously cold weather conditions.

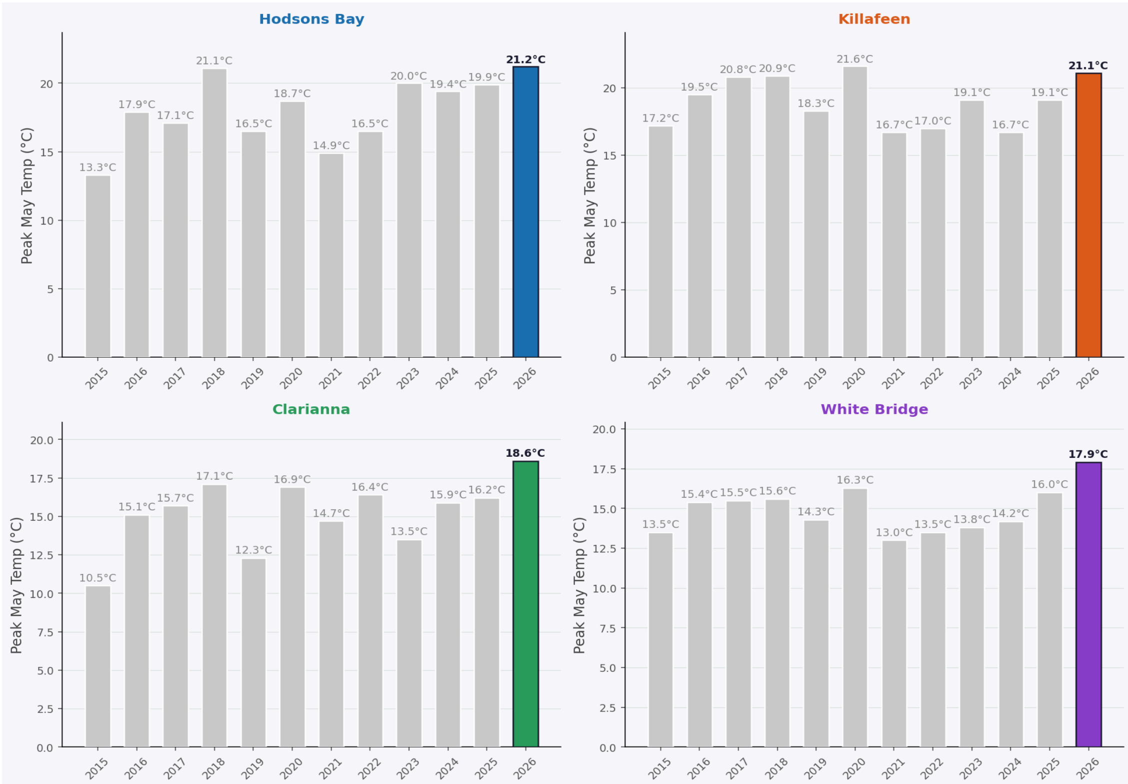

Figure 1.5: Peak May water temperatures for four independent fresh water bodies around Ireland.

Lake water temperatures globally have risen between the period 1985-2009. A study by O'Reilly et al (2015) warns that warmer waters lead to increased risk of algal blooms which pose a significant risk to fish and animal life. Lough Feeagh situated in County Mayo was amongst the lakes analysed in the study, with its waters having warmed by 0.35°C per decade over the study period.

It wasn't just the inland water temperatures which were anomalously high at the end of May. Off the south coast, sea surface temperatures were between 2-3°C warmer than the average at this time of year (Figure 1.6), reaching just over 15°C at the M5 Buoy.

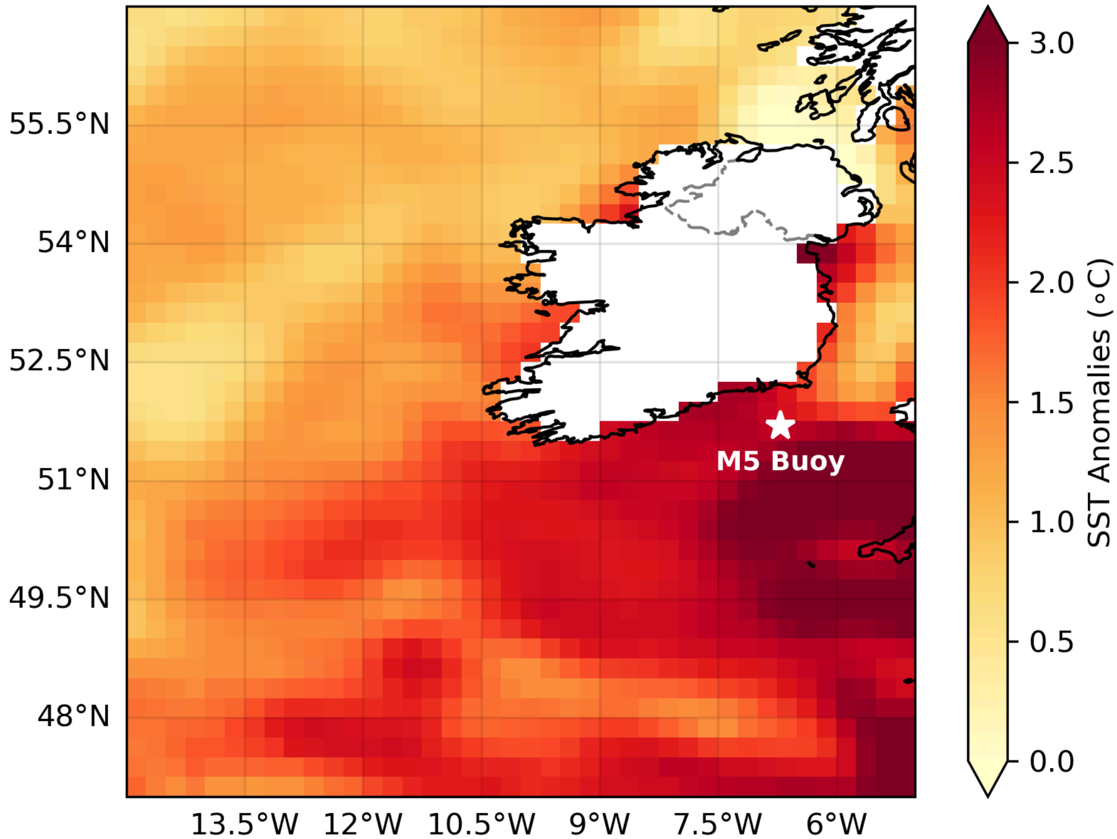

Figure 1.6: Sea Surface Temperature anomalies surrounding Ireland on the 27th May 2026, and the location of the M5 Buoy. Daily anomalies were calculated against a baseline period of 1971-2000 for May 27th. Data source: OISST

1.3 Event Definition

While much of Ireland experienced warm days from the 23rd to 27th of May 2026, it was predominantly the provinces of Leinster and Munster that saw record breaking May temperatures. As a result, the geographical study region for our analysis is restricted to Leinster and Munster. This can be seen in Figure 1.7.

In addition, as we are interested in the May records, all n-day analysis is restricted to the month of May in each year. In order to understand the spatial extent and persistence of the May temperature extremes, we characterise the event using three event definitions:

- **Tx1x** - May maximum of daily maximum temperatures averaged over Leinster and Munster (27th May 2026)
- **Tx5x** - May maximum of five-day running mean of daily maximum temperatures averaged over Leinster and Munster (Exact dates vary between datasets but roughly 24-28th May 2026)
- **Tn1x** - May maximum of nightly minimum temperatures averaged over Leinster and Munster (night of 27th May 2026)

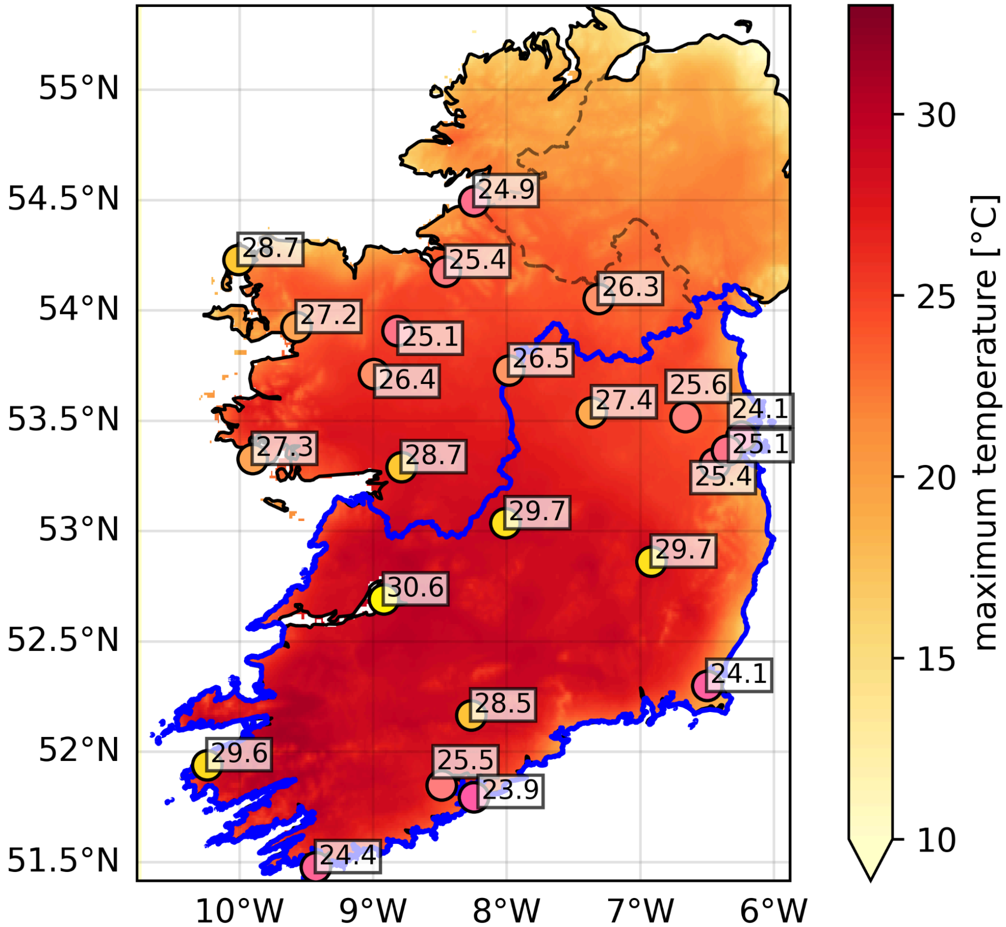

Figure 1.7: Map of the geographical event definition for the hottest day Tx1x made with the Met Éireann gridded product (27th May 2026). The dots represent the synoptic station that broke their previous May station record, with their new record (°C), over the study period 24th to the 27th of May.

2 Data and methods

In this report, we study the influence of anthropogenic climate change by comparing the likelihood and intensity of similar May 1-day and 5-day maximum temperatures and 1-day minimum temperatures at present with those in a 1.3°C cooler climate. We also extend this analysis into the future by assessing the influence of a further 0.2°C, 0.7°C, and 1.7°C of global warming from the present. This is in line with 1.5°C and 2°C of global warming which constitutes the long-term temperature goal of the *Paris Agreement*[1] and 3°C of global warming which is highly likely over the course of this century under current policies (*UNEP, 2024*).

2.1 Observational data

- **ERA5** - The European Centre for Medium-Range Weather Forecasts's 5th generation reanalysis product, ERA5, is a gridded dataset that combines historical observations into global estimates using advanced modelling and data assimilation systems (Hersbach et al., 2020). We use daily maximum and minimum temperature data (tmax and tmin, respectively) from this product at a resolution of 0.25°×0.25°, from the years 1950 to present. At the time of writing reanalysis data were available until the 26th May 2026. We extend the reanalysis data with analysis data until 26th May and forecast data until 29th May, to cover the remaining period of the event.
- **E-OBS** - This is a gridded land-only observation dataset of Europe, formed from the interpolation of station-derived meteorological observations (Cornes et al., 2018). We use version 29.0e of this dataset, at spatial resolution 0.1°×0.1° gridded tmax and tmin, from 1920-present.
- **CPC** - This is the gridded product from NOAA PSL, Boulder, Colorado, USA known as the CPC Global Unified Daily Gridded data, available at 0.5°x0.5° resolution, for the period 1979-present. We use daily tmax and tmin. Data are available from NOAA.
- **Met Éireann** - The Irish national meteorological services gridded product, from 1961-present, with provisional grids for 2026. It has a 1×1km resolution, approximately 0.01°×0.01°. Interpolation methods were used to calculate the temperature grid point values with inputs from observations recorded at Met Éireann stations.

As a measure of anthropogenic climate change we use the (low-pass filtered) global mean surface temperature (GMST), where GMST is taken from the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Science (GISS) surface temperature analysis (GISTEMP, Hansen et al., 2010 and Lenssen et al. 2019).

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[1] *Article 2*

1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:
(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change; [...]

2.2 Model and experiment descriptions

We use two multi-model ensembles from climate modelling experiments using very different framings (Philip et al., 2020): coupled global circulation models (GCMs) and nested regional climate models (RCMs).

- **Euro-CORDEX** - the Coordinated Regional Climate Downscaling Experiment (CORDEX)- European Domain with 0.11° resolution (EUR-11, Jacob et al., 2014; Vautard et al., 2021). The ensemble consists of 11 regional climate models each of which are driven by up to 8 GCMs, although not all GCM-RCM combinations have been produced. In this analysis we use 70 of these GCM-RCM pairs. These simulations are composed of historical simulations from 1950 or 1970 up to 2005, and extended to the year 2100 using the RCP8.5 scenario.
- **CMIP6** - this is a multi-model ensemble of global general circulation models with varying resolutions (Eyring et al., 2016). For all simulations, the period 1850 to 2015 is based on historical simulations, while the SSP5-8.5 scenario is used to project from 2016 to 2070. We use 15 of the participating models with varying resolutions.

2.3 Statistical methods

The methods for observational and model analysis, and for model evaluation and synthesis, follow the World Weather Attribution Protocol, described in Philip et al., (2020), with supporting details found in van Oldenborgh et al., (2021), Ciavarella et al., (2021) and WWA, 2021. The key steps, presented in sections 3-6, are: (3) trend estimation from observations; (4) model evaluation; (5) multi-method multi-model attribution; and (6) synthesis of the attribution statement. In addition, section (7) presents the societal impacts of the extreme weather event and section (8) gives a brief conclusion.

We calculate the return periods, Probability Ratio (PR; the factor-change in the event's probability) and change in intensity of the event under study to compare the climate of now and the climate of the past, defined respectively by the GMST values of now and of the pre-industrial past (1850-1900, based on the Global Warming Index).

To statistically model the one and five day temperature extremes, we use a non stationary Generalized Extreme Value (GEV) distribution. In all three cases, the distribution of block maxima is assumed to shift linearly with the covariates, with the variance remaining constant over time. The parameters of the statistical model are estimated using maximum likelihood. Next, results from observations and models that pass the validation tests are synthesised to produce a single attribution statement.

3 Observational analyses: return period and trend

In this section, trends in observational datasets (the gridded data products set out in section 2.1) are calculated and compared. We analyse the area average Tx1x, Tx5x and Tn1x for all four gridded datasets and calculate the return period, change in intensity and probability ratio (along with 95% confidence intervals for each) between the current climate of 2026 and a 1.3°C cooler past climate, by fitting the parameters of a nonstationary GEV distribution.

3.1 Initial analysis

Initially, the Met Éireann gridded product maximum temperature data was averaged over land for the study area, Leinster and Munster, and the maximum temperatures per day found. Then, the first instances where temperatures were greater than or equal to 25°C were plotted per year in Figure 3.1. Of the 68 years in the record, only 23 years reached 25°C, with the average occurrence getting earlier in the year the closer we get to modern day. Fourteen of those 23 occurrences took place in the 22 years since 2003, and the threshold has been exceeded in five of the last six summers. The 2026 event represents the earliest such occurrence in the record and the first such occurrence in May.

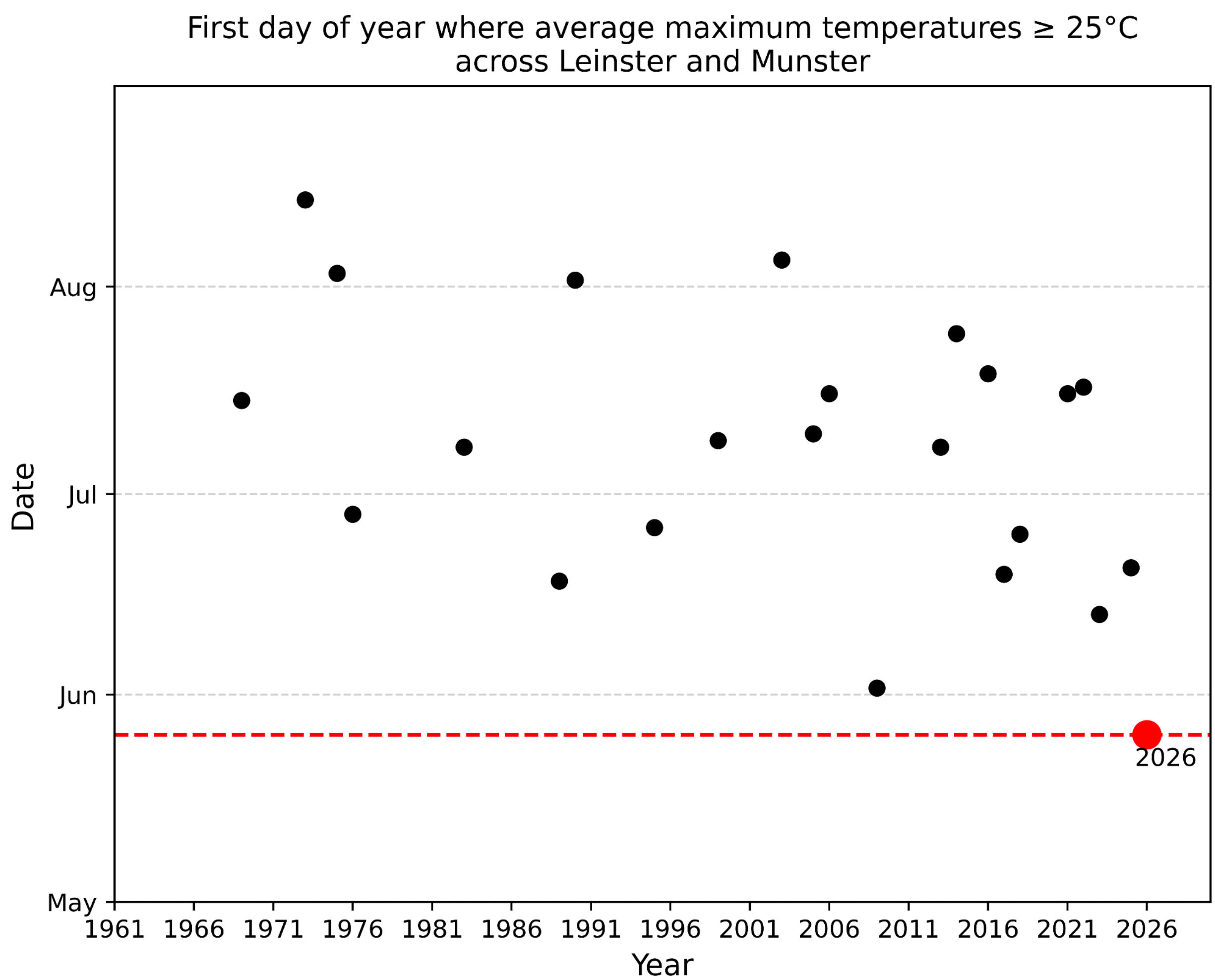


Fig 3.1: First day of the year on which daily maximum temperatures averaged over Leinster and Munster exceeded 25°C (data: Met Éireann).

3.2 Tx1x - Analysis of 1-day May maximum temperatures

The first column of Figure 3.2 shows the time series for Tx1x for May in the four gridded data products, with the fitted GMST-dependent trend overlaid. Although there is some decadal variability not captured by the model, for the most part the GMST-dependent trend (black line) resembles the nonparametric local regression (Loess) smoother fitted over time (green line). This suggests reasonable agreement between the fitted model and the temporal trend. In addition, all four datasets show an upward trend in average 1-day May maximum temperatures. In ERA5, the event has a current day return period of 255 years (bootstrapped 95% confidence interval (CI): 43, infinity), in CPC, 26 years (95% CI: 7, infinity), and Met Éireann, 56 years (95% CI: 11, infinity). We therefore use a return period of 60 years to represent this event in the full attribution analysis.

The second column of Figure 3.2 shows the fitted linear trend plotted against the GMST covariate, rather than time as above. In ERA5 the maximum 1-day May temperature was found to have warmed by 2.2°C (95% CI: 0.8, 4.5) with respect to the pre-industrial baseline. In CPC, by 2.9°C (95% CI: 0.9, 5.3), in Met Éireann, by 4.2°C (95% CI: 2.4, 6.1), and in EOBS, by 1.8°C (95% CI: 0.4, 3.2). The Met Éireann analysis benefits from the inclusion of many stations additional to the synoptic network arising from high quality data sources that are not shared internationally in real-time and therefore may better capture the event particularly as the synoptic network is sparse in several of the areas where the largest hot extremes were observed by non-synoptic stations. This includes 25 synoptic stations and over 40 automated climate stations that feed into the provisional grids. After a few months, data from volunteer-manned rainfall stations and volunteer-manned climate stations are added and used in the final quality-controlled grids. At most, only the 25 synoptic stations in real time feed into the other reanalysis products.

The third and final column of Figure 3.2 shows the modelled change in return levels associated with a 1.3°C increase in GMST from the pre-industrial to the current climate. In all datasets, there is a clear separation between the return levels in the current climate (red) and the past climate (blue). The best estimate of the probability ratio - that is, the factor change in the probability of such an event occurring relative to pre-industrial - is 5560 for ERA5, infinity for CPC, infinity for Met Éireann, and 13 for EOBS. These results, along with the estimated return periods and changes in intensity for all datasets, are summarised in Table 3.1.

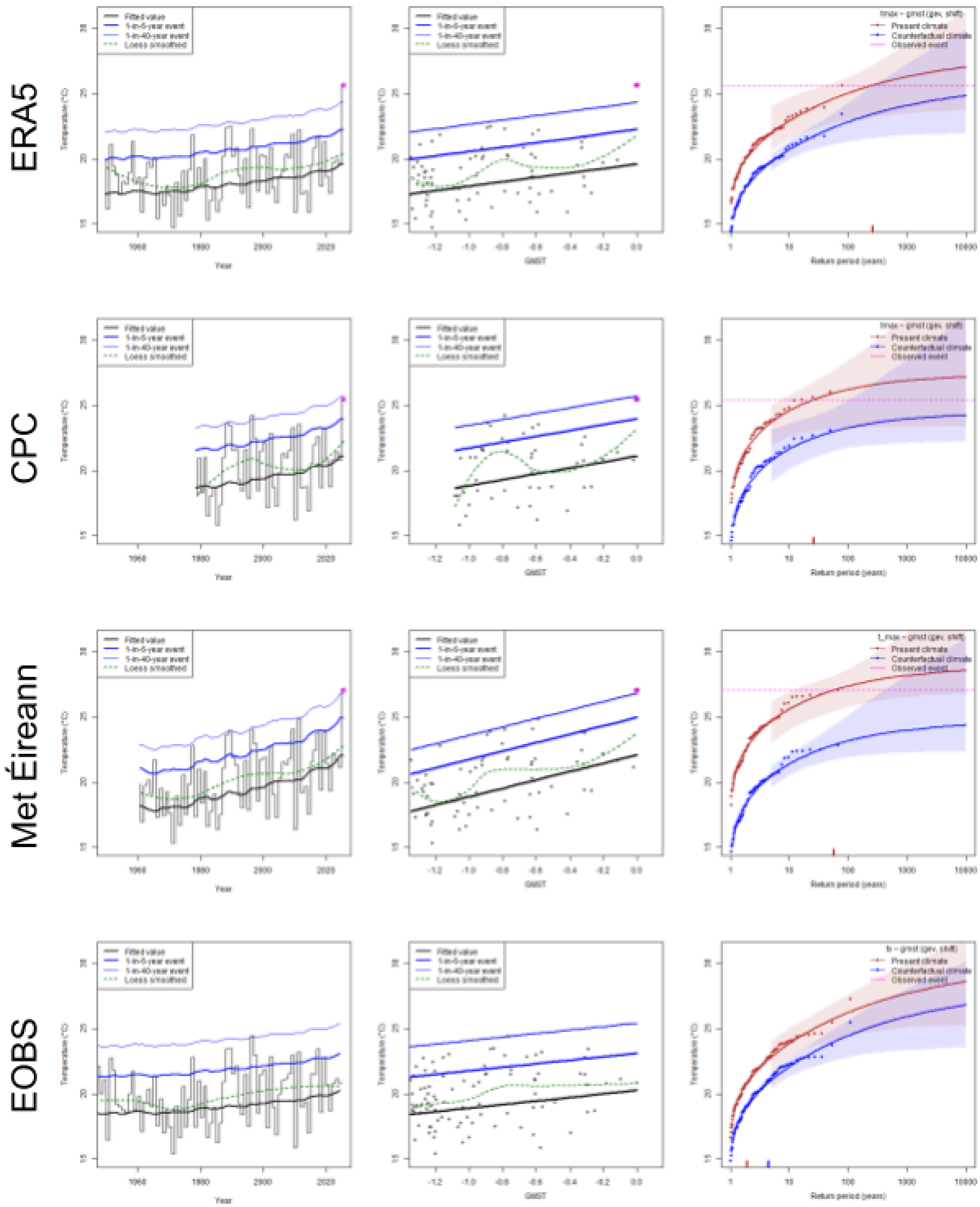


Figure 3.2: All results for Tx1x May over study region. The pink in all graphs marks the 2026 event (not available in EOBS at time of writing). ***Left:*** *Time series with fitted model overlaid. The heavy black line indicates the mean of the fitted Gaussian model, and the blue lines indicate the expected return levels of 6- and 40-year events. The green line is a nonparametric Loess smoother.* ***Middle:*** *Linear trend as a function of GMST (shown as a difference from the 2026 GMST) in three gridded observational data*

products. The thick black line denotes the nonstationary location of the fitted Gaussian distribution, and the blue lines show estimated 6- and 40-year return levels. The vertical lines represent a bootstrapped 95% confidence interval for the Gaussian location parameter in the 2026 climate (GMST anomaly = 0) and a hypothetical 1.3ºC cooler climate. ***Right:*** *Expected return levels in the 2026 climate (red lines) and in a 1.3°C cooler counterfactual climate (blue line), estimated from the statistical model described in section 2.3. Shaded regions represent 95% confidence intervals obtained via a bootstrapping procedure. Red and blue ticks at the x-axis indicate the estimated return level of the event in the 2026 climate and counterfactual climate.*

Tx1x	Observed (°C)	Return period (years)	Change in intensity (°C)	Probability ratio
ERA5	25.61	255 (42.5 to infinity)	**2.20 (0.76 to 4.53)**	**5560 (1.94 to infinity)**
CPC	25.41	25.6 (7.34 to infinity)	**2.93 (0.94 to 5.33)**	**Infinity (2.40 to infinity)**
Met Éireann	27.03	56.3 (11.3 to infinity)	**4.19 (2.36 to 6.11)**	**Infinity (9.04 to infinity)**
EOBS	25.80	60	**1.77 (0.42 to 3.15)**	**13.29 (1.52 to infinity)**

Table 3.1: Summary of fitted model results for Tx1x: event magnitude; return period of 2026 Tx1x in the 2026 climate; change in Tx1x and factor change in likelihood (probability ratio) associated with 1.3°C of global warming. Figures in parenthesis indicate 95% confidence interval obtained via bootstrapping. Statistically significant changes are highlighted in ***bold****.*

3.3 Tx5x - Analysis of 5-day May maximum temperatures

The first column of Figure 3.3 shows the time series for Tx5x in the four gridded data products, with the fitted GMST-dependent trend overlaid. The GMST-dependent trend (black line) shows reasonably good agreement with the nonparametric local regression (Loess) smoother fitted over time (green line), indicating agreement between the fitted model and the temporal trend. All four datasets show a clear upward trend in the average 5-day May maximum temperatures. In ERA5, the event has a current day return period of 48 years (bootstrapped 95% confidence interval (CI): 14, 1040), in CPC, 5 years (95% CI: 3, 220,000), and Met Éireann, 4 years (95% CI: 2, 10). We therefore use a return period of 5 years to represent this event in the full attribution analysis.

The second column of Figure 3.3 shows the fitted linear trend plotted against the GMST covariate, rather than time as above. In ERA5 the maximum 5-day May temperature was found to have warmed by 2.1°C (95% CI: 0.5, 3.5) with respect to the pre-industrial baseline. In CPC, by 3.1°C (95% CI: -0.4, 4.8), in Met Éireann, by 3.7°C (95% CI: 2.8, 5.0), and in EOBS, by 1.9°C (95% CI: 0.7, 3.0).

The third and final column of Figure 3.3 shows the modelled change in return levels associated with a 1.3°C increase in GMST from the pre-industrial to the current climate. In all datasets, there is a clear separation between the return levels in the current climate (red) and the past climate (blue). The best estimate of the probability ratio - that is, the factor change in the probability of such an event occurring - is 68 for ERA5, for 14 CPC, 51 for Met Éireann, and 6 for EOBS. These results, along with the estimated return periods and changes in intensity for all datasets, are summarised in Table 3.2.

Tx5x	**Observed (°C)**	**Return period (years)**	**Change in intensity (°C)**	**Probability ratio**
ERA5	22.47	47.6 (14.2 to 1041)	**2.05 (0.50 to 3.47)**	**67.5 (1.69 to infinity)**
CPC	21.63	5.23 (2.90 to 2.24E+05)	3.09 (-0.38 to 4.82)	13.8 (0.02 to infinity)
Met Éireann	22.11	4.37 (2.30 to 10.38)	**3.70 (2.82 to 4.98)**	**50.7 (4.42 to infinity)**
EOBS	21.03	5	**1.92 (0.73 to 2.99)**	**5.80 (1.93 to 25.3)**

Table 3.2: Summary of fitted model results for Tx5x: event magnitude; return period of 2026 Tx5x in the 2026 climate; change in Tx5x and factor change in likelihood (probability ratio) associated with 1.3°C of global warming. Figures in parenthesis indicate 95% confidence interval obtained via bootstrapping. Statistically significant changes are highlighted in ***bold****.*

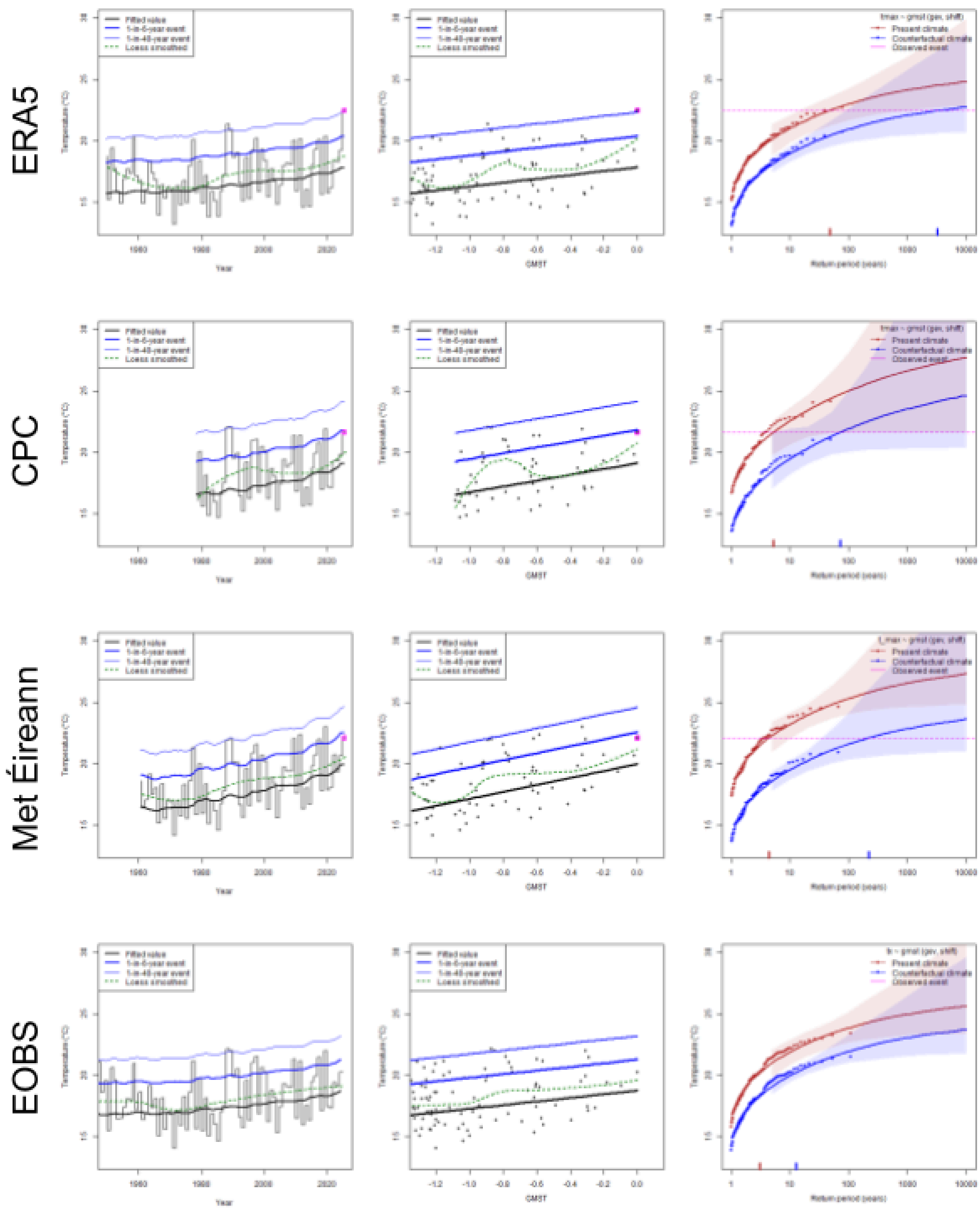


Figure 3.3: All results for Tx5x May over study region. The pink in all graphs marks the 2026 event (not available in EOBS at the time of writing). ***Left:*** *Time series with fitted model overlaid. The heavy black line indicates the mean of the fitted Gaussian model, and the blue lines indicate the expected return levels of 6- and 40-year events. The green line is a nonparametric Loess smoother.* ***Middle:*** *Linear trend as a function of GMST (shown as a difference from the 2026 GMST) in three gridded observational data products. The thick black line denotes the nonstationary location of the fitted Gaussian distribution, and*

the blue lines show estimated 6- and 40-year return levels. The vertical lines represent a bootstrapped 95% confidence interval for the Gaussian location parameter in the 2026 climate (GMST anomaly = 0) and a hypothetical 1.3ºC cooler climate. ***Right:*** *Expected return levels in the 2026 climate (red lines) and in a 1.3°C cooler counterfactual climate (blue line), estimated from the statistical model described in section 2.3. Shaded regions represent 95% confidence intervals obtained via a bootstrapping procedure. Red and blue ticks at the x-axis indicate the estimated return level of the event in the 2026 climate and counterfactual climate.*

3.4 Tn1x - Analysis of 1-day May minimum temperatures

The time series for Tn1x is shown in the first column of Figure 3.4. It shows the four gridded data products, with the fitted GMST-dependent trend overlaid. The GMST-dependent trend (black line) shows a good agreement with the nonparametric local regression (Loess) smoother fitted over time (green line). This indicates a very good agreement between the fitted model and the temporal trend. In addition, a clear upward trend is evident for all four datasets in the average 1-day May high minimum temperatures. In ERA5, the event has a return period of 10 years (bootstrapped 95% confidence interval (CI): 4, 95), in CPC, 2 years (95% CI: 1, 4), and Met Éireann, 3 years (95% CI: 2, 9). We therefore use a present day return period of 3 years to represent this event in the full attribution analysis.

The second column of Figure 3.4 shows the fitted linear trend plotted against the GMST covariate, rather than time as above. In ERA5 the minimum 1-day May temperature was found to have warmed by 1.9°C (95% CI: 1.0, 2.8) with respect to the pre-industrial baseline. In CPC, by 1.4°C (95% CI: -0.1, 2.7), in Met Éireann, by 3°C (95% CI: 2.1, 3.9), and in EOBS, by 2.3°C (95% CI: 1.6, 2.9).

Finally, the third column of Figure 3.4 shows the modelled change in return levels associated with a 1.3°C increase in GMST from the pre-industrial to the current climate. There is a clear separation between the return levels in the current climate (red) and the past climate (blue) for all datasets. The best estimate of the probability ratio - that is, the factor change in the probability of such an event occurring - is infinity for ERA5, for 5.6 CPC, infinity for Met Éireann, and 2700 for EOBS. These results, along with the estimated return periods and changes in intensity for all datasets, are summarised in Table 3.3.

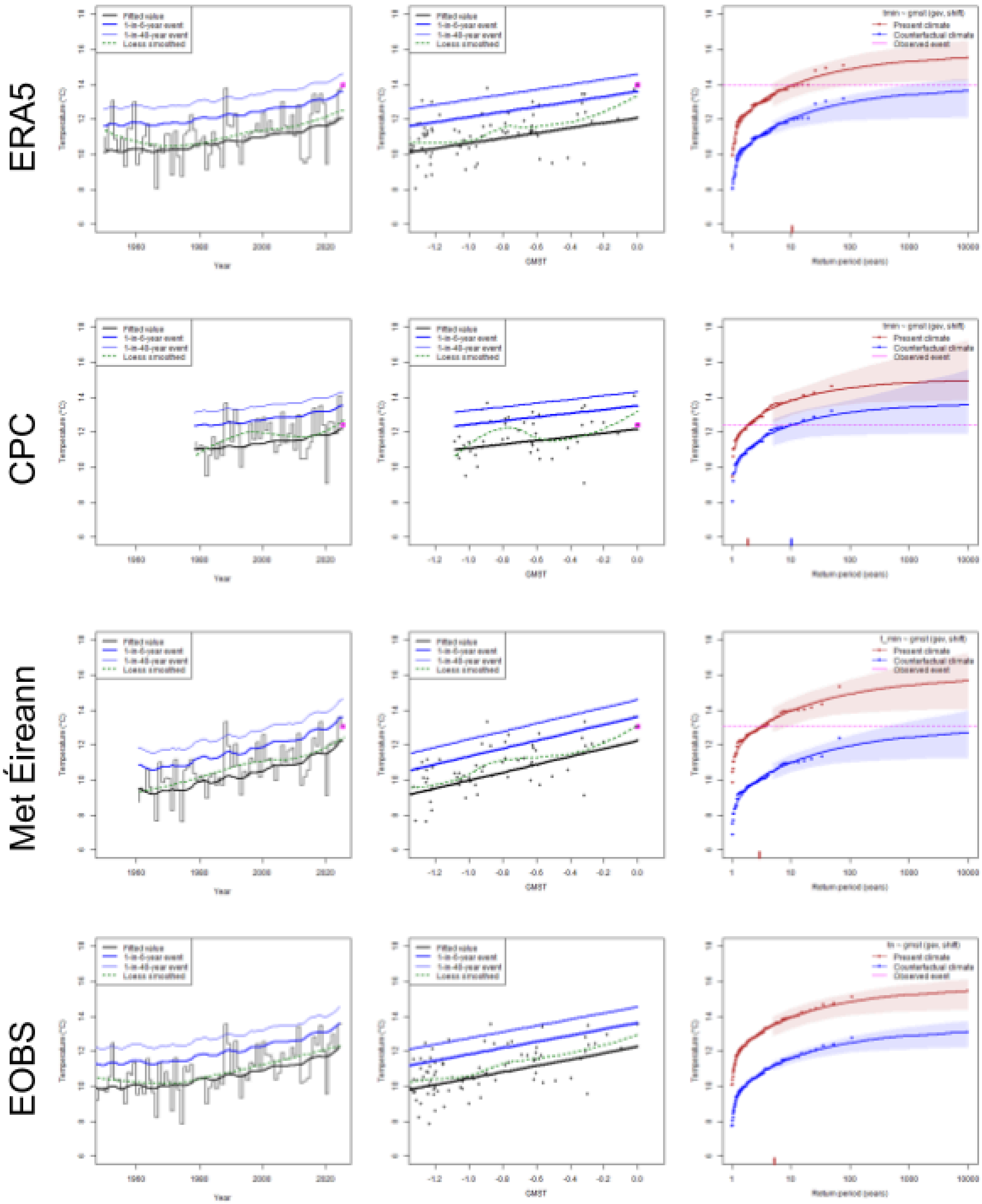


Figure 3.4: All results for Tn1x May over study region. The pink in all graphs marks the 2026 event (not available in EOBS at time of writing). ***Left:*** *Time series with fitted model overlaid. The heavy black line indicates the mean of the fitted Gaussian model, and the blue lines indicate the expected return levels of 6- and 40-year events. The green line is a nonparametric Loess smoother.* ***Middle:*** *Linear trend as a function of GMST (shown as a difference from the 2026 GMST) in three gridded observational data products. The thick black line denotes the nonstationary location of the fitted Gaussian distribution, and*

the blue lines show estimated 6- and 40-year return levels. The vertical lines represent a bootstrapped 95% confidence interval for the Gaussian location parameter in the 2026 climate (GMST anomaly = 0) and a hypothetical 1.3ºC cooler climate. ***Right:*** *Expected return levels in the 2026 climate (red lines) and in a 1.3°C cooler counterfactual climate (blue line), estimated from the statistical model described in section 2.3. Shaded regions represent 95% confidence intervals obtained via a bootstrapping procedure. Red and blue ticks at the x-axis indicate the estimated return level of the event in the 2026 climate and counterfactual climate.*

Tn1x	Observed (°C)	Return period (years)	Change in intensity (°C)	Probability ratio
ERA5	13.95	10.43 (4.31 to 94.9)	**1.90 (0.99 to 2.76)**	**Infinity (52.3 to infinity)**
CPC	12.40	1.82 (1.22 to 4.14)	1.40 (-0.12 to 2.65)	5.60 (0.87 to infinity)
Met Éireann	13.04	2.93 (1.74 to 8.60)	**2.97 (2.08 to 3.92)**	**Infinity (123 to infinity)**
EOBS	13.07	3	**2.34 (1.62 to 2.91)**	**2706 (48.6 to infinity)**

Table 3.3: Summary of fitted model results for Tn1x: event magnitude; return period of 2026 Tn1x in the 2026 climate; change in Tn1x and factor change in likelihood (probability ratio) associated with 1.3°C of global warming. Figures in parenthesis indicate 95% confidence interval obtained via bootstrapping. Statistically significant changes are highlighted in ***bold****.*

4 Model evaluation

In the subsections below we show the results of the model evaluation. The climate models are evaluated against the observations in their ability to capture:

1. Seasonal cycles: For this, we qualitatively compare the seasonal cycles in model outputs against observations-based cycles. We discard the models that exhibit ill-defined peaks in their seasonal cycles.
2. Spatial patterns: Models that do not match the observations in terms of the large-scale temperature patterns are excluded.
3. Parameters of the fitted statistical models: The estimated parameters must lie within the equivalent observational parameter uncertainty range (good), or their uncertainty ranges must overlap (reasonable).

The models are labelled as ‘good’, ‘reasonable’, or ‘bad’ based on their performances in terms of the three criteria discussed above. A model is given an overall rating of ‘good’ if it is rated ‘good’ for all characteristics. If there is at least one ‘reasonable’ the overall rating is ‘reasonable’, and if there is at least one ‘bad’ the overall rating is ‘bad’. Only models that are labelled as ‘good’ overall are used in the final analysis.

Tables showing how the respective models chosen are shown in Tables A.1, A.2 and A.3 in the appendix. Visuals for choosing the seasonal cycles and spatial patterns are shown in Figures A.1 - A.8 respectively.

5 Multi-method multi-model attribution

For models that pass the evaluation in section 4, we repeat the statistical analysis and estimate the change in intensity and probability ratio for an event that, in the climate of 2026, has the return periods given in section 3. These results will be synthesised with the results from the observational data products in section 6. Tables 5.1, 5.2 and 5.3 below show the probability ratios and changes in intensity ΔI for models that passed model evaluation, alongside those from observational data products. This is calculated for both past to present and present to future.

Tx1x		**Preindustrial - Present (1.3˚C)**		**Present - Future (1.5˚C)**		**Present - Future (2.0˚C)**		**Present - Future (3.0˚C)**	
Model / Observations	**Threshold for return period 60- yr**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**
CPC	25.41˚C	infinity(2.4…infinity)	2.93 (0.94…5.33)						
eobs	25.8˚C	13.29 (1.52…infinity)	1.77 (0.42…3.15)						
era5	25.61˚C	5560.92 (1.94…infinity)	2.2 (0.76…4.53)						
me	27.03˚C	infinity(9.04…infinity)	4.19 (2.36…6.11)						
EC-EARTH_r1_COSMO-crCLIM-v1-1	23.65˚C	infinity(Inf…infinity)	2.35 (1.56…3.1)	1.16 (1.05…1.5)	0.11 (0.04…0.15)	1.62 (1.19…3.12)	0.4 (0.14…0.52)	2.98 (1.5…7.79)	0.97 (0.33…1.26)
EC-EARTH_r12_CCLM4-8-17	23.75˚C	11.25 (1.79…infinity)	1.26 (0.35…3.22)	1.16 (1.1…1.29)	0.12 (0.08…0.18)	1.62 (1.37…2.27)	0.4 (0.28…0.64)	2.93 (2.06…5.54)	0.98 (0.67…1.55)
EC-EARTH_r12_COSMO-crCLIM-v1-1	22.23˚C	infinity(Inf…infinity)	1.51 (0.28…2.91)	1.24 (1.23…1.53)	0.16 (0.13…0.23)	2.04 (1.98…3.36)	0.55 (0.44…0.8)	4.67 (4.44…9.11)	1.34 (1.07…1.94)
EC-EARTH_r12_HadREM3-GA7-05	21.42˚C	infinity(Inf…infinity)	1.92 (1.6…2.36)	1.28 (1.12…1.55)	0.23 (0.15…0.3)	2.25 (1.47…3.79)	0.8 (0.52…1.06)	5.99 (2.52…13.31)	1.94 (1.26…2.56)
EC-EARTH_r12_RegCM4-6	20.46˚C	0.37 (0.18…0.56)	-0.64 (-1.39…-0.42)	1.08 (1.06…1.09)	0.12 (0.08…0.15)	1.3 (1.22…1.33)	0.43 (0.29…0.51)	1.88 (1.63…2.01)	1.03 (0.7…1.24)

EC-EARTH_r12_REMO2015	22.46˚C	6.11 (1.88…infinity)	0.47 (0.33…1.31)	1.22 (1.16…1.27)	0.16 (0.15…0.19)	1.93 (1.63…2.19)	0.54 (0.51…0.65)	4.22 (3.08…5.38)	1.32 (1.24…1.58)
EC-EARTH_r12_WRF381P	23.88˚C	2.6 (2.22…3492.07)	0.94 (0.64…2.33)	1.1 (1.11…1.19)	0.11 (0.1…0.15)	1.38 (1.42…1.75)	0.4 (0.36…0.51)	2.14 (2.29…3.36)	0.96 (0.87…1.24)
EC-EARTH_r3_COSMO-crCLIM-v1-1	21.7˚C	0.96 (1.12…infinity)	-0.01 (0.04…1)	1.17 (1.1…1.27)	0.11 (0.08…0.14)	1.67 (1.39…2.13)	0.39 (0.27…0.51)	3.16 (2.13…4.83)	0.94 (0.65…1.23)
HadGEM2-ES_r1_ALADIN63	23.71˚C	1.42 (0.57…10.04)	0.28 (-0.85…0.94)	1.14 (1.11…1.28)	0.09 (0.09…0.13)	1.56 (1.44…2.21)	0.33 (0.31…0.46)	2.73 (2.31…5.15)	0.8 (0.75…1.12)
HadGEM2-ES_r1_HadREM3-GA7-05	25.19˚C	3.47 (1.5…90.76)	1.06 (0.23…1.45)	1.12 (1.1…1.19)	0.14 (0.13…0.15)	1.48 (1.41…1.77)	0.5 (0.46…0.54)	2.5 (2.25…3.54)	1.21 (1.11…1.31)
HadGEM2-ES_r1_HIRHAM5	24.82˚C	3.32 (0.67…10.88)	0.66 (-0.43…1.23)	1.17 (1.14…1.4)	0.13 (0.11…0.2)	1.7 (1.54…2.81)	0.45 (0.39…0.71)	3.21 (2.66…7.63)	1.09 (0.95…1.72)
HadGEM2-ES_r1_RACMO22E	25.17˚C	1.28 (0.93…3.7)	0.36 (-0.09…1.45)	1.07 (1.05…1.15)	0.08 (0.06…0.11)	1.25 (1.18…1.6)	0.29 (0.21…0.38)	1.69 (1.49…2.86)	0.71 (0.52…0.92)
HadGEM2-ES_r1_RCA4	22.53˚C	1.38 (0.61…3.32)	0.21 (-0.38…0.47)	1.08 (1.02…1.19)	0.06 (0.02…0.11)	1.32 (1.08…1.77)	0.2 (0.06…0.4)	1.9 (1.21…3.44)	0.49 (0.15…0.97)
HadGEM2-ES_r1_WRF361H	24.48˚C	0.73 (0.32…1.59)	-0.34 (-1.54…0.19)	1.06 (1.01…1.12)	0.06 (0.02…0.11)	1.22 (1.05…1.46)	0.22 (0.07…0.4)	1.59 (1.12…2.4)	0.52 (0.18…0.97)
HadGEM2-ES_r1_WRF381P	24.18˚C	0.53 (0.03…1.97)	-0.55 (-3.17…0.35)	1.07 (0.95…1.25)	0.05 (-0.03…0.15)	1.27 (0.84…2.03)	0.17 (-0.11…0.53)	1.73 (0.62…4.38)	0.42 (-0.26…1.28)
MPI-ESM-LR_r1_COSMO-crCLIM-v1-1	23.95˚C	1.16 (0.52…3.46)	0.1 (-0.46…1.13)	1.09 (1.04…1.22)	0.06 (0.03…0.16)	1.33 (1.16…1.92)	0.19 (0.11…0.56)	1.94 (1.42…4.1)	0.47 (0.26…1.36)
MPI-ESM-LR_r1_HadREM3-GA7-05	25.01˚C	3.91 (1.4…infinity)	1.45 (0.42…2.38)	1.17 (1.1…1.36)	0.17 (0.13…0.21)	1.71 (1.37…2.67)	0.59 (0.47…0.72)	3.41 (2.13…7.5)	1.44 (1.13…1.75)
MPI-ESM-LR_r2_REMO2009	23.73˚C	0.62 (0.3…0.74)	-0.56 (-1.66…-0.54)	1.13 (1.08…1.2)	0.12 (0.08…0.14)	1.52 (1.3…1.82)	0.43 (0.29…0.49)	2.63 (1.87…3.72)	1.04 (0.7…1.18)
MPI-ESM-LR_r3_COSMO-crCLIM-v1-1	23.77˚C	1.8 (0.71…3.83)	0.46 (-0.37…0.64)	1.18 (1.1…1.27)	0.15 (0.1…0.21)	1.75 (1.37…2.18)	0.54 (0.36…0.74)	3.56 (2.09…5.51)	1.31 (0.88…1.81)
MPI-ESM-LR_r3_REMO2015	24.13˚C	3.45 (0.63…12.19)	0.69 (-0.35…2.55)	1.11 (1.05…1.15)	0.12 (0.07…0.14)	1.44 (1.19…1.6)	0.44 (0.26…0.48)	2.35 (1.5…2.85)	1.06 (0.63…1.18)
NorESM1-M_r1_REMO2015	23.87˚C	666.14 (4.25…infinity)	1.68 (0.72…3.79)	1.17 (1.1…1.17)	0.14 (0.1…0.13)	1.72 (1.38…1.71)	0.48 (0.36…0.45)	3.45 (2.16…3.36)	1.16 (0.88…1.1)

CMCC-ESM2_r1i1p1f1_gn	24.19˚C	12.28 (2.46…26.79)	1.5 (0.64…2.06)	1.29 (1.22…1.28)	0.22 (0.17…0.23)	2.29 (1.96…2.21)	0.78 (0.6…0.82)	6 (4.53…5.45)	1.89 (1.46…1.99)
CNRM-CM6-1_r1i1p1f2_gr	24.84˚C	3.18 (2.04…4.84)	1.22 (0.66…1.83)	1.13 (1.08…1.15)	0.14 (0.08…0.16)	1.52 (1.31…1.63)	0.48 (0.28…0.57)	2.63 (1.89…3.04)	1.16 (0.69…1.39)
EC-Earth3-Veg-LR_r1i1p1f1_gr	21.69˚C	2.1 (1.29…2.26)	0.91 (0.33…1.26)	1.12 (1.06…1.15)	0.14 (0.08…0.15)	1.48 (1.23…1.62)	0.48 (0.28…0.52)	2.54 (1.64…3.08)	1.18 (0.67…1.26)
KACE-1-0-G_r1i1p1f1_gr	25.26˚C	2.92 (3.14…5.13)	1.74 (1.66…2.28)	1.18 (1.16…1.27)	0.22 (0.19…0.27)	1.78 (1.65…2.25)	0.77 (0.67…0.95)	3.74 (3.2…6.1)	1.87 (1.62…2.3)
MRI-ESM2-0_r1i1p1f1_gn	24.22˚C	2.47 (0.6…3.37)	0.69 (-0.36…0.91)	1.13 (1.03…1.18)	0.09 (0.02…0.1)	1.51 (1.11…1.72)	0.32 (0.08…0.36)	2.52 (1.27…3.23)	0.77 (0.2…0.88)
NorESM2-MM_r1i1p1f1_gn	26.84˚C	2.06 (2.18…6.67)	1.09 (1…3.12)	1.29 (1.26…1.43)	0.3 (0.29…0.42)	2.33 (2.22…3.16)	1.04 (1.02…1.48)	6.43 (6.72…11.17)	2.54 (2.49…3.59)

Table 5.1: Event magnitude, probability ratio and change in intensity for 60-year return period for Tx1x for observational datasets and each model that passed the evaluation tests. (a) from pre-industrial climate to the present, (b) from the present to 1.5°C above pre-industrial climate (c) from the present to 2.0°C above pre-industrial climate, and (d) from the present to 3.0°C above pre-industrial climate.

Tx5x		**Preindustrial - Present (1.3˚C)**		**Present - Future (1.5˚C)**		**Present - Future (2.0˚C)**		**Present - Future (3.0˚C)**	
Model / Observations	**Threshold for return period 5 yr**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**
CPC	21.63˚C	13.77 (0.02…infinity)	3.09 (-0.38…4.82)						
eobs	21.03˚C	5.8 (1.93…25.34)	1.92 (0.73…2.99)						
era5	22.47˚C	67.47 (1.69…infinity)	2.05 (0.5…3.47)						
me	22.11˚C	50.69 (4.42…infinity)	3.7 (2.28…4.98)						
EC-EARTH_r1_COSMO-crCLIM-v1-1	20.02˚C	14.69 (4.62…infinity)	2.53 (1.58…3.51)	1.07 (1.03…1.13)	0.11 (0.05…0.15)	1.27 (1.11…1.48)	0.38 (0.16…0.53)	1.71 (1.29…2.24)	0.93 (0.39…1.28)

EC-EARTH_r12_CCLM4-8-17	19.31˚C	2.34 (1.55…7.18)	1.21 (0.64…2.36)	1.04 (1.01…1.09)	0.07 (0.03…0.15)	1.13 (1.05…1.35)	0.24 (0.1…0.54)	1.34 (1.13…1.93)	0.58 (0.23…1.31)
EC-EARTH_r12_COSMO-crCLIM-v1-1	19.02˚C	4.36 (1.79…42.66)	1.47 (0.6…2.86)	1.1 (1.07…1.16)	0.15 (0.1…0.23)	1.38 (1.24…1.62)	0.52 (0.34…0.8)	2.02 (1.65…2.72)	1.27 (0.83…1.95)
EC-EARTH_r12_HadREM3-GA7-05	18.38˚C	8.96 (4…201.15)	1.98 (1.51…2.6)	1.14 (1.1…1.19)	0.22 (0.16…0.26)	1.57 (1.39…1.74)	0.76 (0.54…0.91)	2.66 (2.16…3.05)	1.83 (1.32…2.22)
EC-EARTH_r12_RegCM4-6	17.18˚C	1.02 (0.59…1.24)	0.02 (-0.64…0.21)	1.07 (1.05…1.09)	0.11 (0.07…0.15)	1.27 (1.18…1.35)	0.39 (0.26…0.51)	1.76 (1.5…2.04)	0.94 (0.63…1.24)
EC-EARTH_r12_REMO2015	19.66˚C	3.01 (2.76…19.85)	1.3 (1.25…1.98)	1.08 (1.08…1.12)	0.14 (0.14…0.19)	1.31 (1.3…1.45)	0.48 (0.48…0.66)	1.85 (1.85…2.26)	1.17 (1.17…1.59)
EC-EARTH_r12_WRF381P	18.8˚C	2.55 (2.03…9.44)	1.19 (1.03…2.27)	1.08 (1.08…1.1)	0.13 (0.14…0.16)	1.3 (1.29…1.4)	0.47 (0.48…0.57)	1.82 (1.82…2.11)	1.13 (1.16…1.37)
EC-EARTH_r3_COSMO-crCLIM-v1-1	18.02˚C	0.77 (0.82…1.91)	-0.41 (-0.29…0.86)	1.07 (1.05…1.09)	0.1 (0.07…0.13)	1.25 (1.17…1.35)	0.36 (0.26…0.45)	1.67 (1.45…1.98)	0.86 (0.63…1.1)
HadGEM2-ES_r1_ALADIN63	19.24˚C	1.03 (0.73…1.84)	0.04 (-0.56…0.78)	1.05 (1.05…1.07)	0.07 (0.07…0.09)	1.19 (1.17…1.24)	0.25 (0.23…0.31)	1.49 (1.44…1.63)	0.61 (0.57…0.75)
HadGEM2-ES_r1_HadREM3-GA7-05	20.08˚C	1.7 (1.14…4.2)	0.82 (0.14…1.47)	1.08 (1.08…1.1)	0.13 (0.12…0.16)	1.29 (1.28…1.37)	0.47 (0.41…0.55)	1.78 (1.75…2.03)	1.15 (0.98…1.33)
HadGEM2-ES_r1_HIRHAM5	20.33˚C	1.56 (0.79…3.68)	0.64 (-0.41…1.68)	1.08 (1.07…1.15)	0.14 (0.13…0.22)	1.3 (1.27…1.57)	0.48 (0.44…0.77)	1.8 (1.72…2.55)	1.17 (1.06…1.88)
HadGEM2-ES_r1_RACMO22E	19.24˚C	1.33 (0.73…1.92)	0.49 (-0.5…0.96)	1.03 (1.02…1.05)	0.05 (0.04…0.09)	1.11 (1.08…1.2)	0.19 (0.14…0.3)	1.28 (1.2…1.52)	0.46 (0.35…0.73)
HadGEM2-ES_r1_RCA4	18.41˚C	0.91 (0.67…1.53)	-0.12 (-0.62…0.54)	1.04 (1…1.08)	0.05 (0…0.11)	1.13 (0.99…1.28)	0.18 (-0.01…0.37)	1.33 (0.98…1.73)	0.45 (-0.03…0.9)
HadGEM2-ES_r1_WRF361H	18.88˚C	1.06 (0.49…1.79)	0.11 (-1.24…1.08)	1.04 (1.01…1.05)	0.07 (0.02…0.09)	1.14 (1.03…1.17)	0.24 (0.07…0.31)	1.38 (1.08…1.45)	0.59 (0.16…0.76)
HadGEM2-ES_r1_WRF381P	19.53˚C	0.78 (0.5…1.59)	-0.46 (-1.38…0.72)	1.03 (1…1.07)	0.05 (0…0.13)	1.11 (1…1.27)	0.19 (-0.01…0.45)	1.28 (0.99…1.73)	0.46 (-0.01…1.1)
MPI-ESM-LR_r1_ALADIN63	19.14˚C	1.76 (1.73…8.55)	0.92 (0.98…2.52)	1.04 (1.01…1.07)	0.08 (0.02…0.11)	1.15 (1.03…1.25)	0.26 (0.06…0.37)	1.4 (1.08…1.66)	0.64 (0.15…0.9)
MPI-ESM-LR_r1_COSMO-crCLIM-v1-1	19.58˚C	1.17 (1.04…1.75)	0.22 (0.05…0.79)	1.03 (1…1.09)	0.05 (0.01…0.11)	1.11 (1.02…1.31)	0.16 (0.03…0.38)	1.28 (1.04…1.81)	0.39 (0.07…0.92)

MPI-ESM-LR_r1_HadREM3-GA7-05	19.54˚C	2.67 (1.25…10.76)	1.22 (0.29…2.02)	1.1 (1.06…1.16)	0.13 (0.08…0.19)	1.36 (1.2…1.61)	0.46 (0.27…0.65)	1.98 (1.53…2.63)	1.11 (0.67…1.57)
MPI-ESM-LR_r2_REMO2009	18.6˚C	0.86 (0.69…0.93)	-0.26 (-0.76…-0.1)	1.08 (1.05…1.09)	0.14 (0.1…0.15)	1.29 (1.2…1.36)	0.48 (0.35…0.53)	1.8 (1.54…2.01)	1.16 (0.86…1.29)
MPI-ESM-LR_r3_COSMO-crCLIM-v1-1	19.2˚C	1.69 (0.95…2.84)	0.65 (-0.08…1.45)	1.1 (1.08…1.16)	0.14 (0.12…0.2)	1.36 (1.3…1.6)	0.48 (0.43…0.71)	2 (1.84…2.69)	1.17 (1.05…1.74)
MPI-ESM-LR_r3_REMO2015	19.77˚C	1.86 (1.07…7.18)	0.79 (0.1…2.31)	1.08 (1.04…1.08)	0.13 (0.08…0.13)	1.28 (1.16…1.28)	0.44 (0.27…0.47)	1.75 (1.41…1.76)	1.07 (0.66…1.14)
NorESM1-M_r1_COSMO-crCLIM-v1-1	19.96˚C	2.88 (1.25…7.31)	1.32 (0.32…2.24)	1.07 (1.04…1.08)	0.1 (0.07…0.13)	1.25 (1.15…1.32)	0.36 (0.26…0.47)	1.68 (1.4…1.88)	0.88 (0.63…1.14)
NorESM1-M_r1_HadREM3-GA7-05	19.46˚C	4.76 (3.67…17.24)	1.83 (1.52…3.26)	1.15 (1.12…1.18)	0.2 (0.18…0.21)	1.6 (1.49…1.71)	0.68 (0.61…0.74)	2.77 (2.45…3.05)	1.66 (1.49…1.8)
NorESM1-M_r1_REMO2015	20.58˚C	5.64 (1.89…192.48)	2.07 (0.84…3.51)	1.08 (1.06…1.08)	0.14 (0.11…0.12)	1.32 (1.23…1.28)	0.48 (0.39…0.43)	1.89 (1.64…1.8)	1.18 (0.94…1.05)
AWI-CM-1-1-MR_r1i1p1f1_gn	17.94˚C	1.97 (1.35…2.36)	0.96 (0.44…1.15)	1.14 (1.13…1.18)	0.2 (0.18…0.24)	1.57 (1.49…1.72)	0.71 (0.62…0.84)	2.66 (2.4…3.02)	1.73 (1.5…2.03)
CMCC-ESM2_r1i1p1f1_gn	19.41˚C	2.23 (1.23…3.53)	1.14 (0.3…1.76)	1.12 (1.1…1.11)	0.18 (0.14…0.18)	1.45 (1.38…1.44)	0.62 (0.49…0.63)	2.27 (2.07…2.26)	1.5 (1.19…1.52)
CNRM-CM6-1_r1i1p1f2_gr	18.84˚C	1.79 (1.14…2.61)	0.93 (0.19…1.48)	1.07 (1.05…1.08)	0.12 (0.07…0.14)	1.26 (1.16…1.31)	0.43 (0.25…0.49)	1.72 (1.42…1.84)	1.04 (0.61…1.19)
KACE-1-0-G_r1i1p1f1_gr	18.73˚C	2.64 (2.58…4.89)	1.47 (1.55…2.17)	1.13 (1.13…1.17)	0.21 (0.18…0.25)	1.51 (1.49…1.66)	0.74 (0.62…0.89)	2.44 (2.35…2.92)	1.79 (1.5…2.16)
MRI-ESM2-0_r1i1p1f1_gn	19.19˚C	1.24 (0.74…1.7)	0.34 (-0.5…0.77)	1.05 (1…1.05)	0.07 (0.01…0.08)	1.17 (1.01…1.2)	0.25 (0.02…0.3)	1.45 (1.02…1.52)	0.62 (0.04…0.72)
NorESM2-MM_r1i1p1f1_gn	20.99˚C	2.23 (2.52…5.42)	1.38 (1.48…2.92)	1.16 (1.16…1.23)	0.28 (0.27…0.38)	1.64 (1.63…1.94)	0.96 (0.94…1.33)	2.83 (2.77…3.77)	2.34 (2.28…3.23)

Table 5.2: Event magnitude, probability ratio and change in intensity for 5-year return period for Tx5x for observational datasets and each model that passed the evaluation tests. (a) from pre-industrial climate to the present, (b) from the present to 1.5°C above pre-industrial climate (c) from the present to 2.0°C above pre-industrial climate, and (d) from the present to 3.0°C above pre-industrial climate.

Tn1x		Preindustrial - Present (1.3˚C)		Present - Future (2.0˚C)		Present - Future (2.0˚C)		Present - Future (3.0˚C)	
Model / Observations	**Threshold for return period 3 yr**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**	**Probability ratio PR [-]**	**Change in intensity ΔI [%]**
CPC	12.4˚C	5.6 (0.87…infinity)	1.4 (-0.12…2.65)						
eobs	13.07˚C	2705.62 (48.62…infinity)	2.34 (1.62…2.91)						
era5	13.95˚C	infinity(52.27…infinity)	1.9 (0.99…2.76)						
me	13.04˚C	infinity(123.29…infinity)	2.97 (2.08…3.92)						
CanESM2_r1_REMO2015	13.2˚C	4.06 (3.19…6.74)	1.34 (1.12…1.73)	1.08 (1.08…1.1)	0.11 (0.1…0.13)	1.31 (1.29…1.37)	0.38 (0.35…0.46)	1.78 (1.72…1.93)	0.92 (0.84…1.12)
CNRM-CM5_r1_HIRHAM5	11˚C	2.38 (1.79…11.06)	0.89 (0.69…2.02)	1.1 (1.1…1.12)	0.14 (0.13…0.17)	1.38 (1.36…1.45)	0.5 (0.46…0.58)	1.98 (1.94…2.12)	1.22 (1.12…1.41)
CNRM-CM5_r1_REMO2015	10.54˚C	3.62 (1.8…7.87)	1.39 (0.65…2.13)	1.07 (1.04…1.13)	0.09 (0.05…0.17)	1.25 (1.14…1.48)	0.31 (0.18…0.58)	1.64 (1.37…2.17)	0.76 (0.43…1.42)
EC-EARTH_r1_COSMO-crCLIM-v1-1	12.55˚C	17.3 (2.93…86.38)	2.12 (0.95…2.45)	1.13 (1.09…1.15)	0.16 (0.11…0.16)	1.48 (1.32…1.55)	0.57 (0.38…0.56)	2.17 (1.82…2.34)	1.37 (0.91…1.37)
EC-EARTH_r1_HIRHAM5	12.05˚C	3.66 (2.99…14.14)	1.35 (1.1…2.31)	1.11 (1.11…1.14)	0.13 (0.12…0.14)	1.41 (1.41…1.53)	0.44 (0.41…0.51)	2.06 (2.06…2.34)	1.07 (1…1.23)
EC-EARTH_r12_CCLM4-8-17	11.68˚C	6 (2.53…24.15)	1.54 (0.88…2.18)	1.13 (1.12…1.15)	0.16 (0.14…0.17)	1.48 (1.44…1.55)	0.56 (0.5…0.6)	2.16 (2.09…2.3)	1.35 (1.2…1.45)
EC-EARTH_r12_COSMO-crCLIM-v1-1	11.44˚C	2.96 (1.42…10.76)	0.95 (0.36…1.61)	1.15 (1.11…1.19)	0.19 (0.15…0.21)	1.54 (1.41…1.7)	0.66 (0.52…0.75)	2.32 (2.06…2.57)	1.61 (1.26…1.83)
EC-EARTH_r12_HIRHAM5	11.53˚C	6.09 (6.18…17.77)	1.2 (1.27…1.83)	1.14 (1.13…1.16)	0.14 (0.13…0.15)	1.51 (1.47…1.62)	0.5 (0.46…0.54)	2.24 (2.16…2.51)	1.2 (1.11…1.31)
EC-EARTH_r12_REMO2015	11˚C	3.22 (1.35…5.5)	0.94 (0.23…1.47)	1.15 (1.15…1.2)	0.17 (0.16…0.22)	1.58 (1.55…1.74)	0.58 (0.55…0.76)	2.42 (2.35…2.62)	1.41 (1.33…1.85)

EC-EARTH_r3_COSMO-crCLIM-v1-1	11.42˚C	1.6 (2.3…3.23)	0.44 (0.64…0.94)	1.1 (1.09…1.13)	0.12 (0.1…0.16)	1.36 (1.32…1.47)	0.42 (0.35…0.57)	1.9 (1.8…2.12)	1.01 (0.86…1.39)
EC-EARTH_r3_HIRHAM5	11.96˚C	5.48 (5.56…261.72)	1.55 (1.48…2.34)	1.14 (1.14…1.22)	0.15 (0.14…0.19)	1.54 (1.54…1.8)	0.53 (0.5…0.67)	2.36 (2.4…2.71)	1.29 (1.22…1.63)
HadGEM2-ES_r1_RCA4	12.63˚C	3 (2.86…6.74)	1.01 (0.98…1.35)	1.08 (1.07…1.14)	0.12 (0.11…0.18)	1.29 (1.26…1.49)	0.43 (0.39…0.64)	1.73 (1.65…2.17)	1.04 (0.94…1.55)
MIROC5_r1_CCLM4-8-17	12.98˚C	13.85 (2.52…11.77)	1.49 (0.68…1.44)	1.14 (1.12…1.2)	0.18 (0.14…0.23)	1.52 (1.45…1.73)	0.62 (0.48…0.8)	2.28 (2.1…2.64)	1.5 (1.16…1.95)
MIROC5_r1_REMO2015	12.44˚C	3.77 (1.47…infinity)	1.04 (0.36…1.98)	1.11 (1.09…1.12)	0.16 (0.13…0.17)	1.43 (1.35…1.45)	0.56 (0.44…0.61)	2.12 (1.95…2.18)	1.36 (1.08…1.48)
MPI-ESM-LR_r1_CCLM4-8-17	12.58˚C	3.25 (2.62…5.4)	1.18 (0.96…1.53)	1.09 (1.08…1.13)	0.11 (0.1…0.14)	1.34 (1.31…1.46)	0.39 (0.36…0.5)	1.85 (1.79…2.12)	0.94 (0.88…1.22)
MPI-ESM-LR_r1_COSMO-crCLIM-v1-1	13.19˚C	2.37 (2.4…4.42)	1.02 (0.93…1.79)	1.05 (1.03…1.08)	0.07 (0.03…0.1)	1.18 (1.1…1.29)	0.23 (0.12…0.36)	1.47 (1.24…1.73)	0.57 (0.3…0.88)
MPI-ESM-LR_r1_RACMO22E	11.67˚C	4.87 (1.8…19.42)	1.25 (0.6…1.71)	1.1 (1.07…1.13)	0.11 (0.09…0.13)	1.36 (1.27…1.46)	0.39 (0.31…0.46)	1.9 (1.68…2.14)	0.95 (0.74…1.12)
MPI-ESM-LR_r1_RCA4	11.52˚C	1.22 (0.82…2.33)	0.2 (-0.24…0.63)	1.04 (1…1.06)	0.04 (0…0.06)	1.12 (1…1.2)	0.13 (0…0.22)	1.31 (1.01…1.5)	0.32 (0.01…0.55)
MPI-ESM-LR_r1_RegCM4-6	11.35˚C	1.61 (0.75…6.88)	0.4 (-0.36…0.71)	1.07 (1.05…1.1)	0.07 (0.05…0.1)	1.25 (1.19…1.36)	0.25 (0.19…0.34)	1.62 (1.48…1.85)	0.6 (0.46…0.83)
MPI-ESM-LR_r1_REMO2009	12.23˚C	1.97 (1.47…6.66)	0.71 (0.44…1.22)	1.07 (1.05…1.1)	0.08 (0.06…0.12)	1.24 (1.2…1.37)	0.28 (0.22…0.42)	1.62 (1.51…1.95)	0.67 (0.53…1.02)
MPI-ESM-LR_r2_RCA4	11.27˚C	1.14 (0.43…1.17)	0.15 (-1.67…0.17)	1.11 (1.1…1.14)	0.13 (0.13…0.17)	1.39 (1.37…1.51)	0.46 (0.46…0.59)	1.97 (1.91…2.21)	1.11 (1.11…1.43)
MPI-ESM-LR_r3_COSMO-crCLIM-v1-1	12.99˚C	3.22 (2.99…4.74)	1.07 (0.89…1.49)	1.1 (1.08…1.14)	0.12 (0.1…0.18)	1.37 (1.3…1.52)	0.44 (0.36…0.62)	1.93 (1.74…2.24)	1.06 (0.88…1.52)
NorESM1-M_r1_COSMO-crCLIM-v1-1	12.76˚C	1.12 (0.77…1.56)	0.12 (-0.33…0.41)	1.1 (1.07…1.1)	0.1 (0.08…0.11)	1.34 (1.25…1.36)	0.36 (0.28…0.4)	1.84 (1.63…1.88)	0.88 (0.68…0.96)
NorESM1-M_r1_HadREM3-GA7-05	12.15˚C	2.14 (1.27…4)	0.77 (0.28…1.24)	1.14 (1.11…1.16)	0.16 (0.13…0.19)	1.51 (1.4…1.6)	0.55 (0.45…0.65)	2.23 (1.99…2.4)	1.34 (1.1…1.58)
NorESM1-M_r1_RACMO22E	10.91˚C	0.92 (0.59…1.02)	-0.1 (-0.73…0.03)	1.13 (1.11…1.14)	0.14 (0.13…0.16)	1.48 (1.42…1.51)	0.51 (0.47…0.56)	2.18 (2.04…2.22)	1.23 (1.13…1.35)

CMCC-ESM2_r1i1p1f1_gn	12.13˚C	1.97 (1.22…3.73)	0.79 (0.25…1.21)	1.09 (1.08…1.11)	0.12 (0.09…0.15)	1.34 (1.28…1.42)	0.42 (0.31…0.54)	1.86 (1.69…2.05)	1.01 (0.76…1.3)
CNRM-CM6-1-HR_r1i1p1f2_gr	11.18˚C	4.45 (3.7…8.93)	1.32 (1.15…1.77)	1.16 (1.16…1.16)	0.18 (0.16…0.18)	1.59 (1.58…1.62)	0.62 (0.56…0.65)	2.44 (2.38…2.51)	1.5 (1.35…1.57)
GFDL-ESM4_r1i1p1f1_gr1	12.25˚C	2.81 (2.41…7.14)	0.95 (0.87…1.7)	1.07 (1.06…1.1)	0.08 (0.07…0.12)	1.26 (1.23…1.38)	0.28 (0.23…0.41)	1.66 (1.59…1.97)	0.67 (0.56…1)

Table 5.3: Event magnitude, probability ratio and change in intensity for 3-year return period for Tn1x for observational datasets and each model that passed the evaluation tests. (a) from pre-industrial climate to the present, (b) from the present to 1.5°C above pre-industrial climate (c) from the present to 2.0°C above pre-industrial climate, and (d) from the present to 3.0°C above pre-industrial climate.

6 Hazard synthesis

For each event definition we evaluate the influence of anthropogenic climate change on the event by calculating the probability ratio as well as the change in intensity using observations and climate models. Models which do not pass the evaluation described in section 4 are excluded from the analysis. The aim is to synthesise results from models that pass the evaluation, along with the observation-based products, to give an overarching attribution statement. Results are synthesised using the algorithm described in detail in Otto et al., (2024).

Figures 6.1 - 6.6 show the changes in likelihood and intensity for the observations (blue) and models (red). Before combining them into a synthesised assessment, first, a representation error is added (in quadrature) to the observations, to account for the difference between observations-based datasets that cannot be explained by natural variability. This is shown in these figures as white boxes around the light blue bars. The dark blue bar shows the average over the observation-based products. Next, a term to account for intermodel spread is added (in quadrature) to the natural variability of the models. This is shown in the figures as white boxes around the light red bars. The dark red bar shows the model average, consisting of a weighted mean using the (uncorrelated) uncertainties due to natural variability plus the term representing intermodel spread (i.e., the inverse square of the white bars).

Observation-based products and models are combined into a single result in two ways. Firstly, we neglect common model uncertainties beyond the intermodel spread that is depicted by the model average and compute the weighted average of models (dark red bar) and observations (dark blue bar): this is indicated by the magenta bar. As, due to common model uncertainties, model uncertainty can be larger than the intermodel spread, secondly, we also show the more conservative estimate of an unweighted, direct average of observations (dark blue bar) and models (dark red bar) contributing 50% each, indicated by the white box around the magenta bar in the synthesis figures.

Due to the strength of the warming trend, in many datasets temperatures that occur in today's climate would have been statistically impossible in a 1.3°C cooler climate, leading to infinite probability ratios. Where this occurs, the missing values are imputed using the approach outlined in Otto et al., (2024): where only the upper bound of the confidence interval is infinite, the best estimate and the lower bound are used to estimate the upper bound of a corresponding six-sigma confidence interval; where both the best estimate and the upper bound are infinite, the best estimate is first imputed based on all available finite upper bounds, and this is used to impute the upper bound as before. Datasets with infinite upper bounds are marked with * in the figures below, and datasets with infinite best estimates with **. Any models where the estimated confidence interval spanned from 0 to infinity (meaning that they provide no information) are removed from the analysis altogether.

Results are shown in Tables 6.1 - 6.4, where differences are presented for changes both between a 1.3°C cooler preindustrial climate and the present, and between the present and future 0.2°C, 0.7°C, and 1.7°C warmer climates (1.5°C, 2°C, and 3°C of global warming since pre-industrial times). By combining evidence from the synthesis of model results for the past, projections for the future, and established physical understanding, we derive a best-estimate attribution of the event.

6.1 Tx1x - Analysis of 1-day May maximum temperatures

Figures 6.1 and 6.2 show the synthesised changes in intensity for a present day 1-in-60-year Tx1x May heat event associated with 1.3°C of warming from the pre-industrial period to 2026, and a further 0.2°C, 0.7°C, and 1.7°C of warming from 2026.

Compared to a pre-industrial climate, the one-day maximum temperatures for May averaged over Leinster and Munster have been made 1.1°C warmer, with results presented in Table 6.1. In addition, there is expected to be a further 0.13°C, 0.45°C, and 1.1°C of warming from 2026 levels, respectively, for climates 1.5°C, 2.0°C, and 3.0°C warmer than pre-industrial levels. For all cases these temperatures are best estimates and they have the potential of warming more than this in future, particularly given that most observationally based estimates have warmed more than the majority of models suggest to date.

We find that these one-day maximum temperatures for May would have been effectively impossible in a world without anthropogenic climate change, as shown in Table 6.2. Upper bounds for all observation datasets were infinity, as previously seen in Table 3.1. In addition, best estimates for two observationally-based estimates were infinite. The unweighted mean of the estimates from the observations and models are also given for this event definition (white box around the purple bar in the figures below). Given the large values found for both the best estimate and confidence interval, as well as the large discrepancy between the observed and model data, we do not try to quantify the change in likelihood of experiencing such warm May temperatures from past to present. However, these results suggest that in pre-industrial times these maximum temperatures would have been extremely unlikely and their occurrence now is directly linked to human caused climate change.

However, in today's climate a similar high-temperature event that broke the station records is expected to occur every 60 years. For climates 1.5°C, 2.0°C, and 3.0°C warmer than pre-industrial levels, similar summers will become 1.2, 1.6 and 3 times more likely than today. This means that similar May maximum temperatures will happen 1-in-50 years in a 1.5°C warmer than pre-industrial climate, 1-in-40 years in a 2.0°C warmer climate, and 1-in-20 years in a 3.0°C warmer climate. We note that the future changes are based only on climate models, which simulate less than the observed warming, so these are probably conservative estimates.

Tx1x	**Change in intensity (°C)**			
	Already occurred (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	**2.78 (0.12 to 5.66)**	-	-	-
Models	0.59 (-0.91 to 2.14)	**0.13 (0.02 to 0.25)**	**0.45 (0.07 to 0.86)**	**1.10 (0.16 to 2.08)**
Synthesis	1.10 (-0.74 to 3.04)			

*Table 6.1: Summary of synthesised changes in intensity for Tx1x, presented in Figures 6.1 and 6.2. Statistically significant changes are highlighted in **bold**.*

Tx1x	**Probability ratio**			
	Already occurred (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	1.88E+08 (5.92E-08 to 1.96E+35)			
Models	1.77 (0.27 to 16.88)	**1.14 (1.03 to 1.28)**	**1.57 (1.12 to 2.29)**	**2.82 (1.37 to 6.11)**
Synthesis	1.3 (0.17 to 57.9)			
Unweighted mean	18200 (1.92E-07 to 2.39E+23)			

*Table 6.2: Summary of synthesised changes in the probability ratio for Tx1x, presented in Figures 6.1 and 6.2. Statistically significant changes are highlighted in **bold**.*

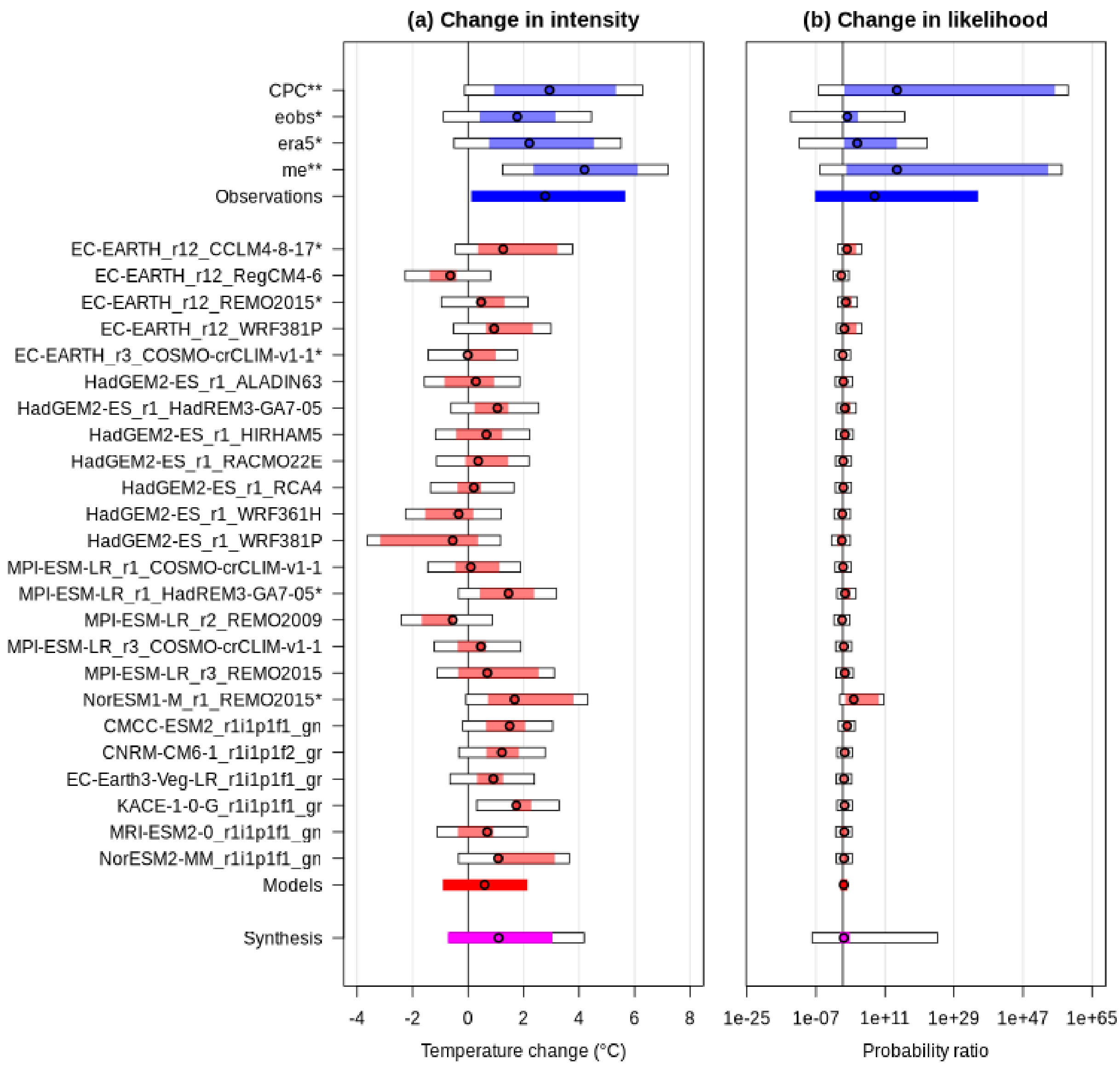


*Figure 6.1: Synthesised changes for a 1-in-60-year (section 3.2) Tx1x event due to GMST. Changes in intensity (left) and PR (right) are shown for a historical period comparing the past 1.3°C cooler climate with the present. Datasets where finite upper bounds for the PR were imputed are marked with *, and datasets where both the upper bound and best estimate were imputed are marked with **.*

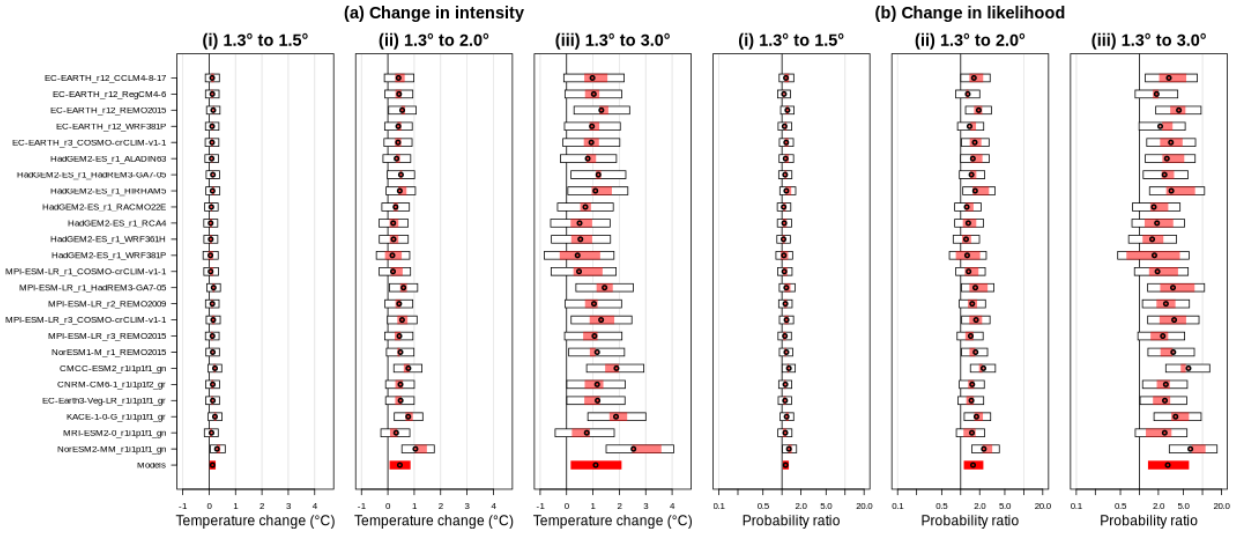


Figure 6.2: Synthesised changes for a 1-in-60-year (section 3.2) Tx1x event due to GMST. Changes in intensity (left) and PR (right) are shown for a future period, based on model projections only, comparing the present and a future warmed climate.

6.2 Tx5x - Analysis of 5-day May maximum temperatures

The synthesised changes in intensity for a present day 1-in-5-year Tx5x May heat event are presented in Figures 6.3 and 6.4. The results are associated with 1.3°C of warming from the pre-industrial period to 2026, and a further 0.2°C, 0.7°C, and 1.7°C of warming from 2026.

Compared to a pre-industrial climate, the five-day maximum temperatures for May averaged over Leinster and Munster have been made 1.4°C warmer, with results presented in Table 6.3. In addition, there is expected to be a further 0.1°C, 0.4°C, and 1.1°C of warming from 2026 levels, respectively, for climates 1.5°C, 2.0°C, and 3.0°C warmer than pre-industrial levels. For all cases these temperatures are best estimates and they have the potential of warming more than this in future. Again, models systematically underestimate observed warming to date hinting at the potential for larger future increases.

The likelihood of a similar event occurring has also increased as a result of human-caused climate change, as shown in Table 6.4. In pre-industrial times these maximum temperatures would've been expected to occur once every 9 years but now they are expected to occur once every 5 years. For climates 1.5°C, 2.0°C, and 3.0°C warmer than pre-industrial levels, similar May heatwaves will become 1.1, 1.3 and 1.8 times more likely than today. This means that similar May maximum temperatures will happen 1-in-5 years in a 1.5°C warmer than pre-industrial climate, 1-in-4 years in a 2.0°C warmer climate, and 1-in-3 years in a 3.0°C warmer climate. Again, we note that the future changes are based only on climate models, which simulate less than the observed warming, so these are probably conservative estimates. The results for Tx5x are better constrained than those for Tx1x, partly because this index reflects temperatures averaged over several days and therefore the index itself is less variable, and partly because the 5-day event was less extreme (expected roughly once every 5 years) than the 1-day event (estimated to have a return period of 60 years). We therefore do not include the unweighted mean here.

Tx5x	**Change in intensity (°C)**			
	Already occurred (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	**2.69 (0.15 to 4.86)**	-	-	-
Models	0.83 (-0.62 to 2.40)	**0.13 (0.02 to 0.24)**	**0.44 (0.05 to 0.83)**	**1.07 (0.13 to 2.02)**
Synthesis	1.37 (-0.46 to 3.14)			

*Table 6.3: Summary of synthesised changes in intensity for Tx5x, presented in Figures 6.3 and 6.4. Statistically significant changes are highlighted in **bold**.*

Tx5x	**Probability ratio**			
	Already occurred (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	22.86 (0.38 to 546,000)	-	-	-
Models	1.70 (0.48 to 8.23)	**1.08 (1.01 to 1.16)**	**1.30 (1.04 to 1.63)**	**1.80 (1.13 to 2.90)**
Synthesis	1.88 (0.43 to 23.23)			

*Table 6.4: Summary of synthesised changes in the probability ratio for Tx5x, presented in Figures 6.3 and 6.4. Statistically significant changes are highlighted in **bold**.*

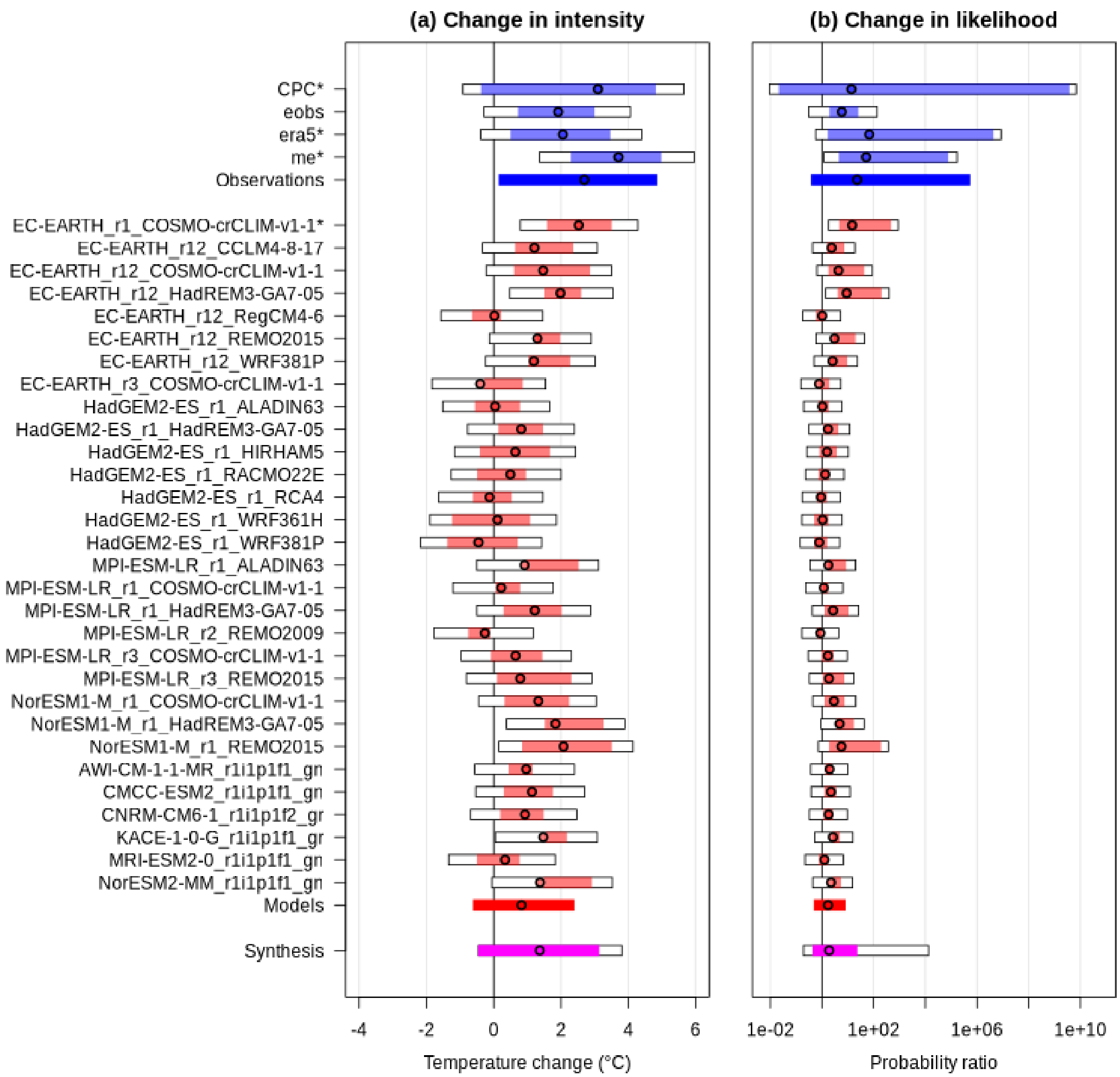


*Figure 6.3: Synthesised changes for a 1-in-5-year (section 3.3) Tx5x event due to GMST. Changes in intensity (left) and PR (right) are shown for a historical period comparing the past 1.3°C cooler climate with the present. Datasets where finite upper bounds for the PR were imputed are marked with *, and datasets where both the upper bound and best estimate were imputed are marked with **.*

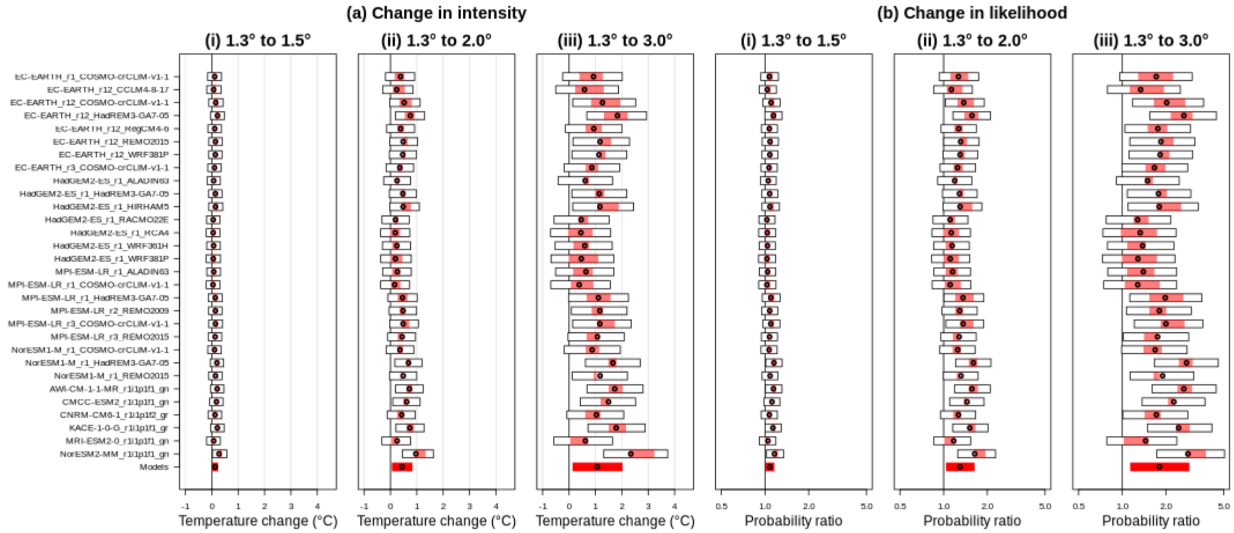


Figure 6.4: Synthesised changes for a 1-in-5-year (section 3.3) Tx5x event due to GMST. Changes in intensity (left) and PR (right) are shown for a future period, based on model projections only, comparing the present and a future warmed climate.

6.3 Tn1x - Analysis of 1-day May minimum temperatures

The synthesised changes in intensity for a 1-in-3-year Tn1x May heat nighttime event (minimum temperatures) are presented in Figures 6.5 and 6.6. The results are associated with 1.3°C of warming from the pre-industrial period to 2026, and a further 0.2°C, 0.7°C, and 1.7°C of warming from 2026.

Compared to a pre-industrial climate, the 1-day high minimum temperatures for May averaged over Leinster and Munster have been made 1.3°C warmer, with results presented in Table 6.5. In addition, there is expected to be a further 0.1°C, 0.4°C, and 1.1°C of warming from 2026 levels, respectively, for climates 1.5°C, 2.0°C, and 3.0°C warmer than pre-industrial levels. For all cases these temperatures are best estimates and they have the potential of warming more than this in future with the same caveats as earlier sections.

The likelihood of a similar event occurring has also increased as a result of human-caused climate change, as shown in Table 6.6. In pre-industrial times these nighttime temperatures would've been expected to occur once every 8 years but now they are expected to occur once every 3 years. For climates 1.5°C, 2.0°C, and 3.0°C warmer than pre-industrial levels, similar May hot nights will become 1.1, 1.4 and 2 times more likely than today. This means that similar high May nighttime minimum temperatures will happen 1-in-2 years in a 1.5°C warmer than pre-industrial climate, 1-in-2 years in a 2.0°C warmer climate, and 1-in-1-to-2 years in a 3.0°C warmer climate.

Tn1x	Change in intensity (°C)			
	Already occurred (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	**2.15 (0.50 to 3.74)**	-	-	-
Models	0.96 (-0.07 to 1.99)	**0.13 (0.06 to 0.20)**	**0.44 (0.20 to 0.70)**	**1.07 (0.48 to 1.71)**
Synthesis	**1.30 (0.06 to 2.52)**			

Table 6.5: Summary of synthesised changes in intensity for Tn1x, presented in Figures 6.5 and 6.6. Statistically significant changes are highlighted in ***bold****.*

Tn1x	Probability ratio			
	Already occurred (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	240,000 (0.00 to 5.2E+19)	-	-	-
Models	2.72 (0.82 to 11.3)	**1.11 (1.05 to 1.17)**	**1.39 (1.17 to 1.66)**	**1.97 (1.46 to 2.67)**
Synthesis	2.80 (0.59 to 24.30)			

Table 6.6: Summary of synthesised changes in the probability ratio for Tn1x, presented in Figures 6.5 and 6.6. Statistically significant changes are highlighted in ***bold****.*

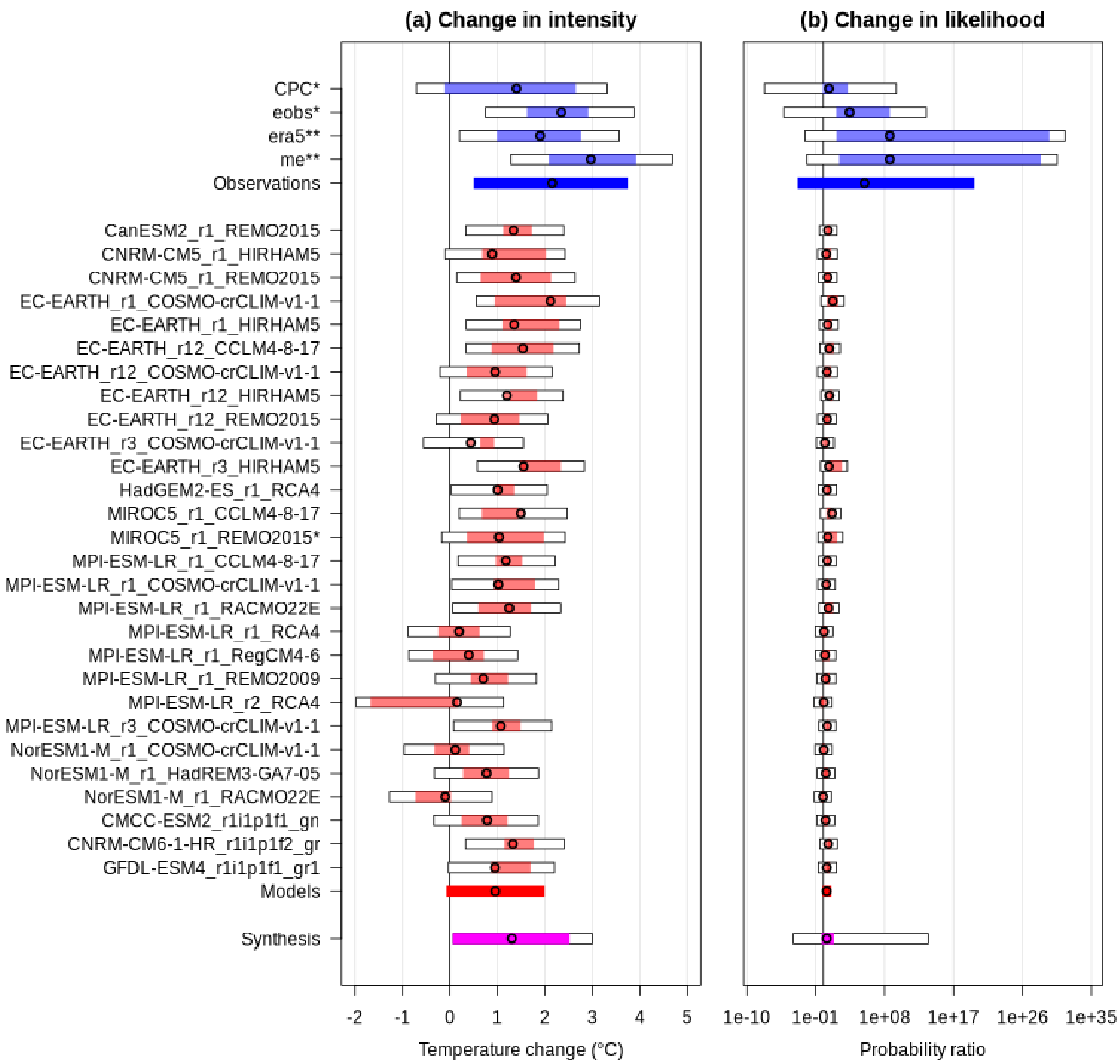


*Figure 6.5: Synthesised changes for a 1-in-3-year (section 3.4) Tn1x event due to GMST. Changes in intensity (left) and PR (right) are shown for a historical period comparing the past 1.3°C cooler climate with the present. Datasets where finite upper bounds for the PR were imputed are marked with *, and datasets where both the upper bound and best estimate were imputed are marked with **.*

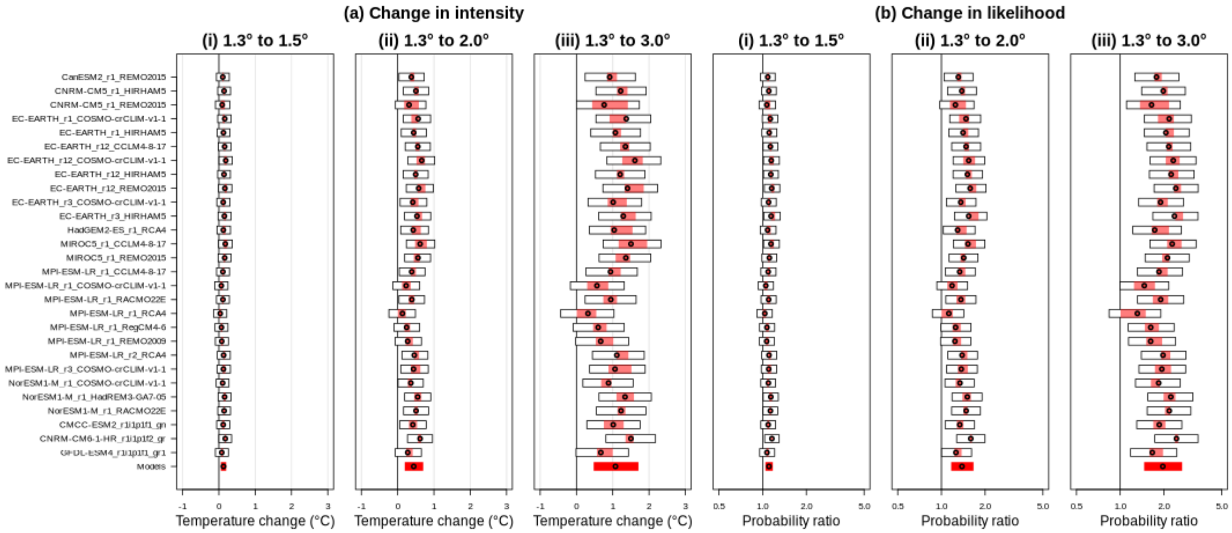


Figure 6.6: Synthesised changes for a 1-in-3-year (section 3.4) Tn1x event due to GMST. Changes in intensity (left) and PR (right) are shown for a future period, based on model projections only, comparing the present and a future warmer climate.

7 Societal impacts

As temperatures began to rise to record breaking heights, the public was warned to exercise caution around lakes and beaches, remain alert for potential forest fires, and be aware of heat stress and uncomfortable sleeping conditions. Sadly, there was one reported death when a 15-year-old lost their life after getting into difficulty off Burrow Beach near Howth, County Dublin on Sunday 24th. There were likely additional excess deaths amongst the old and medically vulnerable and subsequent analysis of rip.ie may highlight the extent of this. It is well established that early season extreme heat before people have had a chance to acclimatise is particularly dangerous.

Two gorse fires had reportedly broken out in the Dublin Mountains on Thursday 28th, with Dublin Fire Brigade tackling the fires and advising people to stay clear of the area and for nearby residents affected by smoke to close their windows and doors.

In addition, Inland Fisheries Ireland implemented their warm water protocol to protect fish species across several fisheries as water temperatures rose above 20°C.

In other parts of Europe, the number of heat or water related deaths were significantly higher, with a news article in the UK reporting 13 had lost their lives due to water related accidents. The French government announced that 7 were confirmed to have died due to the extreme heat, although previous analysis of similar heatwave temperatures suggests that the true number is likely to be much higher (Clarke et al., 2025)

8 Conclusion

This is the first WASITUS study that, using WWA techniques, has found that the event would not have been possible without human interference in the climate system. While noting recent work by Risser et al. (2025) that suggests at least some such findings may not apply across all methods it is undoubtedly the case that a May heatwave of this intensity would have been all but impossible in a world of our recent ancestors. Such record breaking events that would not have been possible in the pre-industrial climate will increasingly become a feature of the Irish climate the longer that global greenhouse gas emissions remain above net-zero and the climate continues to warm.

References

All references are given as hyperlinks in the text.

Appendix

Model / Observations	Seasonal cycle	Spatial pattern	Sigma	Shape	Summary
CPC			2.26 (1.69…2.93)	-0.36 (-1.02…-0.01)	
eobs			1.98 (1.69…2.23)	-0.2 (-0.43…-0.08)	
era5			1.86 (1.57…2.23)	-0.22 (-0.49…-0.05)	
me			2.18 (1.73…2.66)	-0.32 (-0.56…-0.05)	
CNRM-CM5_r1_ALADIN63	reasonable	good	2.08 (1.91…2.28)	-0.23 (-0.3…-0.23)	reasonable
CNRM-CM5_r1_CCLM4-8-17	reasonable	good	2.26 (2.25…2.44)	-0.21 (-0.29…-0.2)	reasonable
CNRM-CM5_r1_HadREM3-GA7-05	reasonable	good	2.08 (2.03…2.32)	-0.13 (-0.27…-0.13)	reasonable
CNRM-CM5_r1_HIRHAM5	reasonable	good	2.06 (1.92…2.63)	-0.25 (-0.48…-0.11)	reasonable
CNRM-CM5_r1_RACMO22E	reasonable	reasonable	1.99 (1.76…2.03)	-0.11 (-0.16…0)	reasonable
CNRM-CM5_r1_RCA4	reasonable	good	1.8 (1.58…2.46)	-0.33 (-1…-0.34)	reasonable
CNRM-CM5_r1_REMO2015	reasonable	good	2.21 (2.11…2.41)	-0.25 (-0.39…-0.21)	reasonable
CNRM-CM5_r1_WRF381P	reasonable	good	1.81 (1.64…1.98)	-0.02 (-0.15…0.12)	reasonable
EC-EARTH_r1_COSMO-crCLIM-v1-1	good	good	1.96 (1.61…1.86)	-0.33 (-0.3…-0.24)	bad

EC-EARTH_r1_HIRHAM5	reasonable	good	1.88 (1.81…2.04)	-0.14 (-0.35…-0.06)	reasonable
EC-EARTH_r1_RACMO22E	bad	reasonable	1.77 (1.61…1.85)	-0.05 (-0.15…-0.03)	bad
EC-EARTH_r1_RCA4	reasonable	reasonable	1.38 (1.27…1.5)	-0.2 (-0.53…-0.14)	bad
EC-EARTH_r12_CCLM4-8-17	good	good	2 (1.87…2.09)	-0.26 (-0.43…-0.2)	good
EC-EARTH_r12_COSMO-crCLIM-v1-1	good	good	1.74 (1.39…1.89)	-0.4 (-0.47…-0.29)	bad
EC-EARTH_r12_HadREM3-GA7-05	good	good	1.76 (1.64…1.82)	-0.44 (-0.6…-0.39)	bad
EC-EARTH_r12_HIRHAM5	reasonable	good	1.81 (1.42…1.9)	-0.24 (-0.27…-0.04)	reasonable
EC-EARTH_r12_RACMO22E	bad	reasonable	1.99 (1.76…2.09)	-0.3 (-0.45…-0.27)	bad
EC-EARTH_r12_RCA4	reasonable	reasonable	1.29 (0.99…1.25)	-0.18 (-0.38…0)	bad
EC-EARTH_r12_RegCM4-6	good	good	1.61 (1.35…1.63)	-0.26 (-0.3…-0.16)	good
EC-EARTH_r12_REMO2015	good	good	1.95 (1.68…2.07)	-0.41 (-0.45…-0.25)	good
EC-EARTH_r12_WRF361H	reasonable	reasonable	1.93 (1.61…1.87)	-0.18 (-0.12…-0.03)	reasonable
EC-EARTH_r12_WRF381P	good	good	2.05 (1.87…2.17)	-0.16 (-0.33…-0.18)	good
EC-EARTH_r3_COSMO-crCLIM-v1-1	good	good	1.88 (1.79…2.2)	-0.39 (-0.62…-0.29)	good
EC-EARTH_r3_HIRHAM5	reasonable	good	1.72 (1.55…1.75)	-0.18 (-0.28…-0.13)	reasonable
EC-EARTH_r3_RACMO22E	bad	reasonable	1.74 (1.54…1.99)	0.03 (-0.1…0.09)	bad
HadGEM2-ES_r1_ALADIN63	good	good	1.79 (1.65…1.92)	-0.19 (-0.28…-0.05)	good
HadGEM2-ES_r1_CCLM4-8-17	reasonable	good	2.25 (2.05…2.31)	-0.25 (-0.27…-0.1)	reasonable
HadGEM2-ES_r1_COSMO-crCLIM-v1-1	reasonable	good	1.78 (1.64…1.95)	-0.29 (-0.36…-0.17)	reasonable
HadGEM2-ES_r1_HadREM3-GA7-05	good	good	1.89 (1.65…1.86)	-0.17 (-0.28…-0.15)	good
HadGEM2-ES_r1_HIRHAM5	good	good	2.09 (1.93…2.4)	-0.29 (-0.38…-0.23)	good
HadGEM2-ES_r1_RACMO22E	good	good	1.88 (1.61…1.99)	-0.06 (-0.17…0.04)	good
HadGEM2-ES_r1_RCA4	good	good	1.88 (1.57…1.88)	-0.26 (-0.35…-0.17)	good
HadGEM2-ES_r1_RegCM4-6	reasonable	good	1.87 (1.83…2.13)	-0.18 (-0.4…-0.22)	reasonable
HadGEM2-ES_r1_REMO2015	reasonable	good	1.98 (1.88…2.26)	-0.27 (-0.39…-0.12)	reasonable

HadGEM2-ES_r1_WRF361H	good	good	2.29 (2.03…2.49)	-0.19 (-0.41…-0.05)	good
HadGEM2-ES_r1_WRF381P	good	good	2.42 (2.25…2.98)	-0.28 (-0.7…-0.32)	good
IPSL-CM5A-MR_r1_HIRHAM5	bad	reasonable	1.81 (1.64…2.18)	-0.13 (-0.57…-0.04)	bad
IPSL-CM5A-MR_r1_RACMO22E	bad	reasonable	1.64 (1.35…2.16)	0.13 (-0.31…0.32)	bad
IPSL-CM5A-MR_r1_RCA4	bad	reasonable	1.32 (0.91…1.29)	0.2 (0.19…0.61)	bad
IPSL-CM5A-MR_r1_REMO2015	reasonable	reasonable	1.94 (1.86…2.06)	-0.08 (-0.33…-0.05)	reasonable
IPSL-CM5A-MR_r1_WRF381P	reasonable	reasonable	1.94 (1.6…2.29)	-0.11 (-0.15…0.09)	reasonable
MIROC5_r1_CCLM4-8-17	reasonable	good	1.83 (1.54…1.99)	-0.26 (-0.36…-0.16)	reasonable
MIROC5_r1_REMO2015	reasonable	good	1.72 (1.51…1.9)	-0.23 (-0.32…-0.17)	reasonable
MPI-ESM-LR_r1_ALADIN63	good	good	1.87 (1.5…1.98)	-0.01 (0.02…0.06)	bad
MPI-ESM-LR_r1_CCLM4-8-17	reasonable	reasonable	2.12 (1.76…2.18)	-0.13 (-0.19…-0.05)	reasonable
MPI-ESM-LR_r1_COSMO-crCLIM-v1-1	good	good	2.13 (1.86…2.31)	-0.29 (-0.34…-0.12)	good
MPI-ESM-LR_r1_HadREM3-GA7-05	good	good	1.86 (1.66…1.95)	-0.12 (-0.31…-0.06)	good
MPI-ESM-LR_r1_HIRHAM5	reasonable	reasonable	2.06 (1.84…2.02)	-0.15 (-0.11…-0.03)	reasonable
MPI-ESM-LR_r1_RACMO22E	bad	reasonable	2.15 (2…2.26)	-0.04 (-0.08…0.09)	bad
MPI-ESM-LR_r1_RCA4	bad	reasonable	1.37 (1.31…1.56)	-0.3 (-0.53…-0.18)	bad
MPI-ESM-LR_r1_RegCM4-6	good	good	1.35 (1.17…1.44)	0.03 (-0.06…0.2)	bad
MPI-ESM-LR_r1_REMO2009	good	reasonable	1.96 (1.78…2.12)	-0.16 (-0.24…-0.1)	reasonable
MPI-ESM-LR_r1_WRF361H	reasonable	good	2.07 (1.21…2.53)	-0.13 (-0.43…0.61)	reasonable
MPI-ESM-LR_r2_COSMO-crCLIM-v1-1	reasonable	good	1.98 (1.7…2.08)	-0.19 (-0.23…-0.14)	reasonable
MPI-ESM-LR_r2_RCA4	bad	reasonable	1.36 (1.17…1.51)	-0.22 (-0.32…-0.04)	bad
MPI-ESM-LR_r2_REMO2009	good	good	1.83 (1.64…1.91)	-0.12 (-0.27…0.01)	good
MPI-ESM-LR_r3_COSMO-crCLIM-v1-1	good	good	1.85 (1.65…1.9)	-0.2 (-0.3…-0.12)	good
MPI-ESM-LR_r3_RCA4	bad	reasonable	1.37 (1.09…1.58)	-0.2 (-0.37…0.06)	bad
MPI-ESM-LR_r3_REMO2015	good	good	2.01 (1.81…2.2)	-0.27 (-0.29…-0.11)	good
NorESM1-M_r1_ALADIN63	reasonable	good	1.44 (1.3…1.51)	-0.08 (-0.19…0.12)	bad

NorESM1-M_r1_COSMO-crCLIM-v1-1	good	good	1.57 (1.46…1.71)	-0.19 (-0.24…-0.08)	reasonable
NorESM1-M_r1_HadREM3-GA7-05	good	good	1.42 (1.22…1.48)	-0.12 (-0.17…-0.03)	bad
NorESM1-M_r1_HIRHAM5	reasonable	good	1.11 (1.02…1.15)	0.07 (-0.07…0.23)	bad
NorESM1-M_r1_RACMO22E	bad	reasonable	1.49 (1.3…1.77)	-0.09 (-0.18…0.02)	bad
NorESM1-M_r1_RCA4	bad	good	1.09 (0.91…1.11)	-0.15 (-0.21…-0.1)	bad
NorESM1-M_r1_RegCM4-6	good	good	1.44 (0.99…1.52)	0.04 (-0.06…0.11)	bad
NorESM1-M_r1_REMO2015	good	good	1.61 (1.45…1.96)	-0.27 (-0.57…-0.17)	good
NorESM1-M_r1_WRF381P	reasonable	good	1.91 (1.75…2.08)	-0.1 (-0.25…-0.07)	reasonable
ACCESS-CM2_r1i1p1f1_gn	reasonable	good	0.92 (0.87…0.95)	-0.12 (-0.19…-0.04)	bad
AWI-CM-1-1-MR_r1i1p1f1_gn	good	good	1.55 (1.41…1.72)	-0.07 (-0.21…-0.03)	reasonable
CMCC-ESM2_r1i1p1f1_gn	good	good	1.97 (1.69…2.21)	-0.23 (-0.33…-0.11)	good
CNRM-CM6-1-HR_r1i1p1f2_gr	reasonable	good	2.16 (2…2.37)	-0.31 (-0.39…-0.26)	reasonable
CNRM-CM6-1_r1i1p1f2_gr	good	good	2.19 (1.99…2.29)	-0.13 (-0.22…-0.03)	good
EC-Earth3-Veg-LR_r1i1p1f1_gr	good	good	1.41 (1.18…1.38)	-0.07 (-0.18…-0.02)	good
GFDL-ESM4_r1i1p1f1_gr1	reasonable	good	1.58 (1.37…1.69)	-0.22 (-0.32…0.03)	reasonable
INM-CM4-8_r1i1p1f1_gr1	good	reasonable	2.65 (2.39…2.62)	-0.01 (-0.12…0.09)	reasonable
INM-CM5-0_r1i1p1f1_gr1	good	reasonable	2.34 (2.05…2.67)	-0.04 (-0.16…0.04)	reasonable
KACE-1-0-G_r1i1p1f1_gr	good	good	1.63 (1.54…1.79)	-0.04 (-0.22…0.07)	good
MPI-ESM1-2-LR_r1i1p1f1_gn	bad	reasonable	1.88 (1.76…2)	-0.05 (-0.09…0.06)	bad
MRI-ESM2-0_r1i1p1f1_gn	good	good	1.78 (1.83…1.91)	-0.13 (-0.36…-0.12)	good
NorESM2-MM_r1i1p1f1_gn	good	good	1.88 (1.53…2.05)	-0.05 (-0.12…-0.03)	good

*Table A.1: Evaluation results of the climate models considered for attribution analysis of Tx1x over the study region. Results of a visual evaluation of the seasonal cycle and spatial pattern are given. For each model, the best estimate of the Sigma parameter is shown, and a 95% confidence interval is given for each, obtained via bootstrapping. The qualitative evaluation is shown in the right-hand column. Models that passed validation and used in the analysis are highlighted in **bold**.*

Model / Observations	Seasonal cycle	Spatial pattern	Sigma	Shape	Summary

CPC			1.84 (1.33…3.1)	-0.17 (-1.06…0.16)	
eobs			1.79 (1.46…2.06)	-0.23 (-0.42…-0.02)	
era5			1.79 (1.47…2.1)	-0.23 (-0.41…-0.02)	
me			1.8 (1.41…2.13)	-0.21 (-0.46…0.08)	
CNRM-CM5_r1_ALADIN63	reasonable	good	1.73 (1.63…1.91)	-0.15 (-0.28…-0.1)	reasonable
CNRM-CM5_r1_CCLM4-8-17	reasonable	good	1.8 (1.77…1.93)	-0.15 (-0.32…-0.09)	reasonable
CNRM-CM5_r1_HadREM3-GA7-05	reasonable	good	1.89 (1.84…2.31)	-0.09 (-0.23…-0.13)	reasonable
CNRM-CM5_r1_HIRHAM5	reasonable	good	1.81 (1.71…2.17)	-0.16 (-0.3…-0.15)	reasonable
CNRM-CM5_r1_RACMO22E	reasonable	reasonable	1.5 (1.24…1.59)	0.04 (-0.03…0.21)	reasonable
CNRM-CM5_r1_RCA4	reasonable	good	1.49 (1.25…1.66)	-0.28 (-0.38…-0.31)	reasonable
CNRM-CM5_r1_REMO2015	reasonable	good	2.12 (2.03…2.33)	-0.23 (-0.33…-0.17)	reasonable
CNRM-CM5_r1_WRF381P	reasonable	good	1.53 (1.37…1.68)	0.08 (-0.11…0.18)	reasonable
EC-EARTH_r1_COSMO-crCLIM-v1-1	good	good	1.8 (1.42…1.7)	-0.24 (-0.28…-0.17)	good
EC-EARTH_r1_HIRHAM5	reasonable	good	1.67 (1.55…1.7)	-0.08 (-0.23…0.05)	reasonable
EC-EARTH_r1_RACMO22E	bad	reasonable	1.56 (1.41…1.65)	0 (-0.09…0.02)	bad
EC-EARTH_r1_RCA4	reasonable	reasonable	1.21 (1.13…1.31)	-0.2 (-0.54…-0.2)	reasonable
EC-EARTH_r12_CCLM4-8-17	good	good	1.79 (1.49…2.05)	-0.16 (-0.22…-0.1)	good
EC-EARTH_r12_COSMO-crCLIM-v1-1	good	good	1.72 (1.33…1.75)	-0.27 (-0.35…-0.17)	good
EC-EARTH_r12_HadREM3-GA7-05	good	good	1.6 (1.47…1.72)	-0.24 (-0.33…-0.12)	good
EC-EARTH_r12_HIRHAM5	reasonable	good	1.59 (1.26…1.76)	-0.1 (-0.19…0.16)	reasonable
EC-EARTH_r12_RACMO22E	bad	reasonable	1.59 (1.3…1.66)	-0.19 (-0.35…-0.06)	bad
EC-EARTH_r12_RCA4	reasonable	reasonable	1.15 (1.02…1.09)	-0.15 (-0.31…-0.09)	bad
EC-EARTH_r12_RegCM4-6	good	good	1.38 (1.16…1.47)	-0.23 (-0.32…-0.12)	good
EC-EARTH_r12_REMO2015	good	good	1.85 (1.42…1.99)	-0.25 (-0.32…0)	good
EC-EARTH_r12_WRF361H	reasonable	reasonable	1.57 (1.36…1.66)	-0.16 (-0.27…-0.04)	reasonable
EC-EARTH_r12_WRF381P	good	good	1.8 (1.54…1.93)	-0.21 (-0.33…-0.07)	good

EC-EARTH_r3_COSMO-crCLIM-v1-1	good	good	1.67 (1.54…2.01)	-0.16 (-0.33…-0.15)	good
EC-EARTH_r3_HIRHAM5	reasonable	good	1.47 (1.28…1.61)	-0.03 (-0.13…0.08)	reasonable
EC-EARTH_r3_RACMO22E	bad	reasonable	1.45 (1.3…1.68)	0.14 (-0.01…0.18)	bad
HadGEM2-ES_r1_ALADIN63	good	good	1.86 (1.81…2.12)	-0.25 (-0.27…-0.14)	good
HadGEM2-ES_r1_CCLM4-8-17	reasonable	good	2.33 (2.07…2.6)	-0.22 (-0.27…0.02)	reasonable
HadGEM2-ES_r1_COSMO-crCLIM-v1-1	reasonable	good	1.83 (1.63…2)	-0.18 (-0.3…-0.04)	reasonable
HadGEM2-ES_r1_HadREM3-GA7-05	good	good	1.66 (1.51…1.64)	-0.09 (-0.23…-0.07)	good
HadGEM2-ES_r1_HIRHAM5	good	good	1.91 (1.72…1.98)	-0.21 (-0.25…-0.12)	good
HadGEM2-ES_r1_RACMO22E	good	good	1.75 (1.54…1.8)	-0.07 (-0.24…-0.01)	good
HadGEM2-ES_r1_RCA4	good	good	1.82 (1.48…1.82)	-0.29 (-0.31…-0.25)	good
HadGEM2-ES_r1_RegCM4-6	reasonable	good	1.71 (1.68…2.03)	-0.16 (-0.66…-0.17)	reasonable
HadGEM2-ES_r1_REMO2015	reasonable	good	2.08 (2.01…2.31)	-0.24 (-0.37…-0.11)	reasonable
HadGEM2-ES_r1_WRF361H	good	good	1.72 (1.43…1.81)	0 (-0.05…0.08)	good
HadGEM2-ES_r1_WRF381P	good	good	2.3 (2.04…2.66)	-0.27 (-0.48…-0.18)	good
IPSL-CM5A-MR_r1_HIRHAM5	bad	reasonable	1.44 (1.24…1.52)	-0.06 (-0.1…0.05)	bad
IPSL-CM5A-MR_r1_RACMO22E	bad	reasonable	1.18 (0.93…1.34)	0.21 (-0.07…0.41)	bad
IPSL-CM5A-MR_r1_RCA4	bad	reasonable	1.18 (0.84…1.14)	0.12 (0.15…0.4)	bad
IPSL-CM5A-MR_r1_REMO2015	reasonable	reasonable	1.8 (1.64…1.94)	-0.04 (-0.22…0)	reasonable
IPSL-CM5A-MR_r1_WRF381P	reasonable	reasonable	1.48 (1.32…1.64)	0.06 (0.03…0.18)	reasonable
MIROC5_r1_CCLM4-8-17	reasonable	good	1.85 (1.58…1.94)	-0.27 (-0.36…-0.22)	reasonable
MIROC5_r1_REMO2015	reasonable	good	1.95 (1.64…2.21)	-0.3 (-0.63…-0.25)	reasonable
MPI-ESM-LR_r1_ALADIN63	good	good	1.69 (1.29…1.81)	-0.07 (-0.07…0.04)	good
MPI-ESM-LR_r1_CCLM4-8-17	reasonable	reasonable	2.05 (1.79…2.03)	-0.15 (-0.29…-0.09)	reasonable
MPI-ESM-LR_r1_COSMO-crCLIM-v1-1	good	good	1.92 (1.73…2.12)	-0.26 (-0.31…-0.17)	good
MPI-ESM-LR_r1_HadREM3-GA7-05	good	good	1.58 (1.4…1.62)	-0.15 (-0.27…-0.11)	good

MPI-ESM-LR_r1_HIRHAM5	reasonable	reasonable	1.84 (1.64…1.83)	-0.15 (-0.12…-0.03)	reasonable
MPI-ESM-LR_r1_RACMO22E	bad	reasonable	1.73 (1.6…1.78)	-0.02 (-0.12…0.05)	bad
MPI-ESM-LR_r1_RCA4	bad	reasonable	1.2 (1.15…1.37)	-0.25 (-0.42…-0.12)	bad
MPI-ESM-LR_r1_RegCM4-6	good	good	1.24 (1.05…1.32)	-0.02 (-0.08…0.16)	bad
MPI-ESM-LR_r1_REMO2009	good	reasonable	1.82 (1.69…2.06)	-0.05 (-0.2…-0.1)	reasonable
MPI-ESM-LR_r1_WRF361H	reasonable	good	1.69 (1.25…2.09)	-0.1 (-0.35…0.3)	reasonable
MPI-ESM-LR_r2_COSMO-crCLIM-v1-1	reasonable	good	1.83 (1.55…1.91)	-0.13 (-0.34…-0.05)	reasonable
MPI-ESM-LR_r2_RCA4	bad	reasonable	1.21 (1.06…1.29)	-0.22 (-0.29…-0.1)	bad
MPI-ESM-LR_r2_REMO2009	good	good	1.7 (1.46…1.79)	-0.04 (-0.25…0.03)	good
MPI-ESM-LR_r3_COSMO-crCLIM-v1-1	good	good	1.61 (1.38…1.78)	-0.19 (-0.22…-0.04)	good
MPI-ESM-LR_r3_RCA4	bad	reasonable	1.22 (1.02…1.4)	-0.25 (-0.48…0.01)	bad
MPI-ESM-LR_r3_REMO2015	good	good	1.92 (1.86…2.04)	-0.27 (-0.3…-0.21)	good
NorESM1-M_r1_ALADIN63	reasonable	good	1.24 (1.17…1.28)	-0.02 (-0.12…0.15)	bad
NorESM1-M_r1_COSMO-crCLIM-v1-1	good	good	1.46 (1.36…1.62)	-0.11 (-0.21…0.02)	good
NorESM1-M_r1_HadREM3-GA7-05	good	good	1.37 (1.07…1.37)	-0.09 (-0.13…-0.01)	good
NorESM1-M_r1_HIRHAM5	reasonable	good	1.12 (1.06…1.19)	-0.02 (-0.21…0.11)	bad
NorESM1-M_r1_RACMO22E	bad	reasonable	1.2 (1.06…1.41)	0.02 (-0.06…0.1)	bad
NorESM1-M_r1_RCA4	bad	good	1.03 (0.81…1.11)	-0.08 (-0.14…0.01)	bad
NorESM1-M_r1_RegCM4-6	good	good	1.24 (0.97…1.35)	0.06 (-0.02…0.1)	reasonable
NorESM1-M_r1_REMO2015	good	good	1.6 (1.45…1.99)	-0.14 (-0.29…-0.05)	good
NorESM1-M_r1_WRF381P	reasonable	good	1.62 (1.48…1.82)	-0.05 (-0.32…0.01)	reasonable
ACCESS-CM2_r1i1p1f1_gn	reasonable	good	0.87 (0.82…0.9)	-0.11 (-0.16…-0.12)	reasonable
AWI-CM-1-1-MR_r1i1p1f1_gn	good	good	1.38 (1.16…1.5)	-0.01 (-0.07…0.18)	good
CMCC-ESM2_r1i1p1f1_gn	good	good	1.64 (1.28…1.86)	-0.09 (-0.15…0.02)	good
CNRM-CM6-1-HR_r1i1p1f2_gr	reasonable	good	2 (1.86…2.1)	-0.28 (-0.32…-0.25)	reasonable
CNRM-CM6-1_r1i1p1f2_gr	good	good	1.89 (1.71…1.84)	-0.09 (-0.17…-0.01)	good

EC-Earth3-Veg-LR_r1i1p1f1_gr	good	good	1.21 (1…1.13)	-0.07 (-0.07…0.08)	bad
GFDL-ESM4_r1i1p1f1_gr1	reasonable	good	1.32 (1.16…1.41)	-0.15 (-0.3…0.03)	reasonable
INM-CM4-8_r1i1p1f1_gr1	good	reasonable	2.11 (1.72…2.06)	0.04 (-0.08…0.16)	reasonable
INM-CM5-0_r1i1p1f1_gr1	good	reasonable	1.94 (1.79…2.25)	0.05 (-0.09…0.17)	reasonable
KACE-1-0-G_r1i1p1f1_gr	good	good	1.52 (1.45…1.53)	-0.06 (-0.18…0.02)	good
MPI-ESM1-2-LR_r1i1p1f1_gn	bad	reasonable	1.58 (1.4…1.79)	0.01 (-0.03…0.08)	bad
MRI-ESM2-0_r1i1p1f1_gn	good	good	1.67 (1.66…1.87)	-0.08 (-0.34…-0.03)	good
NorESM2-MM_r1i1p1f1_gn	good	good	1.79 (1.57…1.88)	-0.07 (-0.25…0.01)	good

*Table A.2: Evaluation results of the climate models considered for attribution analysis of Tx5x over the study region. Results of a visual evaluation of the seasonal cycle and spatial pattern are given. For each model, the best estimate of the Sigma parameter is shown, and a 95% confidence interval is given for each, obtained via bootstrapping. The qualitative evaluation is shown in the right-hand column.Models that passed validation and used in the analysis are highlighted in **bold**.*

Model / Observations	Seasonal cycle	Spatial pattern	Sigma	Shape	Summary
CPC			1.07 (0.71…1.38)	-0.37 (-1.03…-0.08)	
eobs			1.04 (0.87…1.17)	-0.31 (-0.44…-0.22)	
era5			1.14 (0.93…1.3)	-0.31 (-0.58…-0.23)	
me			1.01 (0.78…1.19)	-0.27 (-0.6…-0.13)	
CanESM2_r1_CCLM4-8-17	good	good	1.57 (1.13…1.73)	-0.33 (-0.41…-0.15)	reasonable
CanESM2_r1_REMO2015	good	good	1.14 (0.92…1.15)	-0.17 (-0.17…-0.05)	good
CNRM-CM5_r1_ALADIN63	bad	reasonable	1.29 (1.24…1.47)	-0.26 (-0.4…-0.29)	bad
CNRM-CM5_r1_CCLM4-8-17	reasonable	good	1.18 (1.1…1.29)	-0.25 (-0.4…-0.25)	reasonable
CNRM-CM5_r1_HadREM3-GA7-05	bad	good	1.28 (1.22…1.57)	-0.2 (-0.34…-0.14)	bad
CNRM-CM5_r1_HIRHAM5	good	good	1.32 (1.25…1.49)	-0.27 (-0.3…-0.19)	good
CNRM-CM5_r1_RACMO22E	bad	reasonable	1.27 (1.24…1.35)	-0.22 (-0.33…-0.16)	bad
CNRM-CM5_r1_RCA4	bad	reasonable	1.31 (1.13…1.41)	-0.46 (-0.77…-0.36)	bad
CNRM-CM5_r1_REMO2015	good	good	1.12 (1.01…1.19)	-0.09 (-0.21…-0.04)	good

CNRM-CM5_r1_WRF381P	bad	reasonable	1.62 (1.42…1.87)	-0.2 (-0.26…-0.14)	bad
EC-EARTH_r1_COSMO-crCLIM-v1-1	good	good	1.29 (1.15…1.37)	-0.27 (-0.45…-0.22)	good
EC-EARTH_r1_HIRHAM5	good	good	1.14 (0.94…1.22)	-0.12 (-0.15…-0.09)	good
EC-EARTH_r1_RACMO22E	reasonable	good	1.11 (1.12…1.34)	-0.27 (-0.33…-0.28)	reasonable
EC-EARTH_r1_RCA4	reasonable	good	1.03 (0.83…1.03)	-0.23 (-0.38…-0.11)	reasonable
EC-EARTH_r12_CCLM4-8-17	good	good	1.27 (1.11…1.3)	-0.26 (-0.35…-0.19)	good
EC-EARTH_r12_COSMO-crCLIM-v1-1	good	good	1.23 (1.12…1.35)	-0.3 (-0.42…-0.28)	good
EC-EARTH_r12_HadREM3-GA7-05	reasonable	good	1.12 (1.07…1.16)	-0.3 (-0.45…-0.19)	reasonable
EC-EARTH_r12_HIRHAM5	good	good	1.01 (0.87…1.01)	-0.28 (-0.24…-0.19)	good
EC-EARTH_r12_RACMO22E	bad	bad	1.17 (1.14…1.37)	-0.31 (-0.4…-0.28)	bad
EC-EARTH_r12_RCA4	bad	bad	1.19 (1.13…1.67)	-0.36 (-1…-0.38)	bad
EC-EARTH_r12_RegCM4-6	bad	reasonable	1.3 (1.17…1.23)	-0.54 (-0.57…-0.37)	bad
EC-EARTH_r12_REMO2015	good	good	1.03 (0.8…1.15)	-0.24 (-0.47…-0.2)	good
EC-EARTH_r12_WRF361H	bad	bad	1.45 (1.18…1.53)	-0.39 (-0.53…-0.36)	bad
EC-EARTH_r12_WRF381P	bad	bad	1.7 (1.59…1.77)	-0.48 (-0.65…-0.47)	bad
EC-EARTH_r3_COSMO-crCLIM-v1-1	good	good	1.13 (0.99…1.32)	-0.29 (-0.47…-0.22)	good
EC-EARTH_r3_HIRHAM5	good	good	0.97 (0.84…1.04)	-0.09 (-0.29…-0.06)	good
EC-EARTH_r3_RACMO22E	bad	good	1.02 (0.85…1.06)	-0.17 (-0.26…-0.08)	bad
EC-EARTH_r3_RCA4	bad	good	1.05 (0.96…1.15)	-0.27 (-0.4…-0.2)	bad
HadGEM2-ES_r1_ALADIN63	good	bad	1.35 (1.28…1.45)	-0.4 (-0.46…-0.35)	bad
HadGEM2-ES_r1_CCLM4-8-17	reasonable	bad	1.34 (1.15…1.54)	-0.02 (-0.15…0.3)	bad
HadGEM2-ES_r1_COSMO-crCLIM-v1-1	reasonable	bad	1.43 (1.17…1.55)	-0.21 (-0.21…-0.15)	bad
HadGEM2-ES_r1_HadREM3-GA7-05	good	bad	1.12 (0.91…1.13)	-0.2 (-0.25…0.04)	bad
HadGEM2-ES_r1_HIRHAM5	reasonable	bad	1.21 (1.11…1.48)	-0.06 (-0.2…0.04)	bad
HadGEM2-ES_r1_RACMO22E	good	good	1.39 (1.14…1.55)	-0.21 (-0.34…-0.09)	reasonable

HadGEM2-ES_r1_RCA4	good	good	1.36 (1.21…1.38)	-0.34 (-0.4…-0.23)	good
HadGEM2-ES_r1_RegCM4-6	good	bad	1.28 (1.24…1.9)	-0.42 (-1.05…-0.43)	bad
HadGEM2-ES_r1_REMO2015	reasonable	bad	1.18 (1.02…1.24)	-0.12 (-0.13…-0.03)	bad
HadGEM2-ES_r1_WRF361H	good	reasonable	1.49 (1.11…1.62)	-0.54 (-0.81…-0.45)	reasonable
HadGEM2-ES_r1_WRF381P	reasonable	reasonable	1.52 (1.36…1.72)	-0.21 (-0.31…-0.2)	reasonable
IPSL-CM5A-MR_r1_HIRHAM5	good	good	0.88 (0.76…0.89)	-0.07 (-0.19…0)	reasonable
IPSL-CM5A-MR_r1_RACMO22E	reasonable	good	1.03 (0.94…1.11)	-0.25 (-0.53…-0.15)	reasonable
IPSL-CM5A-MR_r1_RCA4	reasonable	good	1.29 (1.14…1.36)	-0.22 (-0.51…-0.13)	reasonable
IPSL-CM5A-MR_r1_REMO2015	good	good	1.05 (0.93…1.1)	-0.04 (-0.22…0.07)	reasonable
IPSL-CM5A-MR_r1_WRF381P	bad	good	1.56 (1.48…1.85)	-0.26 (-0.37…-0.15)	bad
MIROC5_r1_CCLM4-8-17	good	good	1.16 (1.08…1.14)	-0.36 (-0.4…-0.32)	good
MIROC5_r1_REMO2015	good	good	1.28 (1.1…1.44)	-0.37 (-0.48…-0.17)	good
MPI-ESM-LR_r1_ALADIN63	good	reasonable	1.1 (0.74…1.19)	-0.29 (-0.36…-0.16)	reasonable
MPI-ESM-LR_r1_CCLM4-8-17	good	good	1.19 (1.14…1.34)	-0.19 (-0.31…-0.06)	good
MPI-ESM-LR_r1_COSMO-crCLIM-v1-1	good	good	1.31 (1.14…1.35)	-0.16 (-0.3…-0.03)	good
MPI-ESM-LR_r1_HadREM3-GA7-05	good	reasonable	1.05 (0.88…1.14)	-0.39 (-0.5…-0.28)	reasonable
MPI-ESM-LR_r1_HIRHAM5	good	good	1.1 (0.78…1.15)	-0.08 (-0.07…0.12)	bad
MPI-ESM-LR_r1_RACMO22E	good	good	1.13 (0.98…1.34)	-0.26 (-0.42…-0.07)	good
MPI-ESM-LR_r1_RCA4	good	good	0.96 (0.74…1.09)	-0.16 (-0.21…-0.08)	good
MPI-ESM-LR_r1_RegCM4-6	good	good	1.15 (1.03…1.23)	-0.4 (-0.63…-0.31)	good
MPI-ESM-LR_r1_REMO2009	good	good	1.09 (1.14…1.25)	-0.15 (-0.34…-0.07)	good
MPI-ESM-LR_r1_WRF361H	bad	bad	1.16 (1.08…1.24)	-0.4 (-0.47…-0.23)	bad
MPI-ESM-LR_r2_COSMO-crCLIM-v1-1	good	good	1.06 (0.97…1.2)	-0.06 (-0.22…0.01)	reasonable
MPI-ESM-LR_r2_RCA4	good	good	1.24 (1.08…1.35)	-0.24 (-0.56…-0.18)	good
MPI-ESM-LR_r2_REMO2009	good	good	0.95 (0.91…1.05)	-0.02 (-0.26…0.03)	reasonable

MPI-ESM-LR_r3_COSMO-crCLIM-v1-1	good	good	1.16 (1…1.28)	-0.23 (-0.38…-0.06)	good
MPI-ESM-LR_r3_RCA4	good	bad	1.33 (1.08…1.55)	-0.45 (-0.54…-0.24)	bad
NorESM1-M_r1_ALADIN63	reasonable	bad	1.07 (1.02…1.21)	-0.19 (-0.35…-0.22)	bad
NorESM1-M_r1_COSMO-crCLIM-v1-1	good	good	1.01 (0.82…1.12)	-0.2 (-0.25…-0.03)	good
NorESM1-M_r1_HadREM3-GA7-05	good	good	1.17 (1.06…1.23)	-0.21 (-0.34…-0.14)	good
NorESM1-M_r1_HIRHAM5	good	reasonable	0.85 (0.67…0.92)	-0.13 (-0.37…-0.04)	reasonable
NorESM1-M_r1_RACMO22E	good	good	1.12 (1.03…1.3)	-0.27 (-0.43…-0.28)	good
NorESM1-M_r1_RCA4	reasonable	good	1.13 (0.83…1.17)	-0.34 (-0.35…-0.13)	reasonable
NorESM1-M_r1_RegCM4-6	bad	bad	1.3 (0.93…1.45)	-0.3 (-0.37…-0.13)	bad
NorESM1-M_r1_REMO2015	reasonable	good	1.03 (0.88…1.23)	-0.26 (-0.36…-0.15)	reasonable
NorESM1-M_r1_WRF381P	bad	bad	1.37 (1.29…1.39)	-0.17 (-0.32…-0.1)	bad
ACCESS-CM2_r1i1p1f1_gn	bad	good	0.84 (0.83…0.91)	-0.45 (-0.79…-0.43)	bad
AWI-CM-1-1-MR_r1i1p1f1_gn	bad	good	0.96 (0.84…0.98)	-0.22 (-0.23…-0.14)	bad
CMCC-ESM2_r1i1p1f1_gn	good	good	1.34 (1.09…1.4)	-0.19 (-0.2…-0.11)	good
CNRM-CM6-1-HR_r1i1p1f2_gr	good	good	1.07 (0.99…1.11)	-0.15 (-0.16…-0.05)	good
CNRM-CM6-1_r1i1p1f2_gr	good	good	1.48 (1.27…1.64)	-0.23 (-0.38…-0.04)	reasonable
EC-Earth3-Veg-LR_r1i1p1f1_gr	bad	good	0.97 (0.84…1.01)	-0.15 (-0.27…-0.03)	bad
GFDL-ESM4_r1i1p1f1_gr1	good	good	1.08 (0.93…1.16)	-0.2 (-0.28…-0.07)	good
INM-CM4-8_r1i1p1f1_gr1	bad	bad	1.18 (1.01…1.24)	0 (-0.12…0.1)	bad
INM-CM5-0_r1i1p1f1_gr1	bad	bad	1.02 (0.86…1.07)	0.13 (0.14…0.26)	bad
KACE-1-0-G_r1i1p1f1_gr	bad	good	0.86 (0.81…0.98)	-0.29 (-0.49…-0.27)	bad
MPI-ESM1-2-LR_r1i1p1f1_gn	bad	good	1.03 (0.91…1.05)	0.01 (0.03…0.13)	bad
MRI-ESM2-0_r1i1p1f1_gn	bad	good	1.05 (0.99…1.11)	-0.08 (-0.26…0.02)	bad
NorESM2-MM_r1i1p1f1_gn	bad	good	1.26 (1.16…1.25)	-0.22 (-0.34…-0.2)	bad

Table A.3: Evaluation results of the climate models considered for attribution analysis of Tn1x over the study region. Results of a visual evaluation of the seasonal cycle and spatial pattern are given. For each model, the best estimate of the Sigma parameter is shown, and a 95% confidence interval is given for *each, obtained via bootstrapping. The qualitative evaluation is shown in the right-hand column.Models that passed validation and used in the analysis are highlighted in **bold**.*

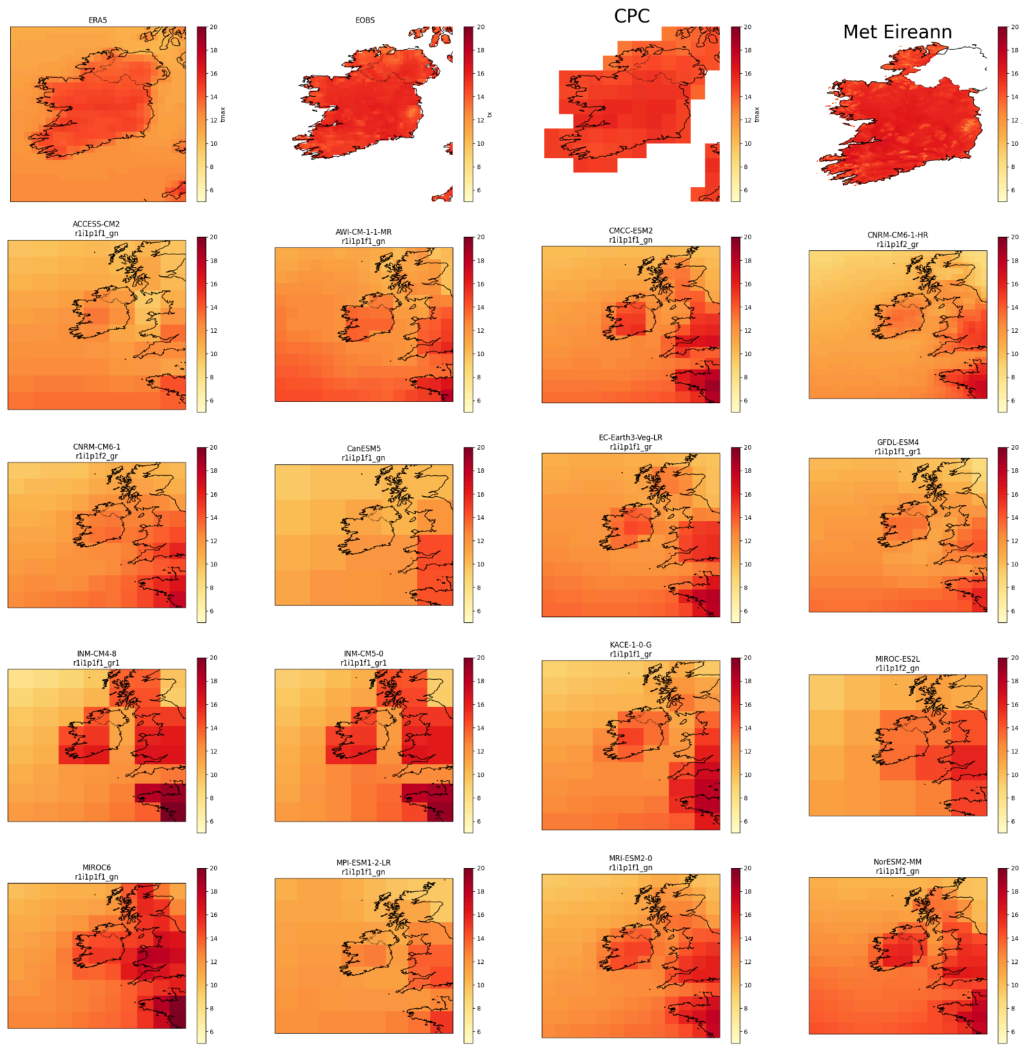


Figure A.1: Spatial patterns of daily maximum temperatures in observations and CMIP6 models.

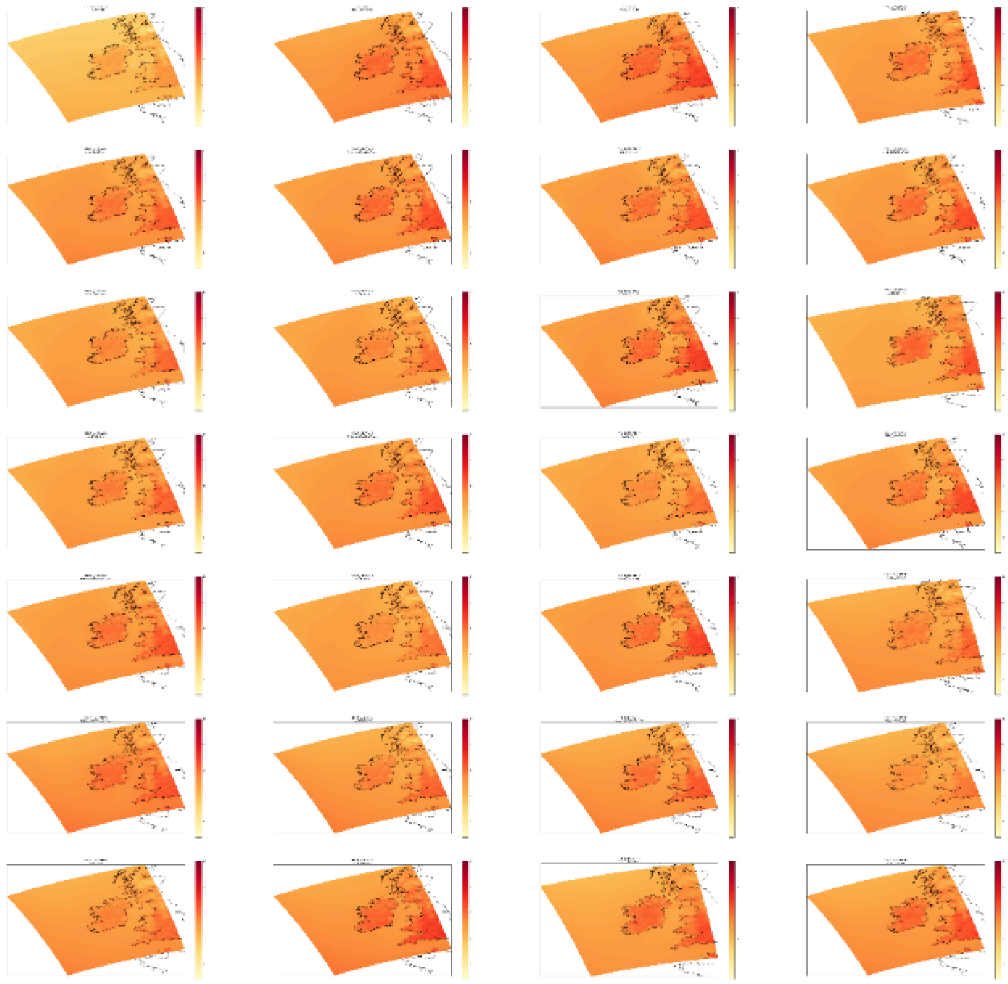


Figure A.2: Spatial patterns of daily maximum temperatures in observations and CORDEX models.

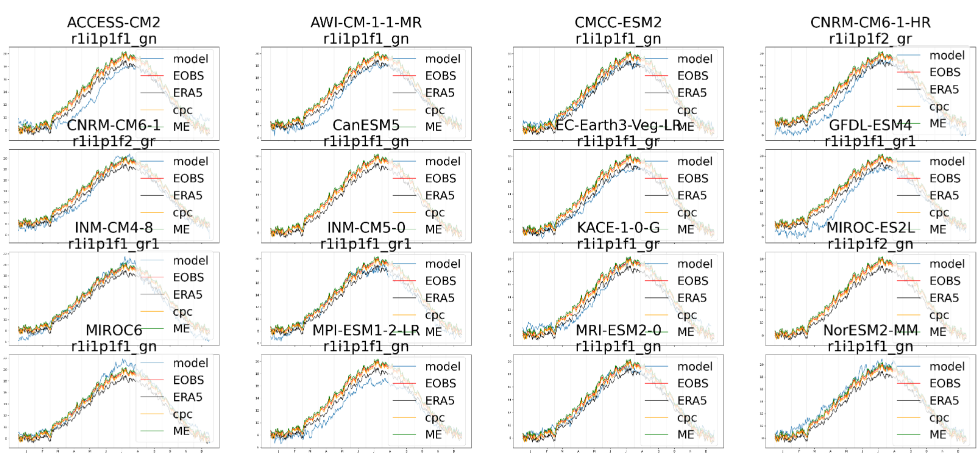
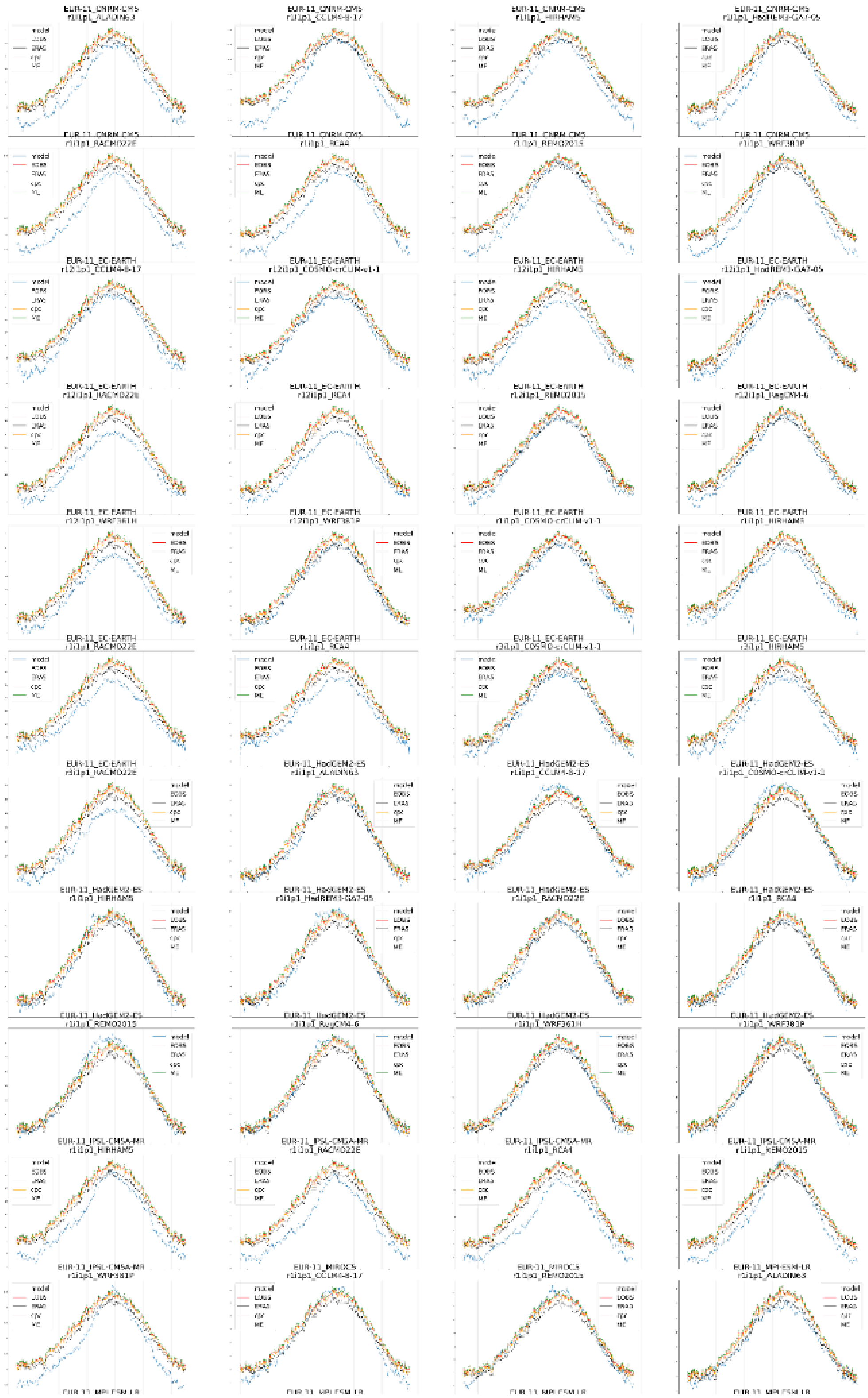


Figure A.3: Seasonal cycles of daily maximum temperatures in observations, EOBS shown in red, ERA5 shown in black, CPC in yellow, Met Éireann in green, and CMIP6 models, shown in blue.



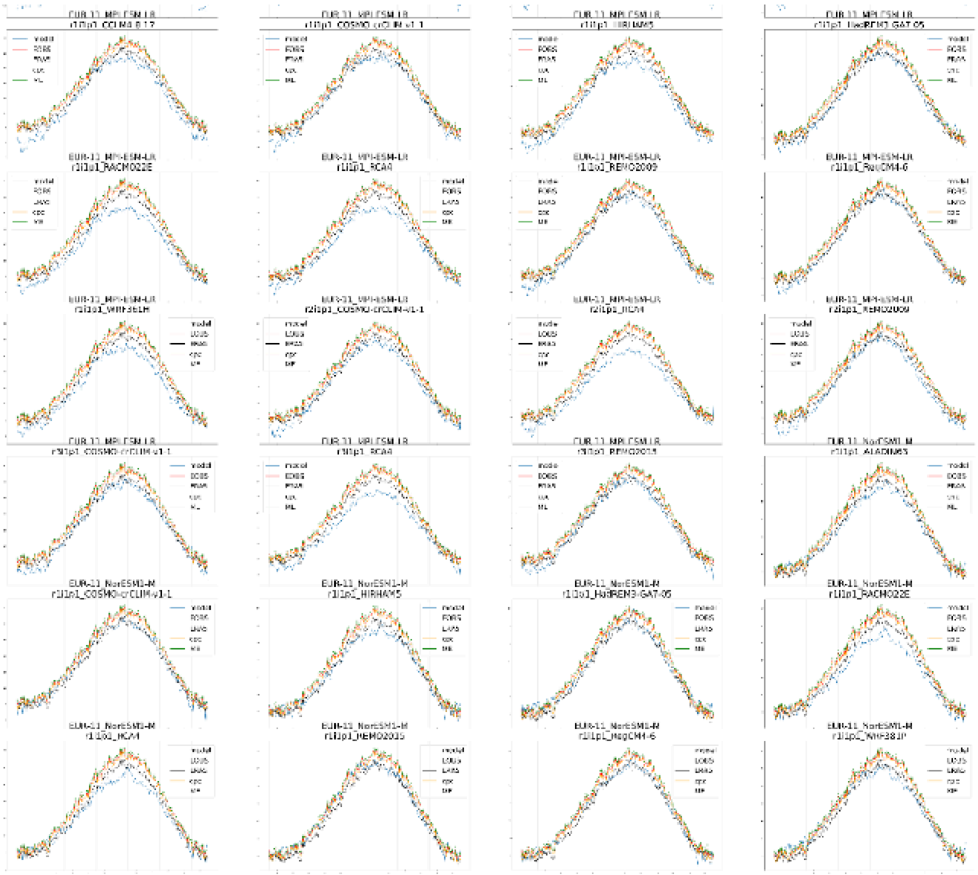


Figure A.4: Seasonal cycles of daily maximum temperatures in observations, EOBS shown in red, ERA5 shown in black, CPC in yellow, Met Éireann in green, and CORDEX models, shown in blue.

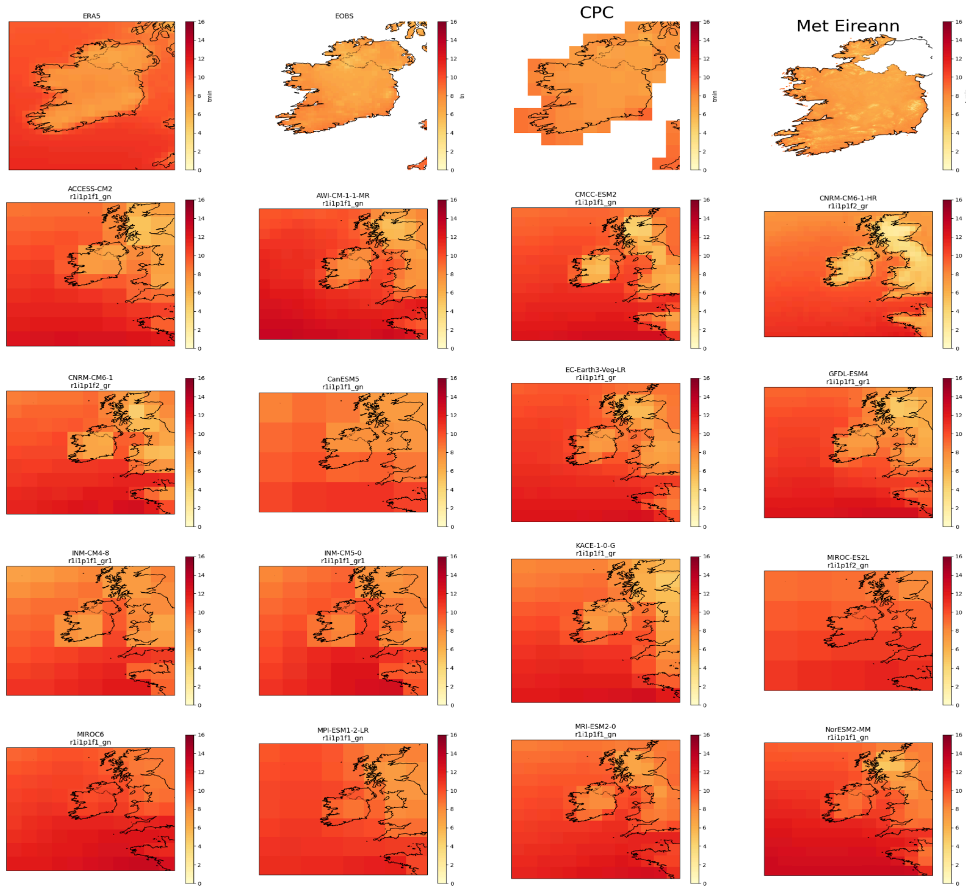


Figure A.5: Spatial patterns of daily minimum temperatures in observations and CMIP6 models.

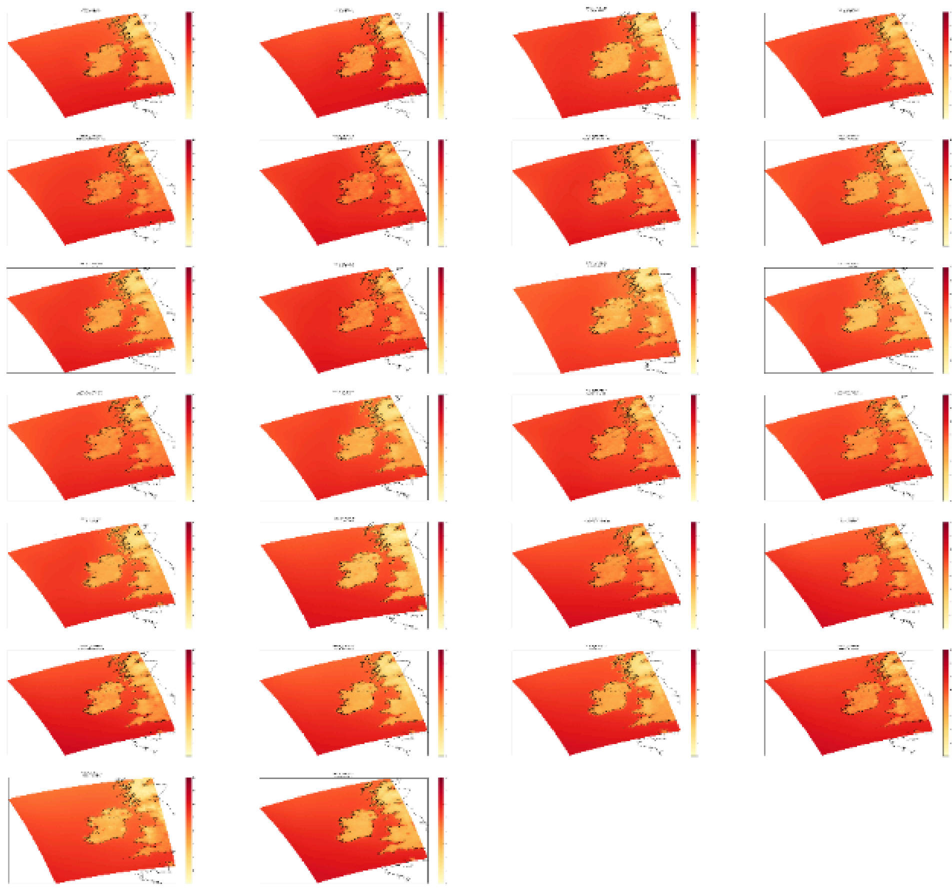


Figure A.6: Spatial patterns of daily minimum temperatures in observations and CORDEX models.

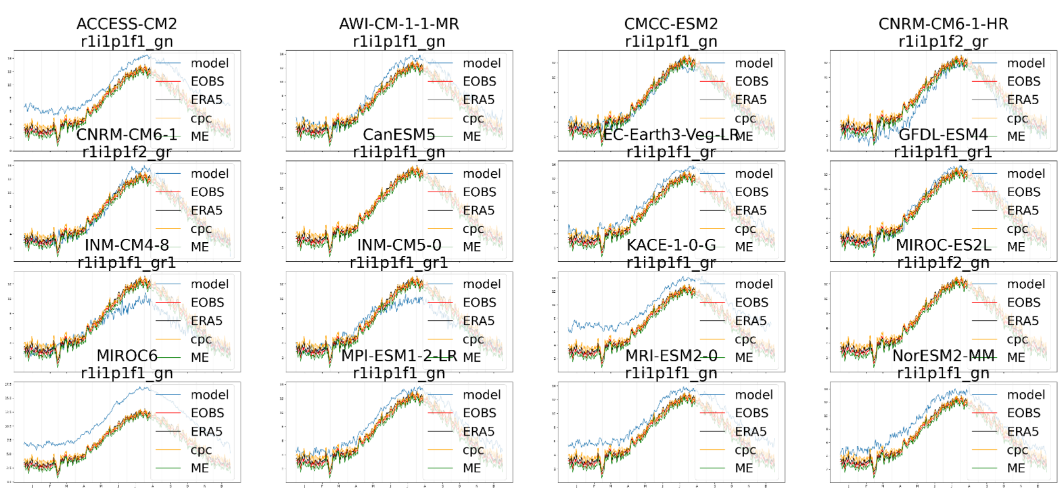
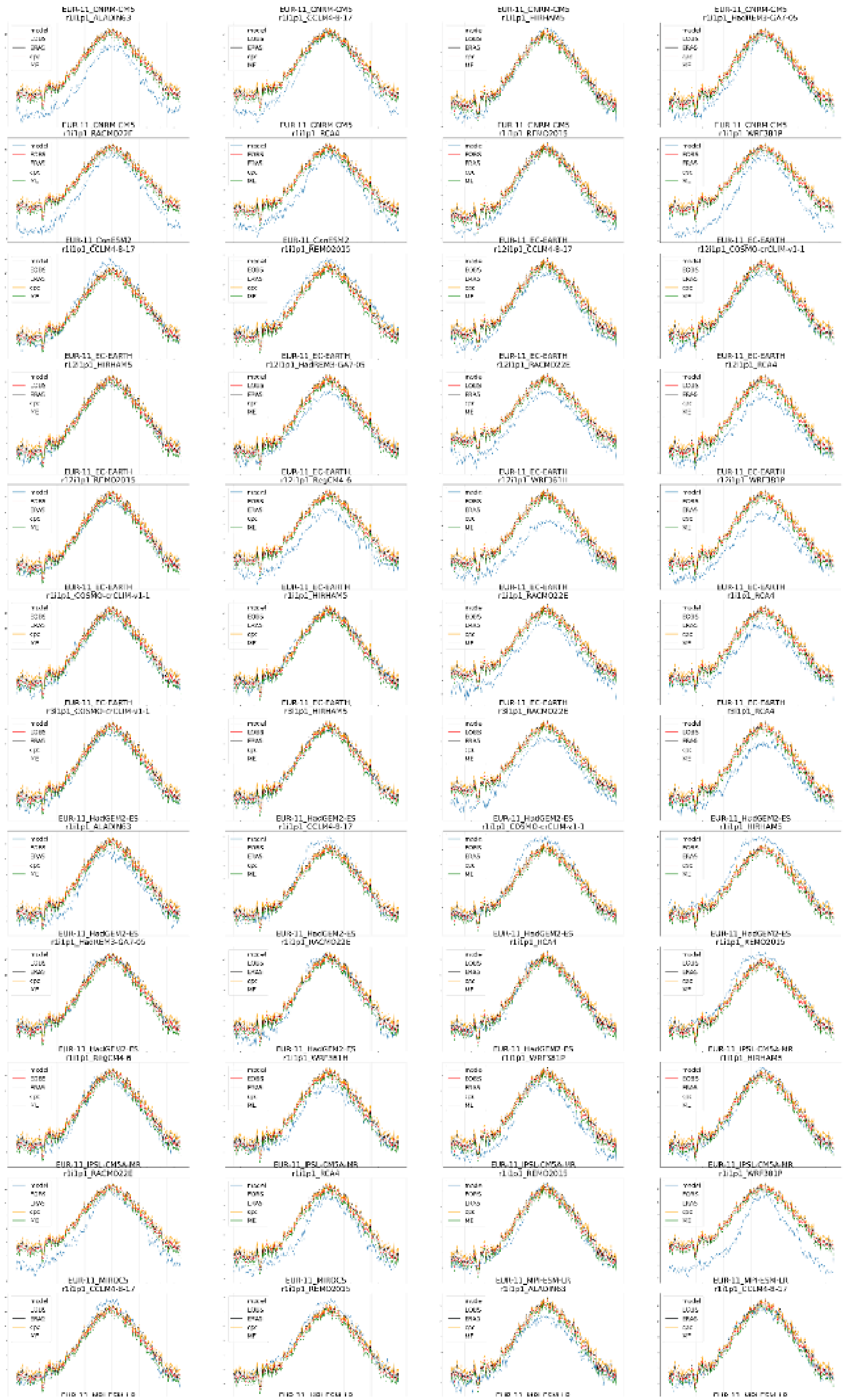


Figure A.7: Seasonal cycles of daily minimum temperatures in observations, EOBS shown in red, ERA5 shown in black, CPC in yellow, Met Éireann in green, and CMIP6 models, shown in blue.



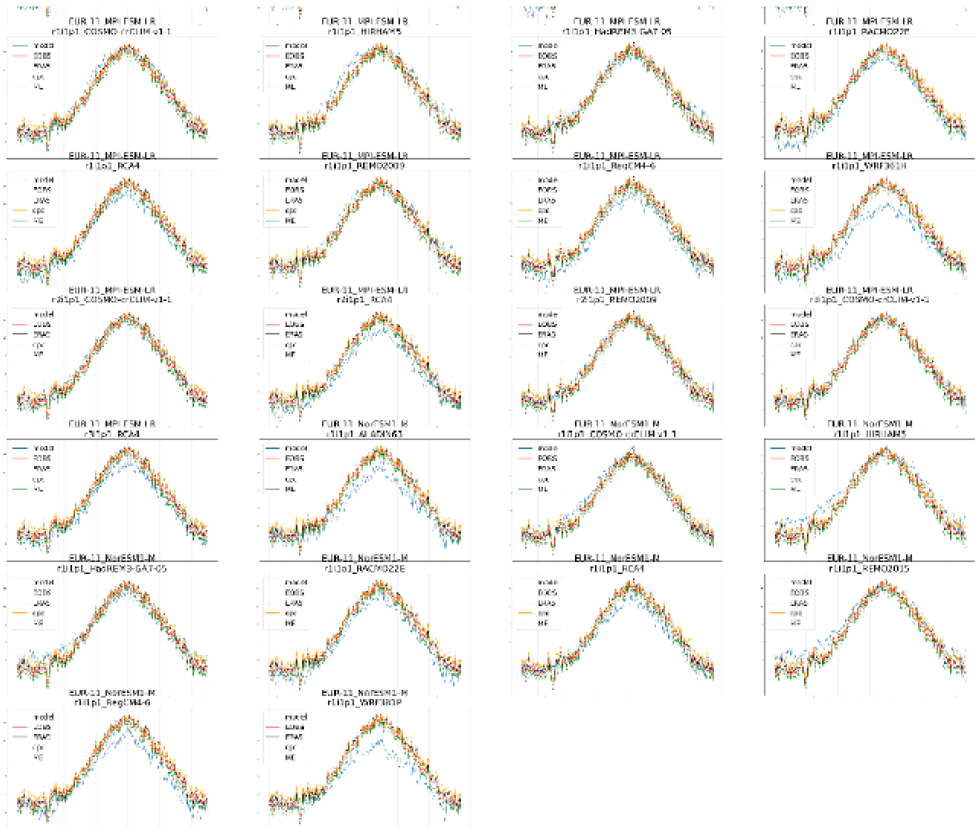


Figure A.8: Seasonal cycles of daily minimum temperatures in observations, EOBS shown in red, ERA5 shown in black, CPC in yellow, Met Éireann in green, and CORDEX models, shown in blue.