



WASITUS Retrospective Attribution Study:

Warm Summer Months of June & July 2018 Exacerbated by Anthropogenic Climate Change

Author list: *Lionel Swan*

Review author list: *Claire Bergin, Peter Thorne, Clair Barnes*

Report No. 0005



Warm Summer Months of June & July 2018 Exacerbated by Anthropogenic Climate Change

Authors

Lionel Swan, *ICARUS Climate Research Centre, Maynooth University, Maynooth, Ireland*

Review Authors

Claire Bergin, *ICARUS Climate Research Centre, Maynooth University, Maynooth, Ireland*

Peter Thorne, *ICARUS Climate Research Centre, Maynooth University, Maynooth, Ireland*

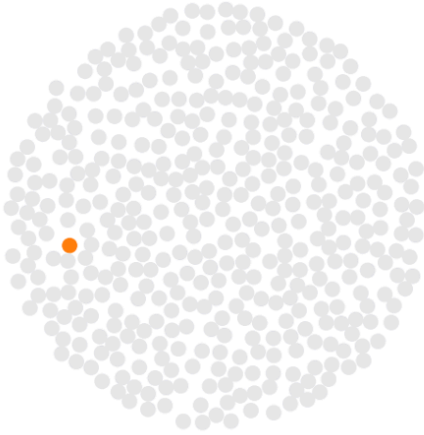
Clair Barnes, *Centre for Environmental Policy, Imperial College, London, UK*

Main findings

- The average daily maximum temperatures experienced in June-July of 2018 became 6 times more likely in 2018 compared to the pre-industrial period, changing from a 1-in-420 year event to a 1-in-70 year event.
- In the 2026 climate (1.3°C of warming), and under further warming to 1.5°C, 2°C and 3°C above pre-industrial, similar average daily maximum temperatures are projected to happen once every 53 years, 38 years, 19 years and 6 years respectively.
- While average night-time temperatures of June-July 2018 were not as extreme, they have become 23 times more likely in 2018 compared to a pre-industrial climate changing from a 1-in-230 year event to a 1-in-10 year event.
- Similar minimum temperatures have become a 1-in-7 year event under a 2026 climate (1.3°C), and with further warming to 1.5°C, 2°C and 3°C above pre-industrial, projected return periods are 1-in-5 years, 1-in-3 years and 1-in-1 years (every year) respectively.
- The minimum 30-day precipitation during June and July of 2018 was found to have a return period of 30 years. Its probability in 2018 was 0.66 times the pre-industrial probability, indicating similarly low precipitation events had become less likely to occur compared to the pre-industrial period.
- Similar low precipitation extremes are expected to occur 1.04 times more in 2026 compared to in 2018, with projections showing an additional increase in the likelihood of 1.07, 1.17 and 1.37 times under future warming of 1.5°C, 2°C and 3°C respectively.
- The low precipitation event was found to be less extreme, becoming 3% wetter in 2018 compared to the pre-industrial period. However, observational data indicates a much higher increase in the intensity of this event than the climate models. Although it is hard to say for certain, there is a possibility that these climate models have underpredicted the change in intensity. The discrepancy between modelled and observed behaviour means there is low confidence in the analysis of precipitation change.

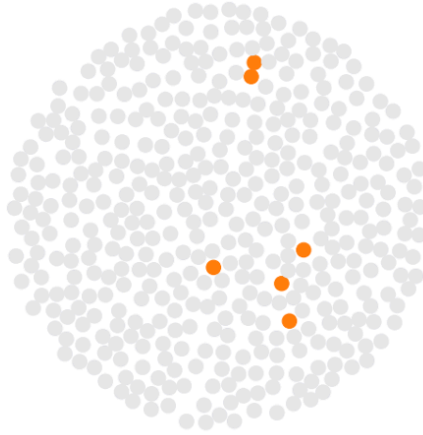
How often the average daily maximum temperatures of June-July 2018 are expected to happen relative to different levels of global temperature increase since pre-industrial times

Pre-industrial climate



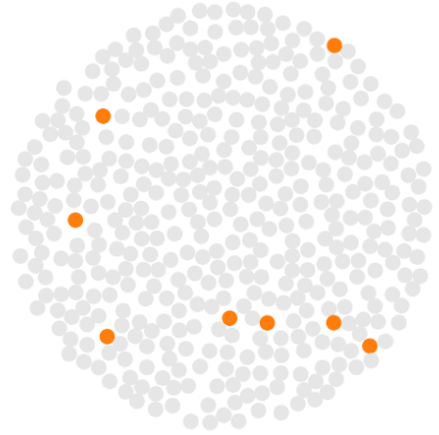
1 in 420-year event

2018 with 1.1 °C warming



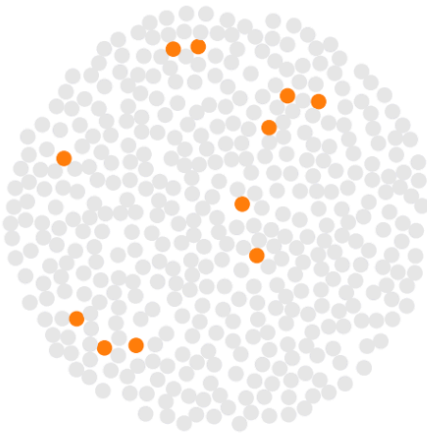
1 in 70-year event

Present (2026) with 1.3 °C warming



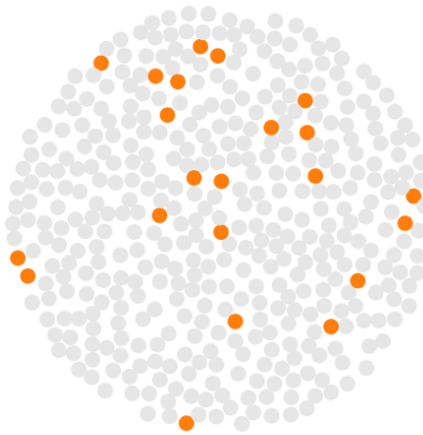
1 in 53-year event

Future with 1.5 °C warming



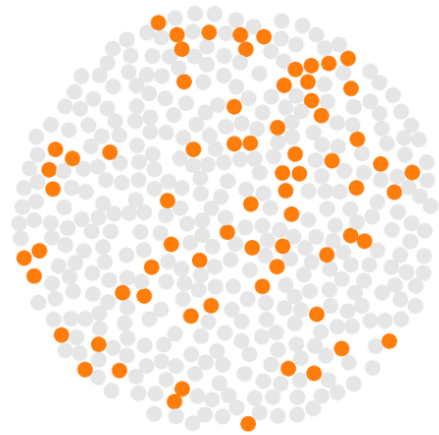
1 in 38-year event

Future with 2.0 °C warming



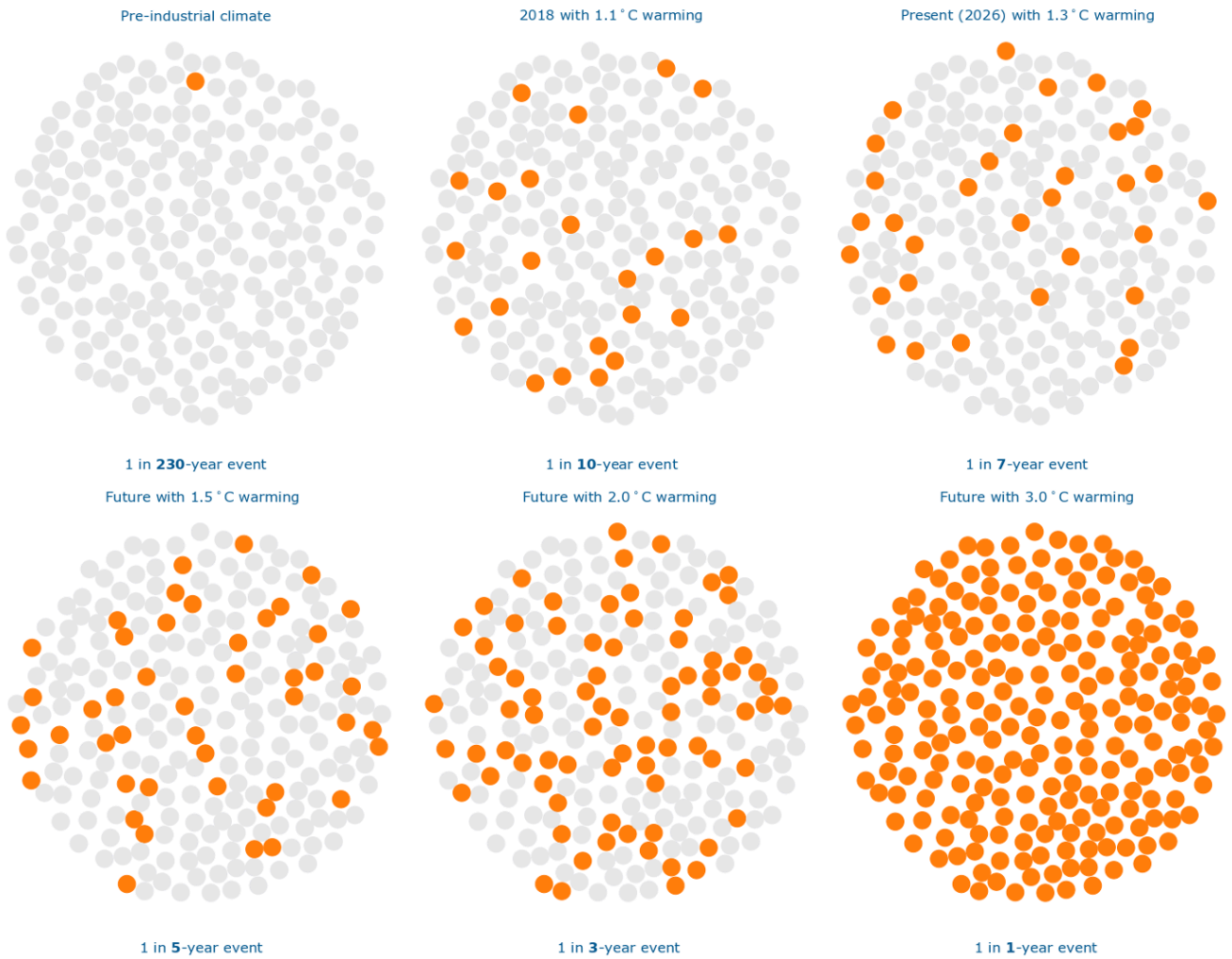
1 in 19-year event

Future with 3.0 °C warming

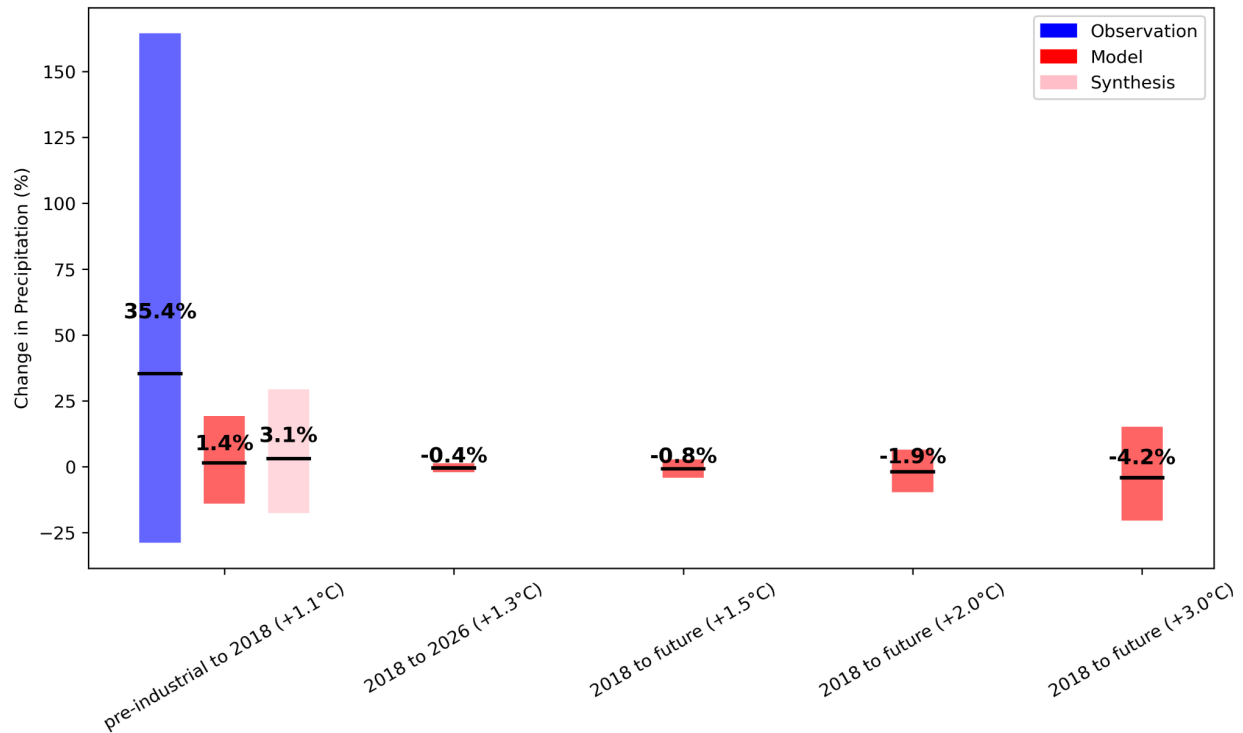


1 in 6-year event

How often the average daily minimum temperatures of June-July 2018 are expected to happen relative to different levels of global temperature increase since pre-industrial times



Change in precipitation (%) of the annual minimum 30-day precipitation during June and July relative to different levels of global temperature increase since pre-industrial times



1 Introduction

During the months of June and July of 2018, Ireland experienced prolonged periods of exceptionally hot, dry and sunny weather. Heatwave conditions (≥ 5 consecutive days of maximum temperatures exceeding 25°C , [Met Eireann, 2020a](#)) were recorded across the country at 15 synoptic stations between the 24th June and 4th July. Rainfall was also unusually low for Ireland and the majority of north-western Europe throughout June and July 2018 ([Figure 1.1](#)). Cork Airport recorded its driest summer on record, while the Phoenix Park station experienced its second driest June-July since 1880 ([Met Eireann, 2020a](#)). The combination of high temperatures and low rainfall led to meteorological drought conditions across much of the country. In Ireland, meteorological droughts can take the form of one of the following three classifications; [1] - A Dry Spell: Refers to 15 or more consecutive days where rainfall is less than 1 mm; [2] - An Absolute Drought: Refers to 15 or more consecutive days with less than 0.2mm of rainfall experienced per day; [3] - A Partial Drought - Refers to 29 or more consecutive days where rainfall totals average less than 0.2mm per day ([Met Eireann, 2020b](#)). A total of 5 synoptic stations recorded dry spell conditions at varying times between the 18th June and 14th July, while 20 stations recorded absolute drought conditions and 7 stations recorded partial drought conditions beginning in June and ending in July ([Met Eireann, 2020a](#)).

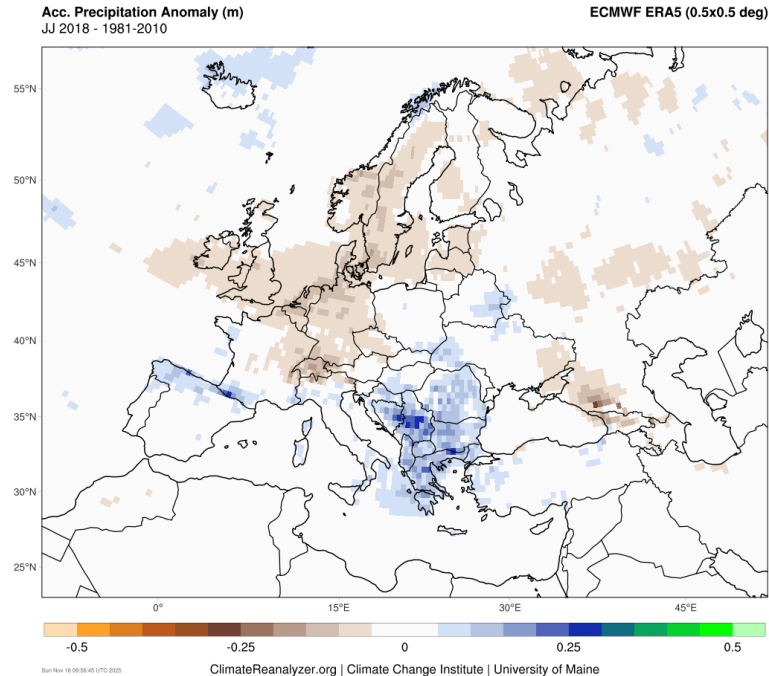


Figure 1.1: Accumulated Precipitation Anomaly (m) for June-July 2018 over Europe using ECMWF ERA5 (0.5x0.5 resolution) data. Anomalies were calculated off the baseline period 1981-2010
 Source: [Climate Reanalyzer](https://climate-reanalyzer.org)

June-July 2018 saw the highest temperature recorded by a synoptic station (Shannon Airport : 32°C). However, this record has since been broken in 2022 with a reading of 33°C at the Phoenix Park station ([Met Eireann, 2022](https://www.met.ie)). The extreme temperature experienced at the Phoenix Park station in 2022 is not defined as Ireland’s highest temperature ever; that record has remained since 1887 at Kilkenny Castle with a temperature of 33.3°C, however there is debate over the robustness of this figure ([Dooley et al., 2023](#); [Kelly et al., 2025](#)).

While June 2018 began with intense thunderstorms, conditions quickly resumed to the dry and settled weather that was experienced at the end of May. A high pressure system dominated the first two weeks of June, before Storm Hector brought unsettled conditions as it moved past the northwest of Ireland. Despite the change in conditions, rainfall remained exceptionally low, especially in the south and east of the country. For the remainder of the month, Ireland was subject to further high pressure conditions moving from the west of the country to east ([Figure 1.2](#)). This prompted the movement of a hot tropical continental air mass towards Ireland from the southeast, resulting in the highest temperatures of the summer ([Met Eireann, 2020a](#)).

July 2018 began how June ended, with warm and dry conditions across the country. This was caused by a high pressure system originating from the Azores and stretching up to Scandinavia ([Figure 1.2](#)). While pressure remained high until the 26th, occasional fronts brought rainfall on the 15th, 20th and 23rd, and overall cooler temperatures. All drought conditions were broken as Ireland became dominated by a low pressure system from the 26th of July until the end of the month. Temperatures fell to more typical levels and rainfall returned via heavy showers ([Met Eireann, 2020](#)).

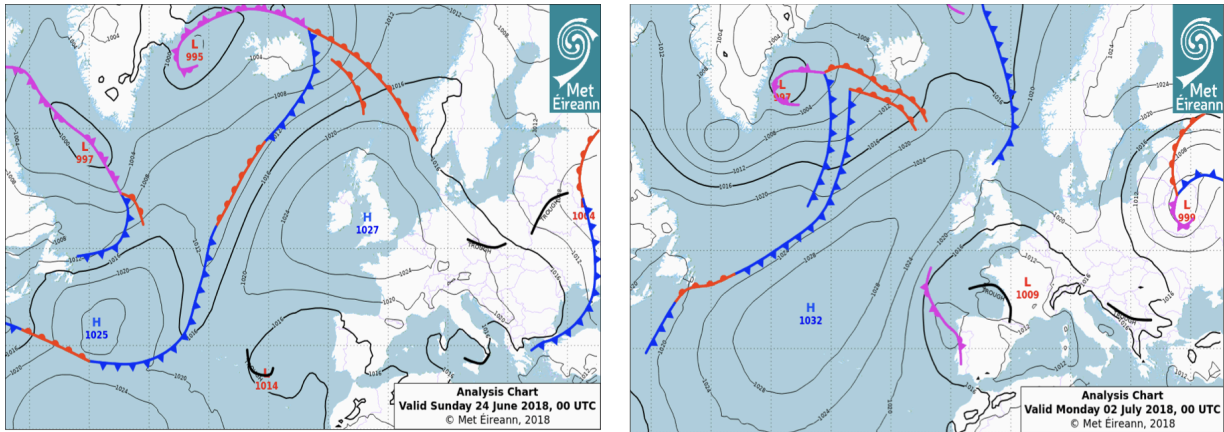


Figure 1.2: Synoptic weather conditions during 24th June 2018 (Left) and 02nd July 2018 (Right). Highlights the dominant high pressure systems that influenced Ireland's temperature over that period
Source: [Met Eireann](https://www.met.ie)

1.1 Summer 2018 and the Contributing Factors

At the time, the meteorological summer (June, July and August) of 2018 was the fourth warmest summer on record in Ireland since 1900 ([Met Eireann, 2025](https://www.met.ie)). Due to the record breaking temperatures of summer 2025 ([Bergin et al., 2025](#)), 2018 was subsequently pushed down to 5th on that list with an average temperature of 15.77°C. The heatwave conditions experienced in 2018 were caused by an atmospheric blocking event ([Nakamura and Huang, 2018](#)). This occurs when the jet stream stalls over Europe, creating a heat or high pressure 'dome' ([Figure 1.3](#)), which elevates temperatures past their usual levels ([Woolway et al., 2020](#)). The latest Irish Climate Change Assessment Report suggests these extreme temperature events are projected to increase in intensity and frequency due to human-induced climate change ([Noone et al., 2023](#)).

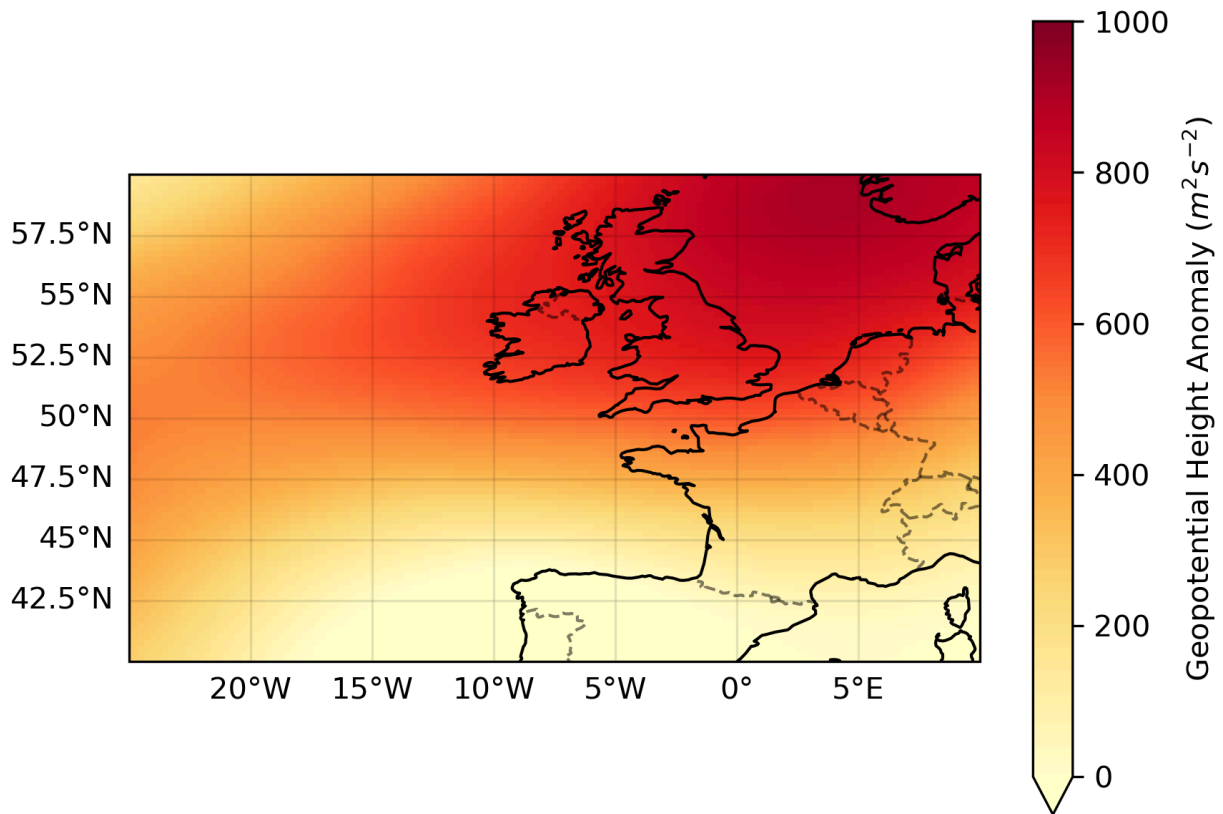


Figure 1.3: Geopotential Height (500hPa) Anomaly for June-July 2018 over Ireland using ERA5 (0.25x0.25 resolution) data. Anomalies were calculated off the baseline period 1981-2010.

The drought conditions of summer 2018 were the focus of national headlines. We have to go back as far as summer 1976 to see drought conditions rivaling those experienced in 2018 ([Met Eireann, 2025](#)). [Falzoi et al., 2019](#) confirmed that the drought conditions of summer 2018 were the most severe recorded during the period 1981 - 2018. The months of May, June and July were found to be the driest, as illustrated by examining Soil Moisture Deficit readings from the centrally situated Mullingar meteorological observation station ([Figure 1.4](#)). Most worrying is that Ireland was one of the countries in western Europe that saw the largest increase in meteorological droughts over the period 1981-2018 according to a study by [Vicente-Serrano et al., 2020](#).

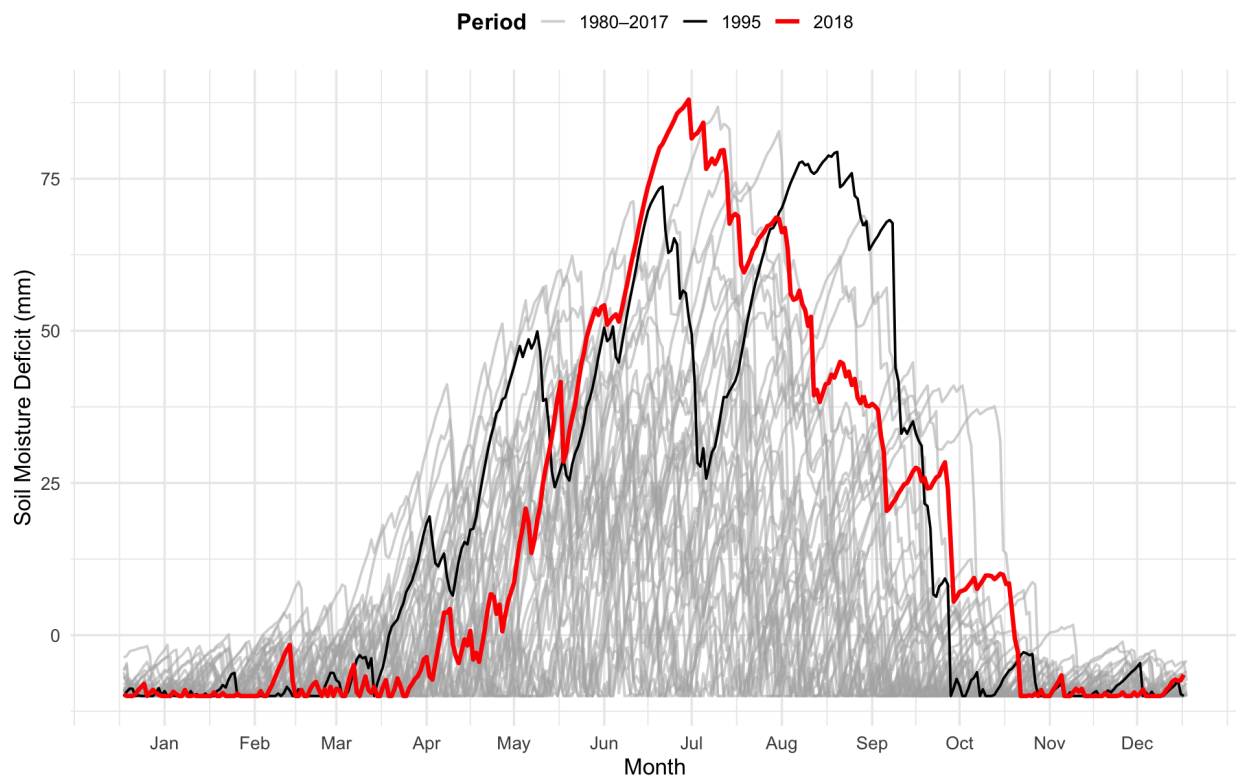


Figure 1.4: Daily Soil Moisture Deficit (poorly drained) reading from Met Eireann's Mullingar Station showing the anomalously dry soils in May, June & July of 2018 (red line). Black line represents 1995, a year that experienced similar conditions of extreme heat and low precipitation

Sea Surface Temperatures (SSTs) surrounding Ireland were anomalously high for the June-July period ([Figure 1.5](#)). From late June until the end of July, SSTs off the west coast (June) and south coast (July) of Ireland were up to 3°C warmer than the baseline (1981-2010). These higher than average ocean temperatures allowed for warm air masses moving towards Ireland to retain much more of their heat than would normally be possible. In the years since 2018, there has been a clear increase in the frequency of anomalously high SSTs in Irish waters. [McCarthy et al., 2023](#) explained how the years between 2021-2023 encapsulated 3 of the 4 highest maximum Marine Heat Wave activities recorded in Irish waters. This trend is only likely to continue, with the [IPCC](#) warming of projected increases in Marine Heat Wave frequency as the planet continues to warm.

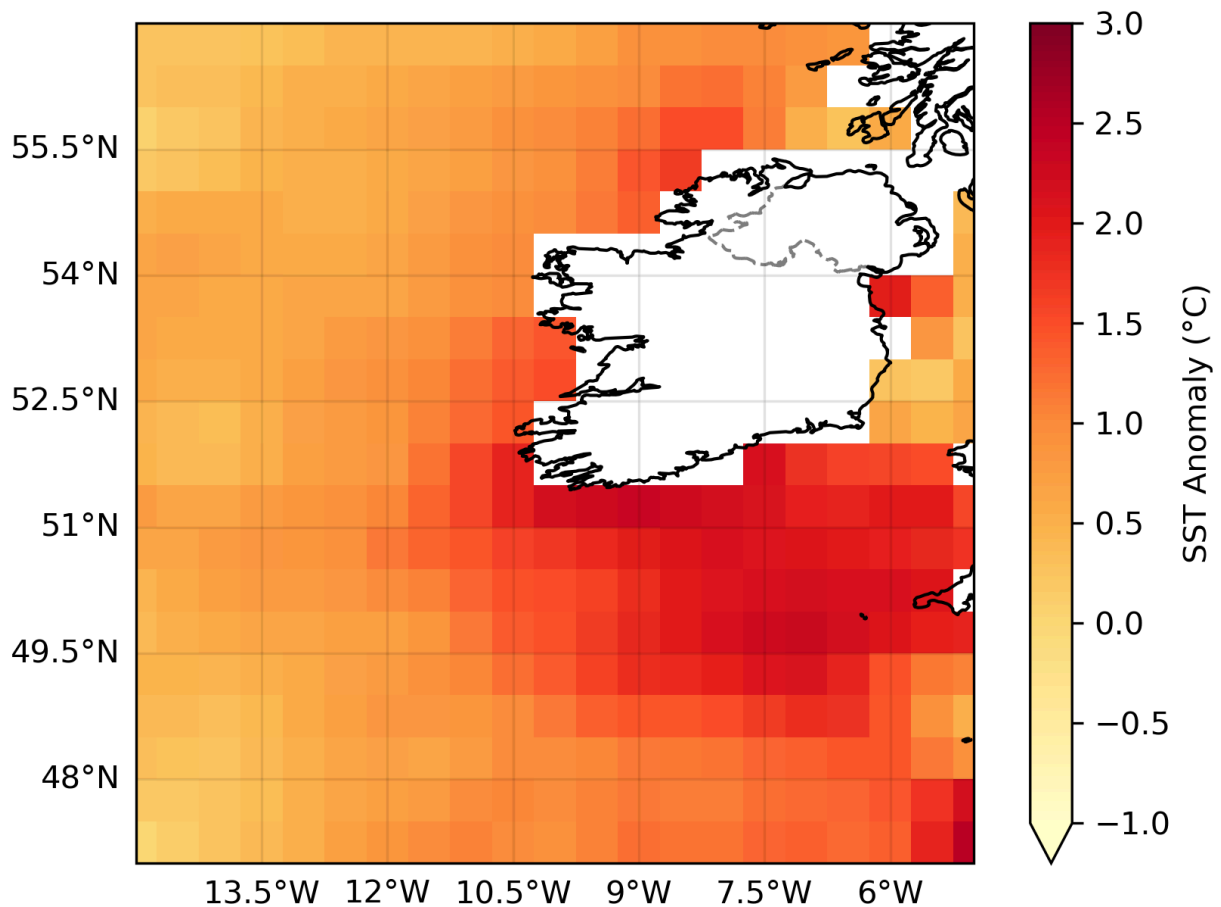


Figure 1.5: Sea Surface Temperature anomalies surrounding Ireland for June-July 2018. Anomalies calculated against a baseline period of 1981-2010. Data source: [OISST](#)

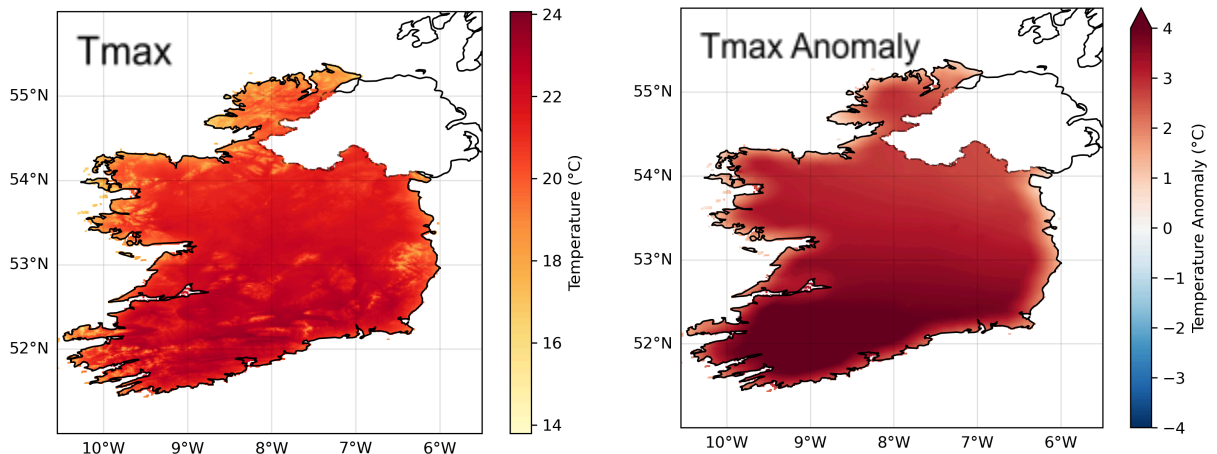
While an attribution study on the summer 2018 heatwave and drought had not previously been carried out from a purely Irish perspective, studies focusing on the heatwave in Northern Europe and the UK were conducted. Scientists at World Weather Attribution released a study suggesting human-induced climate change resulted in the hottest three-day period experienced in Ireland becoming twice as likely as it would have been in a pre-industrial climate ([Carbon Brief, 2018a](#)). And for the UK, the UK Met Office suggested the average temperatures recorded during the entire season (June, July & August) were 30 times more likely due to climate change, when compared to a 1901-1930 baseline ([Carbon Brief, 2018b](#)). A retrospective study on UK hot summers was conducted by [Kay et al., 2020](#), and they found that the likelihood of a similarly extreme summer mean temperature event occurring was less than 1% in the 1960s but had increased to ~10% by the 2010s. They further emphasize how a 1-in-5 year summer mean temperature event in the UK between 1981-2010 had doubled in likelihood by 2020, the year of study.

1.2 Event Definition

While the meteorological summer of 2018 (June, July & August) was certainly above average with regards to temperature and anomalous with respect to the presence of drought conditions, the months of June and July were particularly extreme. The average maximum temperatures for June-July 2018 were the highest recorded (1960-2018) for all four observational datasets considered herein (Section 2.1). Average precipitation was found to be the lowest across the observational time series when using a 30 day rolling mean for the June-July period. As a result, this study uses the two month average of daily minimum (night-time) and maximum (day-time) temperatures for June and July to investigate temperature and a 30 day rolling mean across June and July to investigate precipitation.

To gauge the spatial and temporal extent of the extreme temperatures during the summer of 2018, two event definitions were characterised:

- Tx2month - Two-month average of daily maximum temperatures for June and July, averaged over the Republic of Ireland
- Tn2month - Two-month average of daily minimum temperature for June and July, averaged over the Republic of Ireland



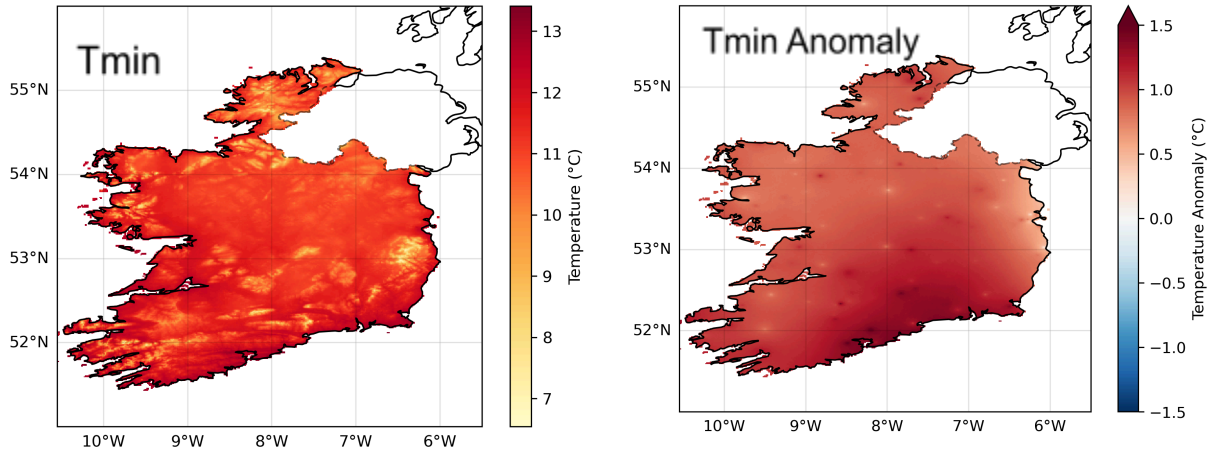


Figure 1.6: Top: June-July average maximum temperatures 2018, left, and 2018 anomalies, right (Baseline 1980-2010). Bottom: June-July average minimum temperatures 2018, left, and 2018 anomalies, right (1980-2010). Data source: [Met Eireann Gridded Products](#)

To gauge the spatial and temporal extent of precipitation, the following definition was characterised:

- Rn30day - Annual minimum 30-day precipitation during June and July, averaged over the Republic of Ireland

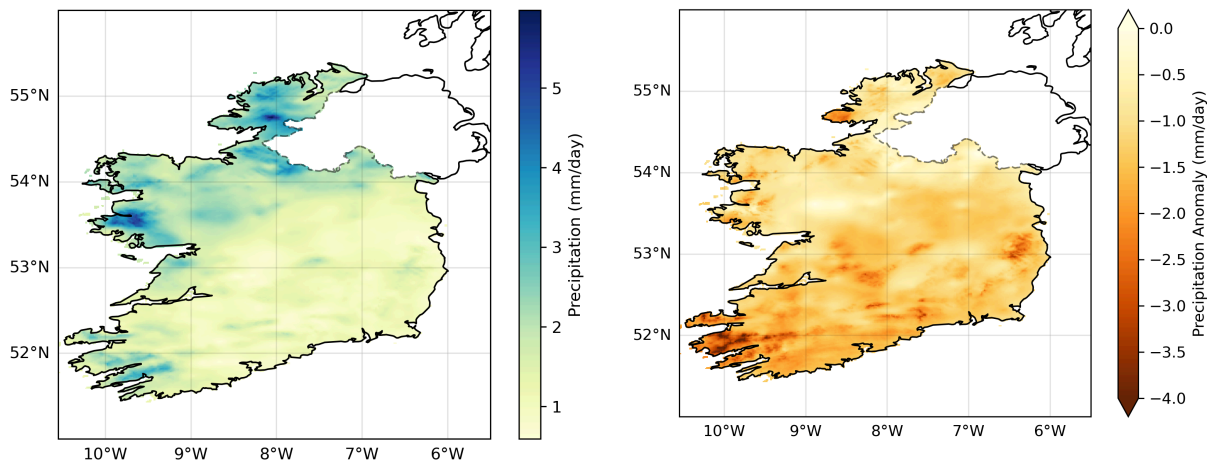


Figure 1.7: Annual minimum 30-day precipitation during June and July (Left) and 2018 anomalies (Right). Anomalies were calculated off the baseline period 1980-2010. Data source: [Met Eireann Gridded Products](#)

2 Data and methods

In this retrospective attribution report, we study the influence of human-induced climate change by comparing the likelihood and intensity of similar extremes (two-month average maximum and minimum temperatures for June and July; and annual minimum 30-day precipitation during June and July for low precipitation) at the time of the event (2018) with those in a 1.1°C cooler climate representing a preindustrial climate (1850-1900) ([IPCC,2021](#)). We also extend this analysis into the present (2026) and future by assessing the influence of a further 0.2°C, 0.4°C, 0.9°C and 1.9°C of global warming from 2018 (1.1°C). This is in line with the long term temperature goals set out by the [Paris Agreement](#) to limit warming to well under 2°C (+0.9°C), and strive for 1.5°C (+0.4°C). We also assess 3°C (+1.9°C) of global warming as this is a likely outcome over the course of this century under our 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](#)). In our analysis, we use maximum and minimum temperature data from this product at a resolution of 0.25°×0.25°, from the years 1960 to 2018. We also use precipitation data at a resolution of 0.25°×0.25°, from the years 1950 to 2018.
- **E-OBS** - This is a gridded land-only observation dataset of Europe, formed from the interpolation of station-derived meteorological observations ([Comes et al., 2018](#)). We use version 31.0e of this dataset, at spatial resolution 0.1° × 0.1° gridded. Variables used in our analysis were maximum & minimum temperature from 1960-2018, and precipitation from 1920-2018.
- **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° x 0.5° resolution, for the period 1979-2018. We use daily maximum & minimum temperatures and precipitation data, available from [NOAA](#).
- **Met Éireann** - The Irish national meteorological service, provides a [gridded product](#) at 1×1km resolution covering 1961 to 2018 for maximum and minimum temperature, and from 1940-2018 for precipitation. Interpolation methods were used to calculate the grid point values with inputs from observations recorded at Met Éireann stations.

As a measure of human-induced 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](#)).

2.2 Model and experiment descriptions

We use two multi-model ensembles from climate modelling experiments using very different framings ([Philip et al., 2020](#)): regional climate models (Euro-CORDEX) and coupled global circulation models (CMIP6)

- **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 8 global climate models. These simulations are composed of historical simulations up to 2005, and extended to the year 2100 using the RCP8.5 scenario. Euro-CORDEX was used for both temperature and precipitation analysis.
- **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. In our analysis, we use 15 of the participating models. CMIP6 was used for the temperature analysis only.

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 the change in intensity of the event in order to compare the climate of today to the climate of the past. These climates are defined respectively by the Global Mean Surface Temperature (GMST) of today's climate and of the pre-industrial climate (1850-1900) ([Global Warming Index](#)).

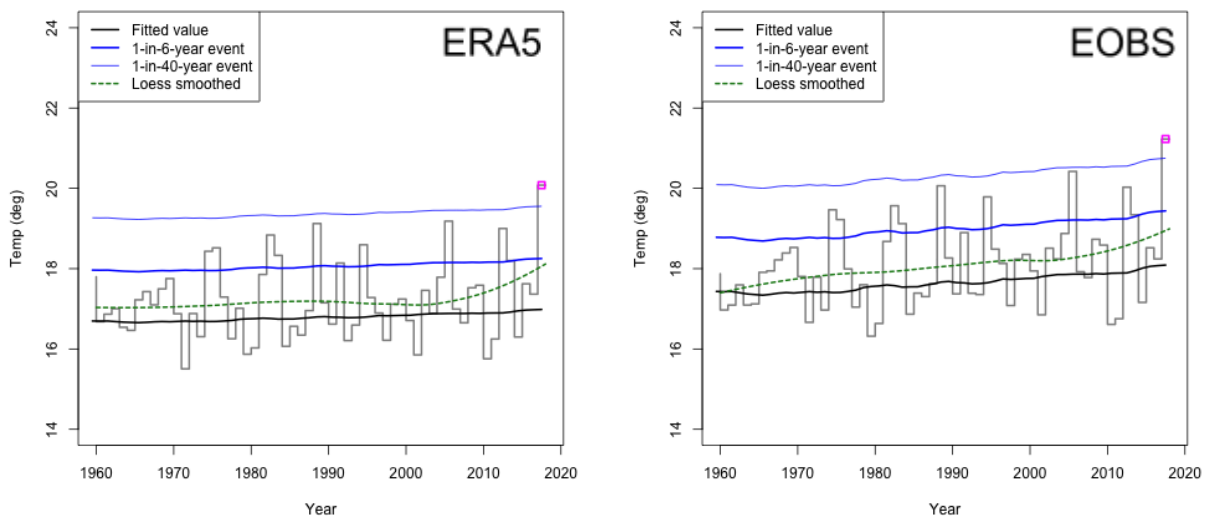
A Generalised Extreme Value distribution (GEV) was used to model the two-month average maximum and minimum temperatures, while a Log-normal distribution was used to model the annual minimum 30-day precipitation during June and July. The Akaike Information Criterion (AIC), a statistical metric used to compare distributions or statistical models, was used to select the best statistical model for each event definition. All parameters were estimated using maximum likelihood methods. Results from the observations and models were validated and then synthesised to produce a single attribution statement.

3 Observational analyses: return period and trend

For this part of the analysis, trends in observational datasets (the gridded data products set out in section 2.1) are calculated and compared. We analyse the area average Tx2month, Tn2month and Rn30day for all four gridded datasets and calculate the return period, change in intensity and probability ratio (along with the 95% confidence interval) between the 2018 climate and a past climate, that is 1.1°C cooler, by fitting statistical models to the data (GEV for Temperature and Log-normal for Precipitation).

3.1 Tx2month - Analysis of June-July Average Daily Maximum Temperatures

Figure 3.1 shows the time series for Tx2month for the four gridded data products, with the fitted GMST-dependent trend overlaid (black line). All four observational time series show an increasing trend in the average June-July maximum temperature over time, with the pink box highlighting the 2018 value the warmest on record until that date for all datasets examined. For ERA5, the 2018 event had a return period of 95 years (bootstrapped 95% confidence interval (CI): 28, 120000), for EOBS, 91 years (CI: 26, 71500), for CPC, 26 years (CI: 7, 456) and Met Eirean, 65 years (CI: 22, 4570). Therefore, a 70 year return period was decided upon to represent this event for the full attribution analysis.



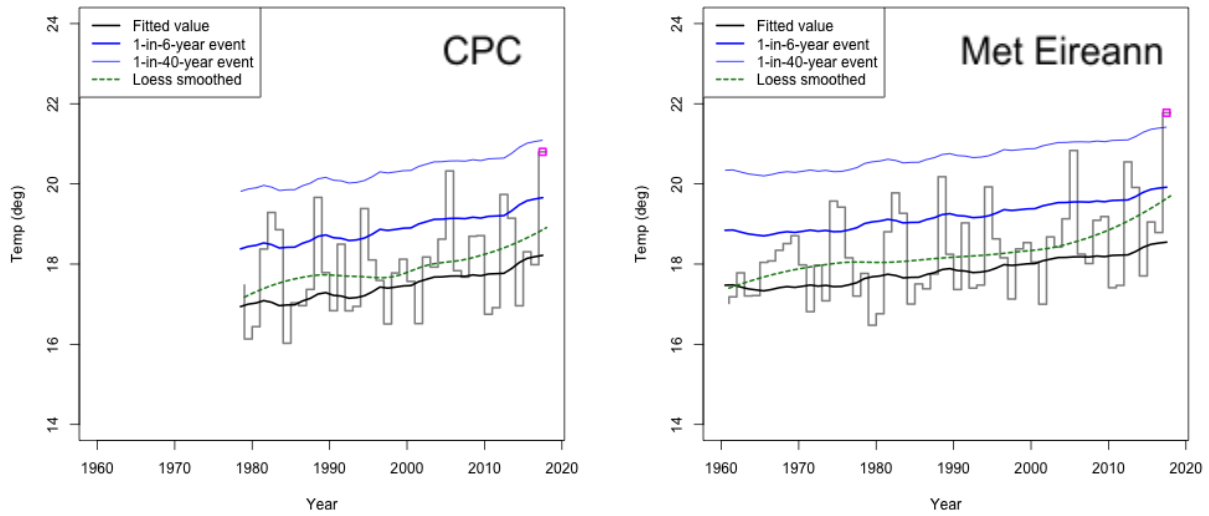
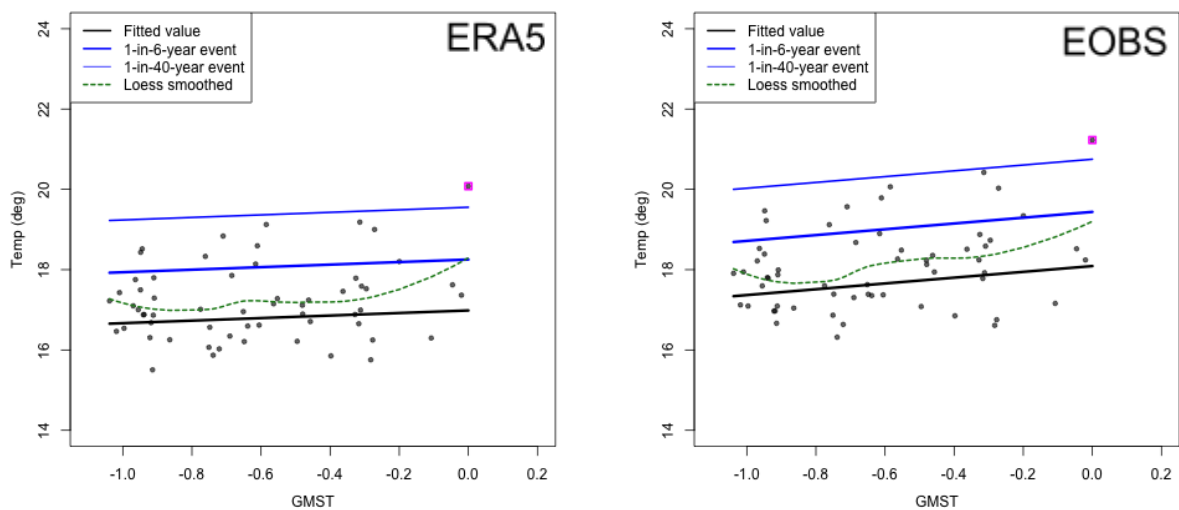


Figure 3.1: Time series of Tx2month over Ireland, with fitted model overlaid. The pink square marks the 2018 event; the heavy black line indicates the mean of the fitted Gaussian model, and the blue lines indicate the expected return levels of 6- and 40-year events. The green line is a nonparametric Loess smoother.

The fitted linear trend was also plotted against the GMST covariate as seen in Figure 3.2. For ERA5, the 2018 June-July maximum temperatures had warmed by 0.4°C (CI: -0.6, 1.4) with respect to the pre-industrial climate. In EOBS, temperatures warmed by 0.8°C (CI: -0.2, 2.2), CPC warmed by 1.8°C (CI: 0.5, 3.6) and Met Eireann warmed by 1.3°C (CI: 0.4, 2.7).



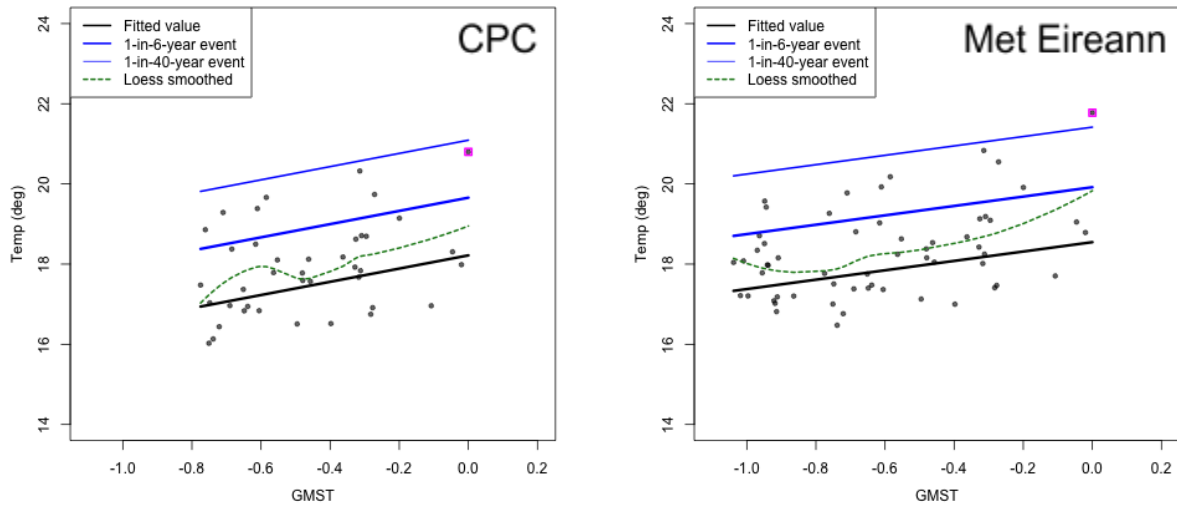


Figure 3.2: Linear trend in $T_{x2month}$ over Ireland as a function of GMST (shown as a difference from the 2018 GMST) in four gridded observational data products. The pink square marks the 2018 event; the thick black line denotes the nonstationary location of the fitted Gaussian distribution, and the 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 2018 climate (GMST anomaly = 0) and a hypothetical 1.1°C cooler climate.

The change in return level of the event from a pre-industrial climate to 2018's climate (1.1°C increase in GMST) was calculated and can be seen in [Figure 3.3](#). Across all observational datasets, a clear distinction can be made between the return levels of the current climate (red) and the pre-industrial climate (blue) for this extreme event (less so for ERA5). Best estimates of the probability ratio (factor change in the probability of such an event occurring) were calculated for each dataset: 1.8 for ERA5, 4.6 for EOBS, 18.2 for CPC and 6.1 for Met Eireann. All best estimates and their associated 95% CI's, plus the return periods and changes in intensity can be found summarised in [Table 3.1](#).

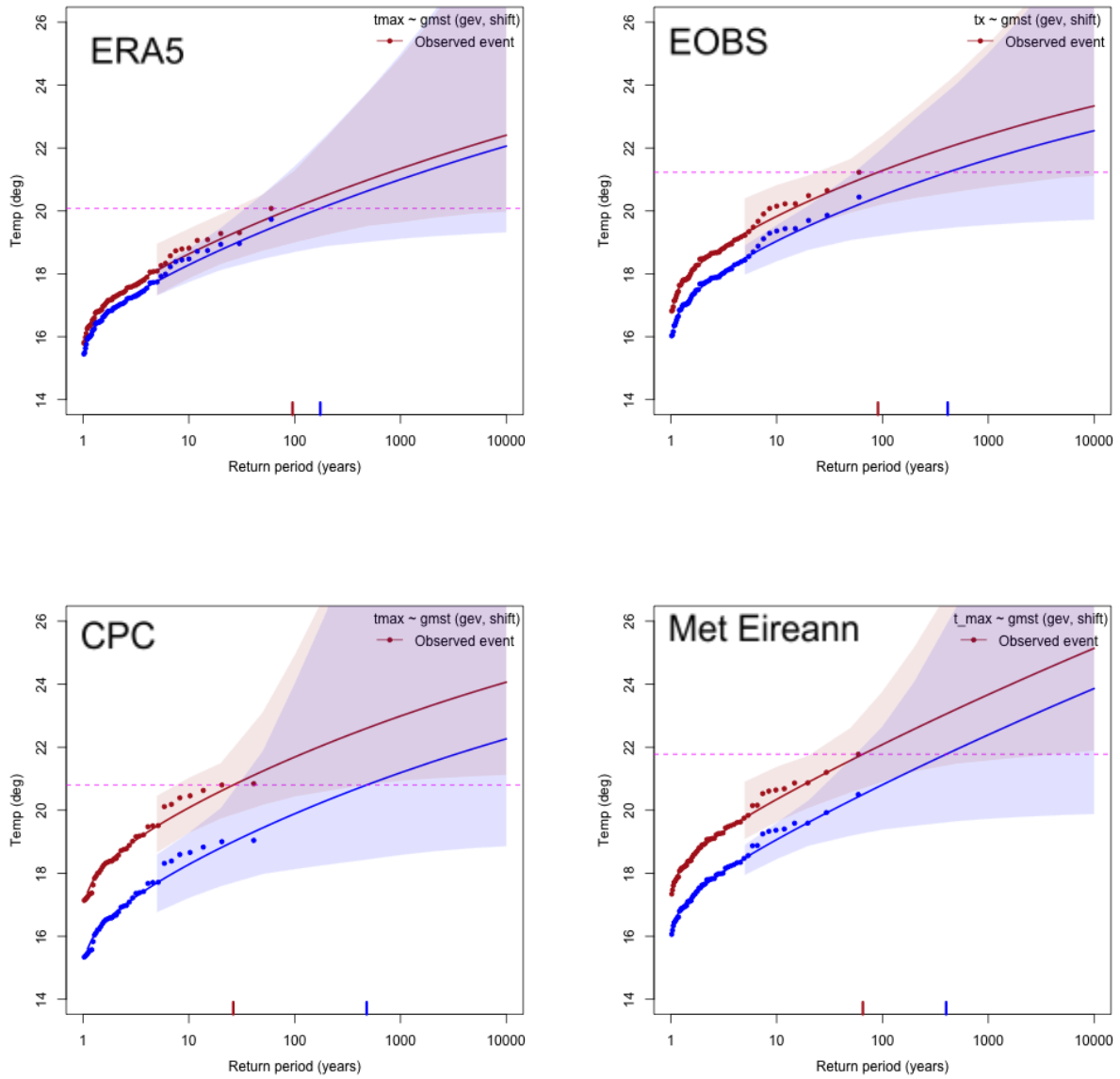


Figure 3.3: Expected return levels of Tx2month over Ireland in the 2018 climate (red lines) and in a 1.1°C cooler counterfactual climate (blue line), estimated from the statistical model described in section 2.3. Shaded regions represent 95% confidence intervals obtained via a bootstrapping procedure. The pink line shows the 2-month average temperature observed during June-July 2018. Red and blue ticks at the x axis indicate the estimated return level of the event in the 2018 climate and counterfactual climate.

*Table 3.1: Summary of fitted model results for Tx2month: event magnitude; return period of 2018 Tx2month in the 2018 climate; change in Tx2month and factor change in likelihood (probability ratio) associated with 1.1°C of global warming. Figures in parenthesis indicate 95% confidence interval obtained via bootstrapping. Statistically significant changes are highlighted in **bold**.*

Tx2month	Observed (°C)	Return Period (Years)	Change in Intensity (°C)	Probability Ratio
ERA5	20.1	95.4 (28.2, 120000)	0.35 (-0.6, 1.43)	1.83 (0.33, Inf)
EOBS	21.2	90.6 (25.6, 71500)	0.79 (-0.2, 2.21)	4.56 (0.83, Inf)
CPC	20.8	26.3 (7.2, 456)	1.8 (0.47, 3.57)	18.24 (1.38, Inf)
Met Eireann	21.8	65.2 (21.7, 4570)	1.28 (0.44, 2.73)	6.13 (1.54, Inf)

3.2 Tn2month - Analysis of June-July Average Daily Minimum Temperatures

Figure 3.4 shows the time series for Tn2month for the four gridded data products, with the fitted GMST-dependent trend overlaid (black line). Three of the four observational time series show an increasing trend in the average June-July minimum temperature over time (the exception being CPC), with the pink box highlighting the 2018 value. Apart from ERA5, minimum temperatures were not unusually high compared to past years. For ERA5, the 2018 event had a return period of 48 years (bootstrapped 95% confidence interval (CI): 11, 3.2e+07), for EOBS, 4 years (CI: 2, 10), for CPC, 6 years (CI: 3, 77) and Met Eireann, 5 years (CI: 2, 12). Therefore, a 10 year return period was decided upon to represent this event for the full attribution analysis.

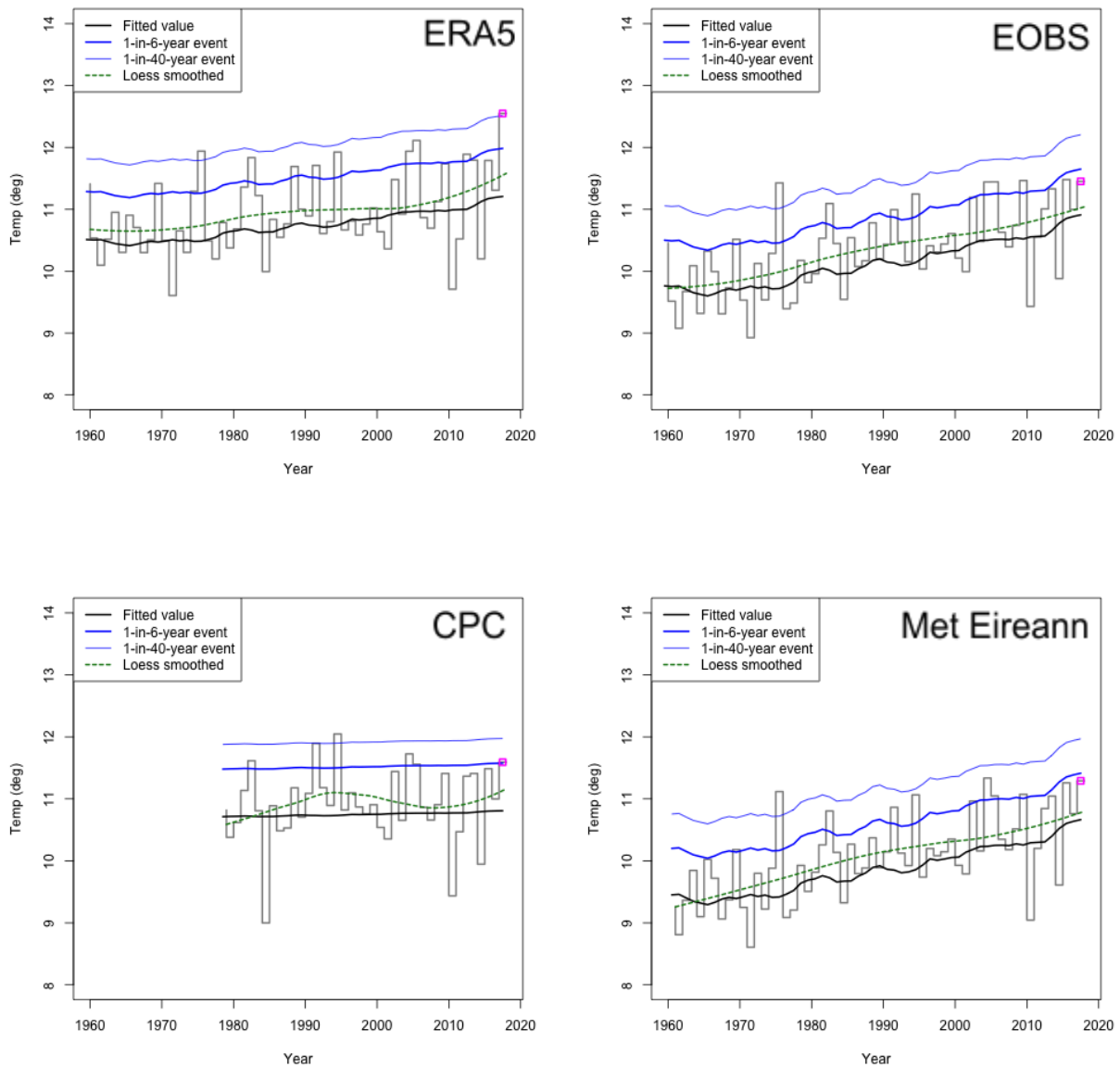


Figure 3.4: Time series of $T_{n2month}$ over Ireland, with fitted model overlaid. The pink square marks the 2018 event; the heavy black line indicates the mean of the fitted Gaussian model, and the blue lines indicate the expected return levels of 6- and 40-year events. The green line is a nonparametric Loess smoother.

The fitted linear trend was also plotted against the GMST covariate as seen in [Figure 3.5](#). For ERA5, the 2018 June-July minimum temperatures had warmed by 0.8°C (CI: 0.1, 1.5) with respect to the pre-industrial climate. In EOBS, temperatures warmed by 1.4°C (CI: 0.9, 2.1), CPC warmed by 0.1°C (CI: -0.7, 1.0) and Met Eireann warmed by 1.4°C (CI: 0.9, 2.2).

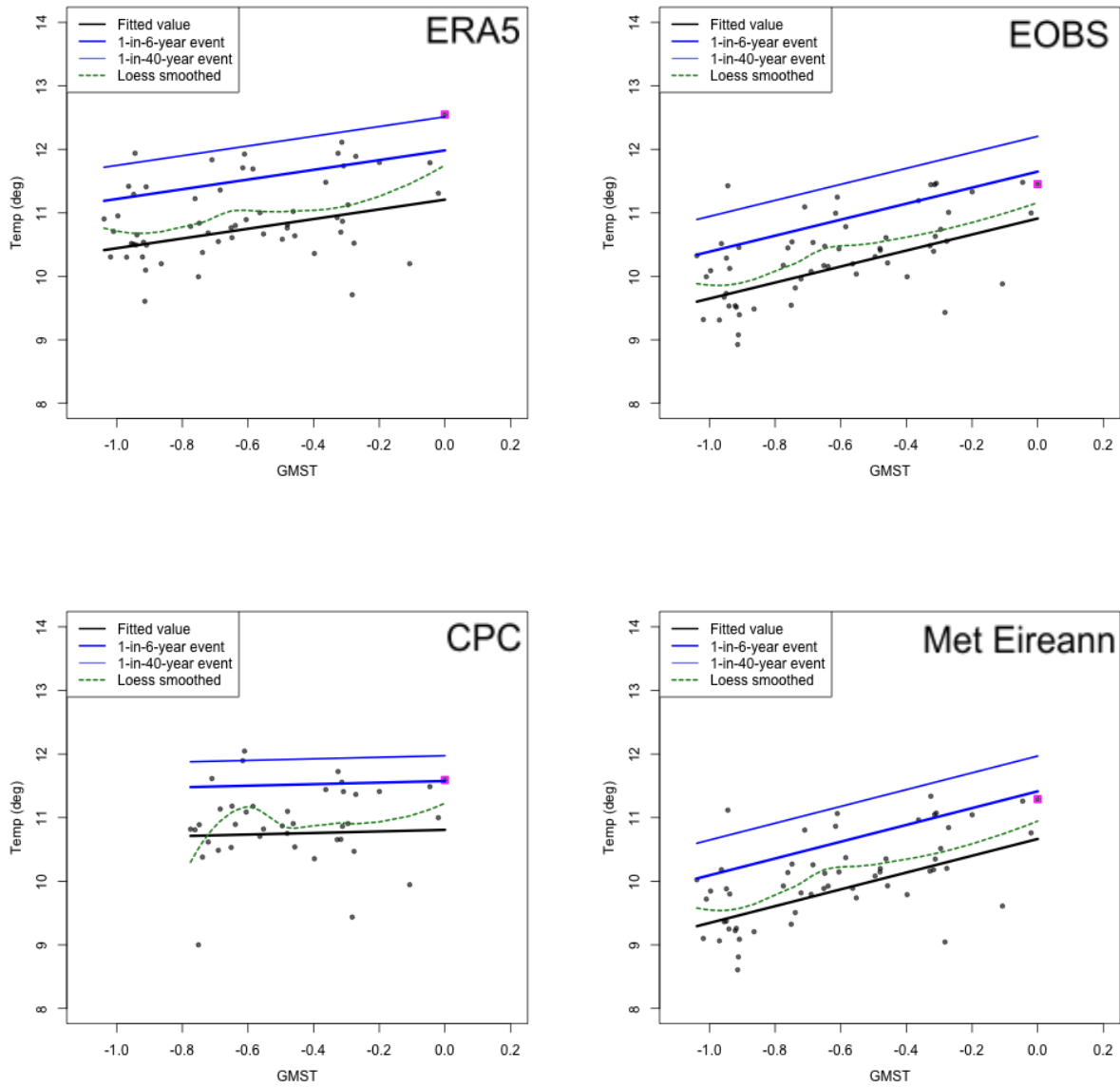


Figure 3.5: Linear trend in $T_{n2month}$ over Ireland as a function of GMST (shown as a difference from the 2018 GMST) in four gridded observational data products. The pink square marks the 2018 event; the thick black line denotes the nonstationary location of the fitted Gaussian distribution, and the 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 2018 climate (GMST anomaly = 0) and a hypothetical 1.1°C cooler climate.

The change in return level of the event from a pre-industrial climate to 2018's climate (1.1°C increase in GMST) was calculated and can be seen in [Figure 3.6](#). Across all observational datasets, a clear distinction can be made between the return levels of the current climate (red) and the pre-industrial climate (blue) for this extreme event (less so for CPC). Best estimates of

the probability ratio (factor change in the probability of such an event occurring) were calculated for each dataset: Infinite for ERA5, 1120 for EOBS, 1.6 for CPC and 26600 for Met Eireann. These exceptionally high probability ratios for EOBS and Met Eireann, plus the Infinite reading for ERA5 strongly suggest this type of extreme was all but impossible under a pre-industrial climate. All best estimates and their associated 95% CI's, plus the return periods and changes in intensity can be found summarised in [Table 3.2](#).

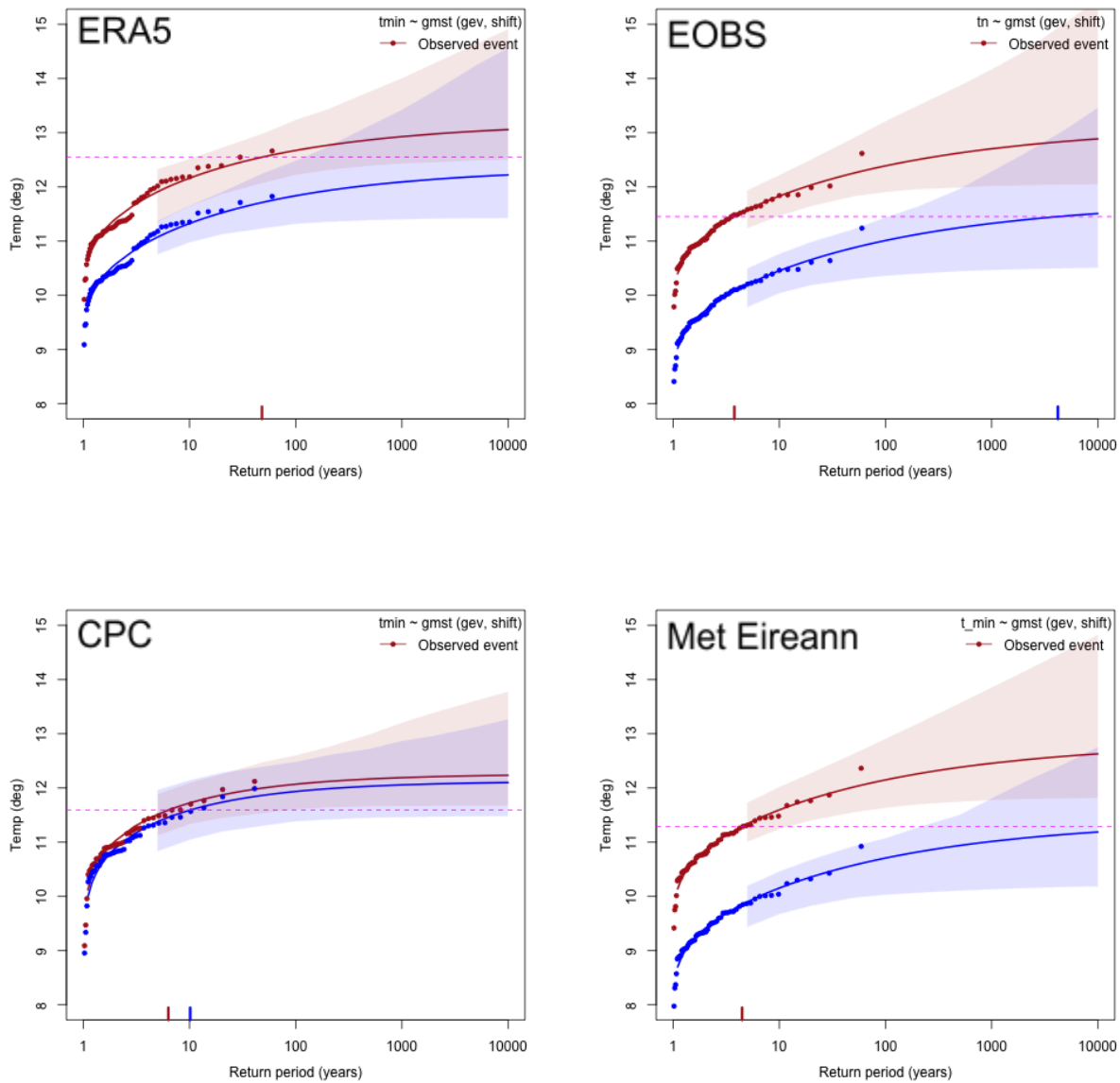


Figure 3.6: Expected return levels of Tn2month over Ireland in the 2018 climate (red lines) and in a 1.1°C cooler counterfactual climate (blue line), estimated from the statistical model described in section 2.3. Shaded regions represent 95% confidence intervals obtained via a bootstrapping procedure. The pink line shows the 2-month average temperature observed during June-July 2018. Red and blue ticks at the x axis indicate the estimated return level of the event in the 2018 climate and counterfactual climate.

*Table 3.2: Summary of fitted model results for Tn2month: event magnitude; return period of 2018 Tn2month in the 2018 climate; change in Tn2month and factor change in likelihood (probability ratio) associated with 1.1°C of global warming. Figures in parenthesis indicate 95% confidence interval obtained via bootstrapping. Statistically significant changes are highlighted in **bold**.*

Tn2month	Observed (°C)	Return Period (Years)	Change in Intensity (°C)	Probability Ratio
ERA5	12.6	48.1 (11.2, 3.2e+07)	0.84 (0.11, 1.47)	Inf (1.64, Inf)
EOBS	11.5	3.8 (1.8, 9.5)	1.38 (0.87, 2.07)	1120 (23.0, Inf)
CPC	11.6	6.3 (2.7, 77.2)	0.13 (-0.73, 1.01)	1.61 (0.04, Inf)
Met Eireann	11.3	4.5 (2.0, 11.8)	1.44 (0.91, 2.24)	26600 (42.39, Inf)

3.3 Rn30day - Analysis of the annual minimum 30-day precipitation during June and July

Figure 3.7 shows the time series for Rn30day for the four gridded data products, with the fitted GMST-dependent trend overlaid (black line). The fitted models generally show a small increase in rainfall during the annual minimum 30-day period, however there is some decadal variability not being captured by the models. All four datasets agree that the annual minimum 30-day precipitation during June-July of 2018 was one of the lowest recorded, highlighted by the pink box in Figure 3.7. For ERA5, the event had a return period of 460 years (bootstrapped 95% confidence interval (CI): 42, 91400), for EOBS, 13 years (CI: 6, 38), for CPC, 46 years (CI: 9, 2090) and Met Eireann, 25 years (CI: 8, 144). Therefore, a 30 year return period was decided upon to represent this event for the full attribution analysis.

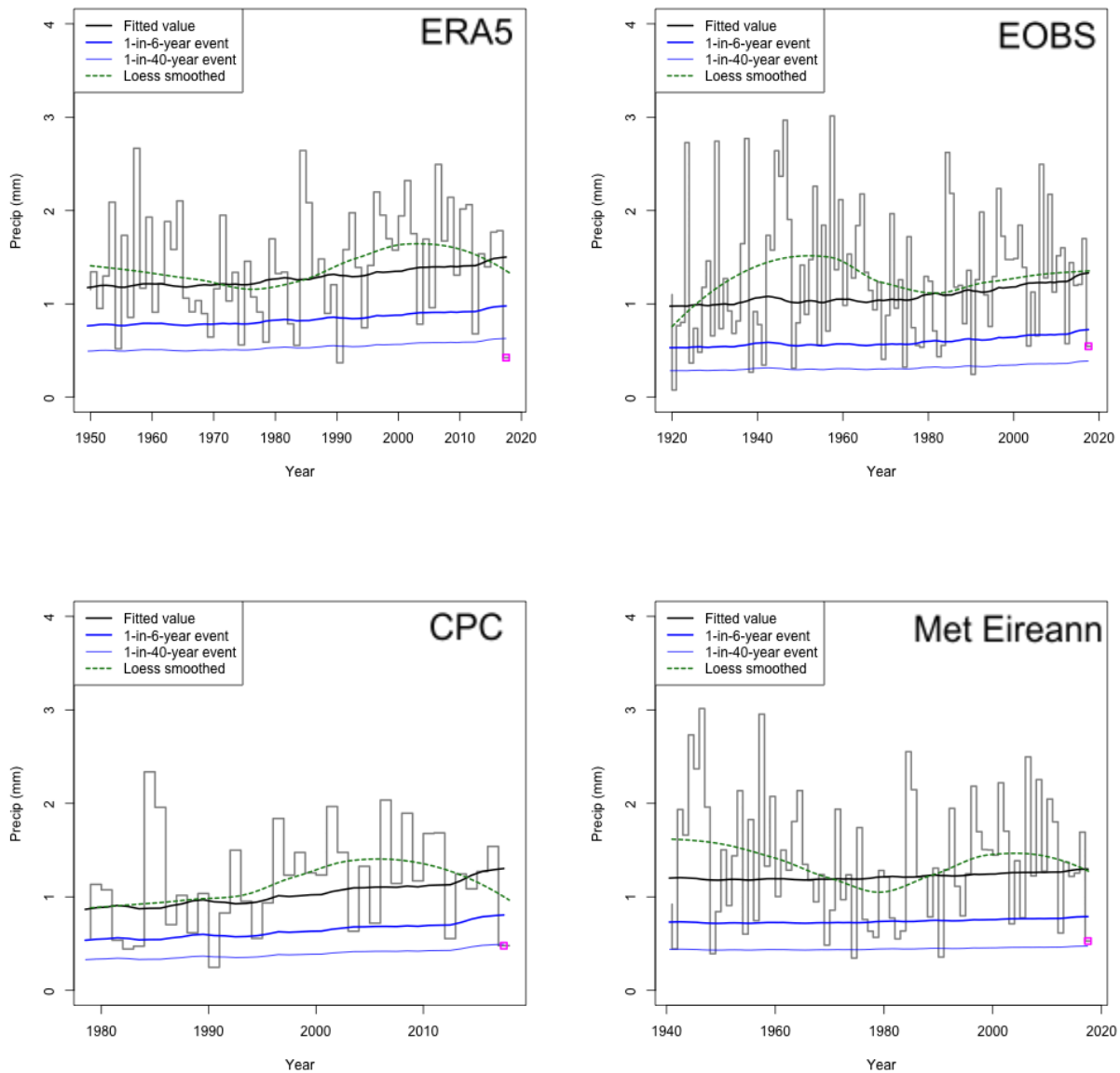


Figure 3.7: Time series of Rn_{30day} over Ireland, with fitted model overlaid. The pink square marks the 2018 event; the heavy black line indicates the mean of the fitted Gaussian model, and the blue lines indicate the expected return levels of 6- and 40-year events. The green line is a nonparametric Loess smoother.

The fitted linear trend was also plotted against the GMST covariate as seen in Figure 3.8. For ERA5, the annual minimum 30-day precipitation during June and July has become 28.8% wetter (CI: -14.2, 95) with respect to the pre-industrial climate. In EOBS, 32.9% wetter (CI: -13.5, 100.2), CPC 77.7% wetter (CI: -19.4, 358.2) and Met Eireann 10.5% wetter (CI: -27.6, 66.6) with respect to the pre-industrial climate.

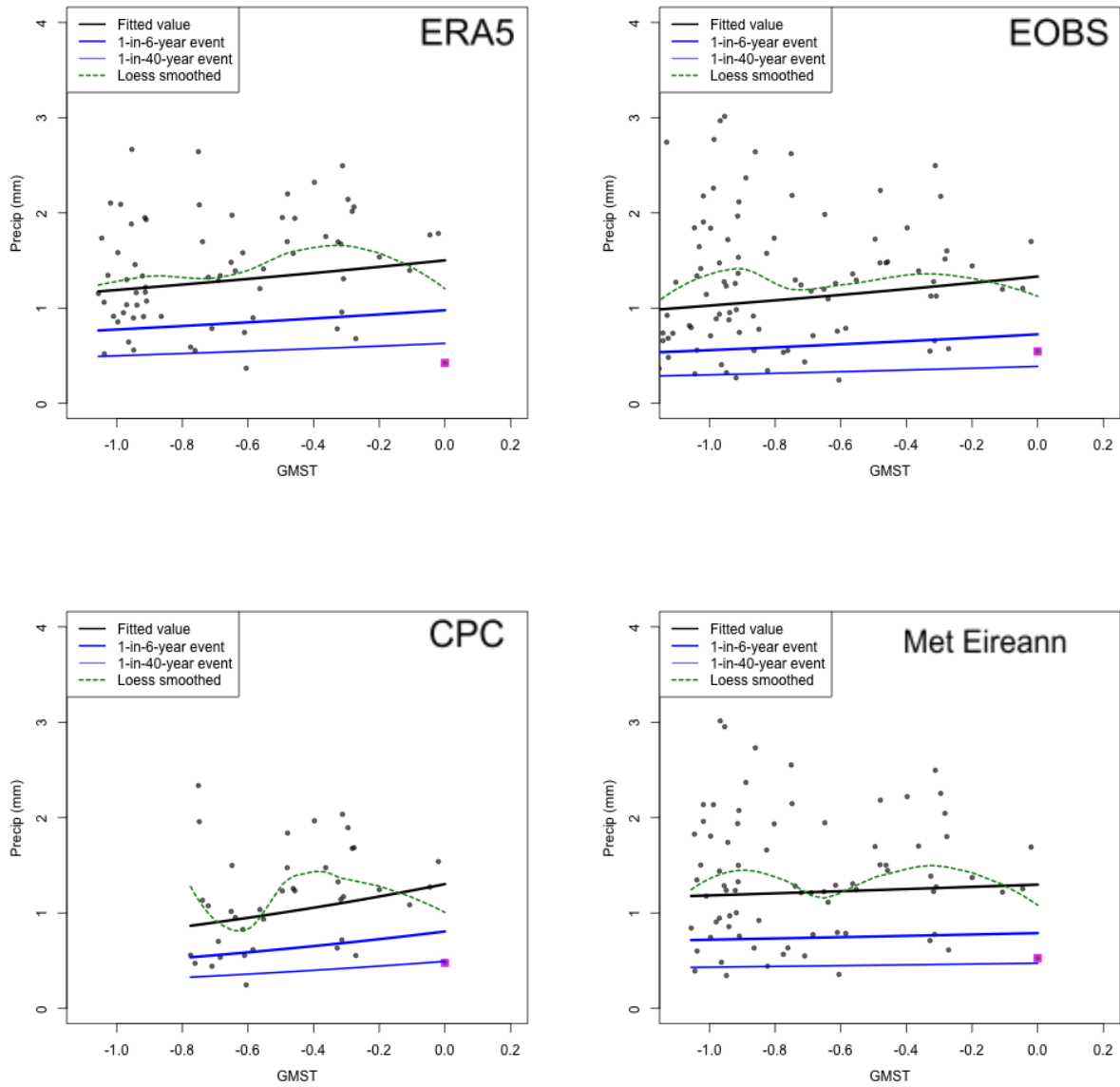


Figure 3.8: Linear trend in Rn30day over Ireland as a function of GMST (shown as a difference from the 2018 GMST) in four gridded observational data products. The pink square marks the 2018 event; the thick black line denotes the nonstationary location of the fitted Gaussian distribution, and the blue 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 2018 climate (GMST anomaly = 0) and a hypothetical 1.1°C cooler climate.

The change in return level of the event from a pre-industrial climate to 2018's climate (1.1°C increase in GMST) was calculated and can be seen in [Figure 3.9](#). Best estimates of the probability ratio (factor change in the probability of such an event occurring) were calculated for each dataset: 0.19 for ERA5, 0.47 for EOBS, 0.11 for CPC and 0.67 for Met Eireann. All best estimates and their associated 95% CI's, plus the return periods and changes in intensity can be found summarised in [Table 3.3](#).

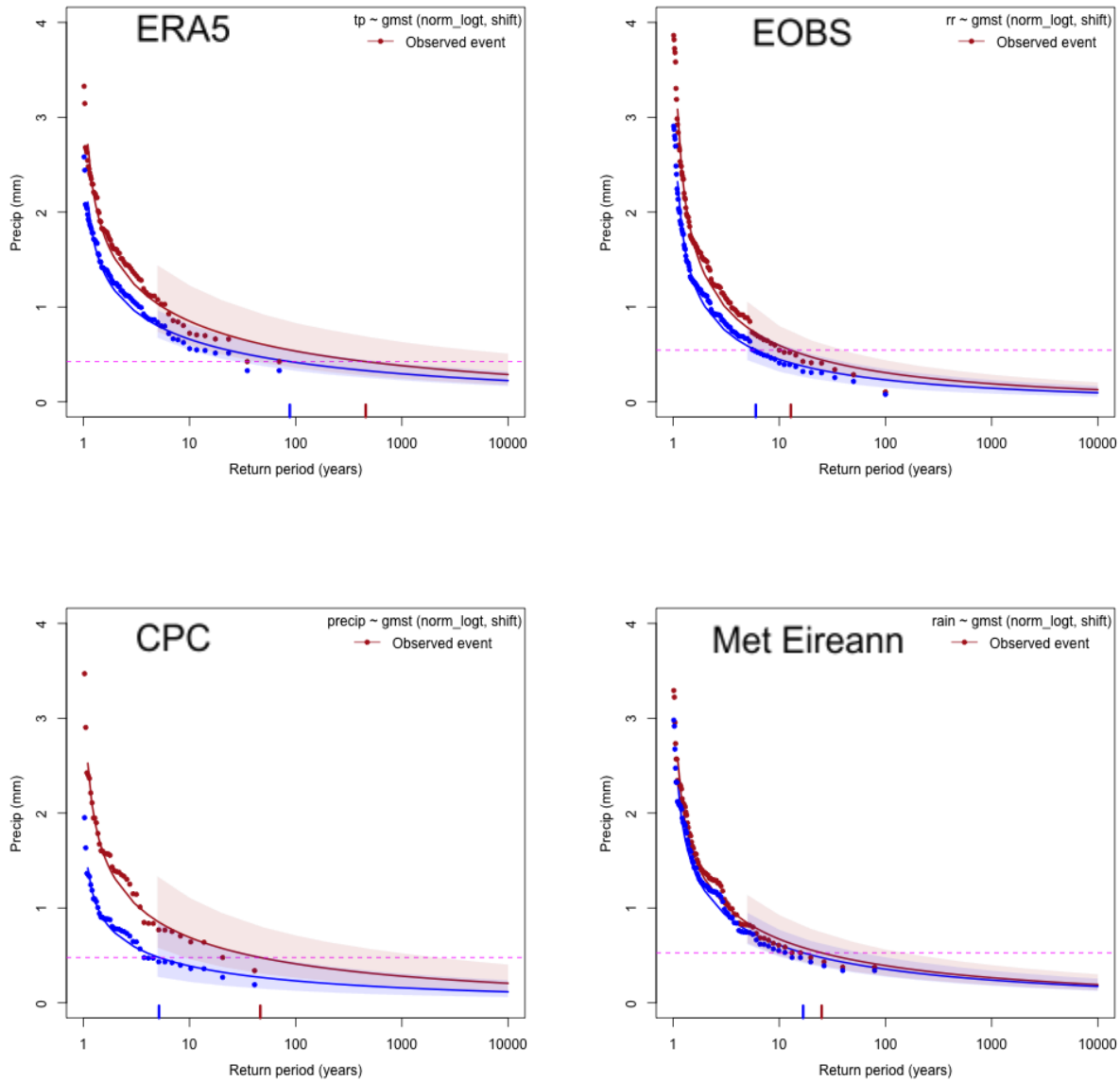


Figure 3.9: Expected return levels of Rn30day over Ireland in the 2018 climate (red lines) and in a 1.1°C cooler counterfactual climate (blue line), estimated from the statistical model described in section 2.3. Shaded regions represent 95% confidence intervals obtained via a bootstrapping procedure. The pink line shows the annual minimum 30-day precipitation observed across June-July 2018. Red and blue ticks at the x axis indicate the estimated return level of the event in the 2018 climate and counterfactual climate.

*Table 3.3: Summary of fitted model results for Rn30day: event magnitude; return period of 2018 Rn30day in the 2018 climate; change in Rn30day and factor change in likelihood (probability ratio) associated with 1.1°C of global warming. Figures in parenthesis indicate 95% confidence interval obtained via bootstrapping. Statistically significant changes are highlighted in **bold**.*

Rn30day	Observed (mm)	Return Period (Years)	Change in Precipitation (%)	Probability Ratio
ERA5	0.42	456.9 (41.8, 91400)	28.84 (-14.17, 95.01)	0.19 (0, 2.51)
EOBS	0.55	12.8 (5.9, 37.8)	32.89 (-13.47, 100.18)	0.47 (0.15, 1.58)
CPC	0.48	46.4 (8.8, 2090)	77.73 (-19.41, 358.17)	0.11 (0, 3.25)
Met Eireann	0.53	25 (8.3, 143.9)	10.49 (-27.55, 66.62)	0.67 (0.09, 3.54)

4 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 or precipitation patterns are excluded.
3. Parameters of the fitted statistical models: The statistical fit 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 A1, A2 & A3 show the model ratings for each characteristic, while Figures A1 - A10 show examples of the visual seasonal cycles and spatial patterns used to rate the models.

Before any synthesis of the models can be carried out, the models that passed the evaluation in section 4 must be gathered and their results combined for the synthesis outlined in section 6. Tables A4, A5 & A6 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 2018, 2018 to present (2026, 1.3°C of global warming) and 2018 to future (1.5°C, 2°C, and 3°C of global warming).

While the climate models appear to capture the event magnitude of the average daily maximum and minimum temperatures well with regards to the observations, the annual minimum 30-day precipitation event magnitudes captured by the models appear to over estimate the amount of rainfall compared to the observations, suggesting June and July 2018 was wetter than observed ([Table A4, A5 & A6](#)).

5 Hazard synthesis

For the event definitions described above we evaluate the influence of anthropogenic climate change on the events 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 above 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.

[Figures 5.1 - 5.6](#) show the changes in probability 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.

Results are shown in [Tables 5.1 - 5.6](#), where differences are presented for changes both between the past, pre-industrial climate (1.1°C cooler), the 2018 climate (1.1°C), present day climate of 2026 (+0.2°C) and between 2018's climate and future climates (+0.4°C, +0.9°C and +1.9°C). By combining evidence from the synthesis of model results from the past, the projections for the future, and our established physical understandings, we can derive a best-estimate attribution of the event.

5.1 Tx2month - Attribution Analysis

The synthesised change in intensity for a 1-in-70-year Tx2month event associated with 1.1°C of warming from the pre-industrial period to 2018, and further warming up to present day of 0.2°C (2026), followed by future warming of 0.4°C, 0.9°C and 1.9°C throughout the century can be seen in [Figures 5.1 - 5.2](#).

[Table 5.1](#) highlights how June-July average daily maximum temperatures have been made 0.9°C warmer compared to the pre-industrial climate. Models suggest this has increased by a further 0.16°C under the 2026 climate (1.3°C). It is projected that an additional temperature increase of 0.31°C, 0.7°C and 1.48°C above 2018 levels will occur under a 1.5°C, 2°C and 3°C warmer world. These are best-estimates and thus there is potential for temperatures to warm more in the future.

The change in likelihood of this event happening is seen in [Table 5.2](#). Under the 2018 climate (1.1°C warmer world), this event has become 6 times more likely to occur compared to the pre-industrial climate. This equates to this event having a return period of ~420 years during a pre-industrial climate compared to occurring once every 70 years under the 2018 climate. The warming from 2018 to 2026 has made this event a further 1.4 times more likely to occur, making this event a 1-in-53 year event now. When we look at future climates, 1.5°C, 2°C and 3°C, this event is projected to become 1.9, 3.7 and 11.4 times more likely than in 2018. This suggests a similarly extreme event will be expected to happen once in 38 years in a 1.5°C warmer world, once in 19 years in a 2°C warmer world and once every 6 years in a 3°C warmer world.

*Table 5.1: Summary of synthesised changes in intensity for Tx2month, presented in Figures 5.1 and 5.2. The projected temperatures are for °C warmer than pre-industrial time (1.1°C cooler than 2018's climate). Statistically significant changes are highlighted in **bold**.*

Tx2month	Change in intensity (°C)				
	2018 (+1.1°C)	2026 (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	1.05 (-0.55, 2.94)	-	-	-	-
Models	0.85 (0.26, 1.57)	0.16 (0.1, 0.21)	0.31 (0.2, 0.43)	0.7 (0.44, 0.96)	1.48 (0.93, 2.02)
Synthesis	0.87 (0.08, 1.83)	-	-	-	-

*Table 5.2: Summary of synthesised changes in the probability ratio for Tx2month, presented in Figures 5.1 and 5.2. The projected temperatures are for °C warmer than pre-industrial time (1.1°C cooler than 2018's climate). Statistically significant changes are highlighted in **bold**.*

Tx2month	Probability Ratio				
	2018 (+1.1°C)	2026 (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	5.53 (0.4, 1890)	-	-	-	-
Models	6.48 (0.54, 512)	1.37 (1.16, 1.66)	1.85 (1.35, 2.62)	3.69 (2.03, 6.93)	11.44 (4.63, 28.73)
Synthesis	6.08 (0.48, 905)	-	-	-	-

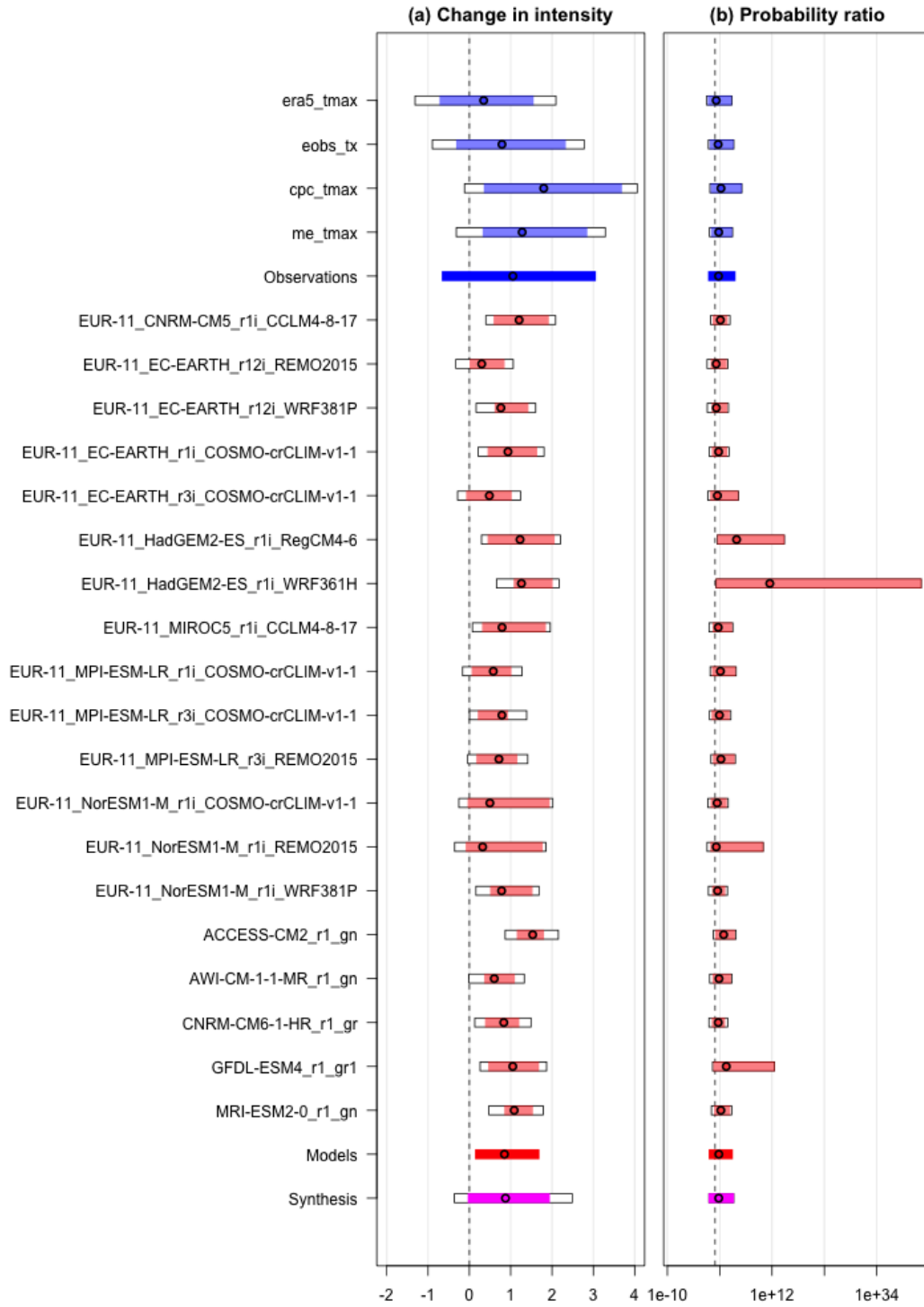


Figure 5.1: Synthesised changes for a 1-in-70-year (section 3.1) Tx2month event due to GMST. Changes in intensity (left) and PR (right) are shown for a historical period comparing the past 1.1°C cooler climate with the 2018 climate.



Figure 5.2: Synthesised changes for a 1-in-70-year (section 3.1) Tx2month event due to GMST. Changes in intensity (left) and PR (right) are shown for the 2026 climate (1.3°C) and future periods, based on model projections only, comparing the 2018 climate to the 2026 climate and future climates.

Both observational and climate model results indicate a clear trend towards an increase in the intensity and frequency of a Tx2month event occurring in a 2018 climate when compared to the pre-industrial period. Model projections up until present (2026) and into the future (+1.5°C, +2.0°C & +3.0°C) further indicate a Tx2month event across June and July will become warmer and occur more frequently due to human induced climate change.

6.2 Tn2month - Attribution Analysis

The synthesised change in intensity for a 1-in-10-year Tn2month event associated with 1.1°C of warming from the pre-industrial period to 2018, and further warming up to present day of 0.2°C (2026), followed by future warming of 0.4°C, 0.9°C and 1.9°C throughout the century can be seen in [Figure 5.3 - 5.4](#).

[Table 5.3](#) highlights how June-July minimum temperatures have been made 0.9°C warmer compared to the pre-industrial climate. This has increased by a further 0.14°C under the 2026 climate (1.3°C). It is projected that an additional temperature increase of 0.29°C, 0.65°C and 1.38°C above 2018 levels will occur under a 1.5°C, 2°C and 3°C warmer world. These are best-estimates and thus there is potential for temperatures to warm more in the future.

The change in likelihood of this event happening is seen in [Table 5.4](#). Under the 2018 climate (1.1°C warmer world), this event has become 23 times more likely to occur compared to the pre-industrial climate. This equates to this event having a return period of ~230 years during a pre-industrial climate compared to occurring once every 10 years under the 2018 climate. The warming from 2018 to 2026 has made this event a further 1.4 times more likely to occur, making this event a 1-in-7 year event now. When we look at future climates, 1.5°C, 2°C and 3°C, this event will become 1.9, 3.5 and 7.2 times more likely than in 2018. This suggests a similarly extreme event will happen 1-in-5 years in a 1.5°C warmer world, 1-in-3 years in a 2°C warmer world and will happen every year in a 3°C warmer world.

*Table 5.3: Summary of synthesised changes in intensity for Tn2month, presented in Figures 5.3 and 5.4. The projected temperatures are for °C warmer than pre-industrial time (1.1°C cooler than 2018's climate). Statistically significant changes are highlighted in **bold**.*

Tn2month	Change in intensity (°C)				
	2018 (+1.1°C)	2026 (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	0.95 (-0.41, 2.35)	-	-	-	-
Models	0.87 (0.15, 1.63)	0.14 (0.09, 0.2)	0.29 (0.19, 0.4)	0.65 (0.42, 0.9)	1.38 (0.88, 1.88)
Synthesis	0.89 (-0.02, 1.83)	-	-	-	-

Table 5.4: Summary of synthesised changes in the probability ratio for Tn2month, presented in Figures 5.3 and 5.4. The projected temperatures are for °C warmer than pre-industrial time (1.1°C cooler than 2018's climate). Statistically significant changes are highlighted in **bold**.

Tn2month	Probability Ratio				
	2018 (+1.1°C)	2026 (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	133000 (3E-7, 5E22)	-	-	-	-
Models	20.62 (0.98, 1080)	1.4 (1.17, 1.72)	1.89 (1.37, 2.7)	3.51 (2.03, 6.25)	7.23 (4.07, 12.95)
Synthesis	22.66 (0.37, 7140)	-	-	-	-

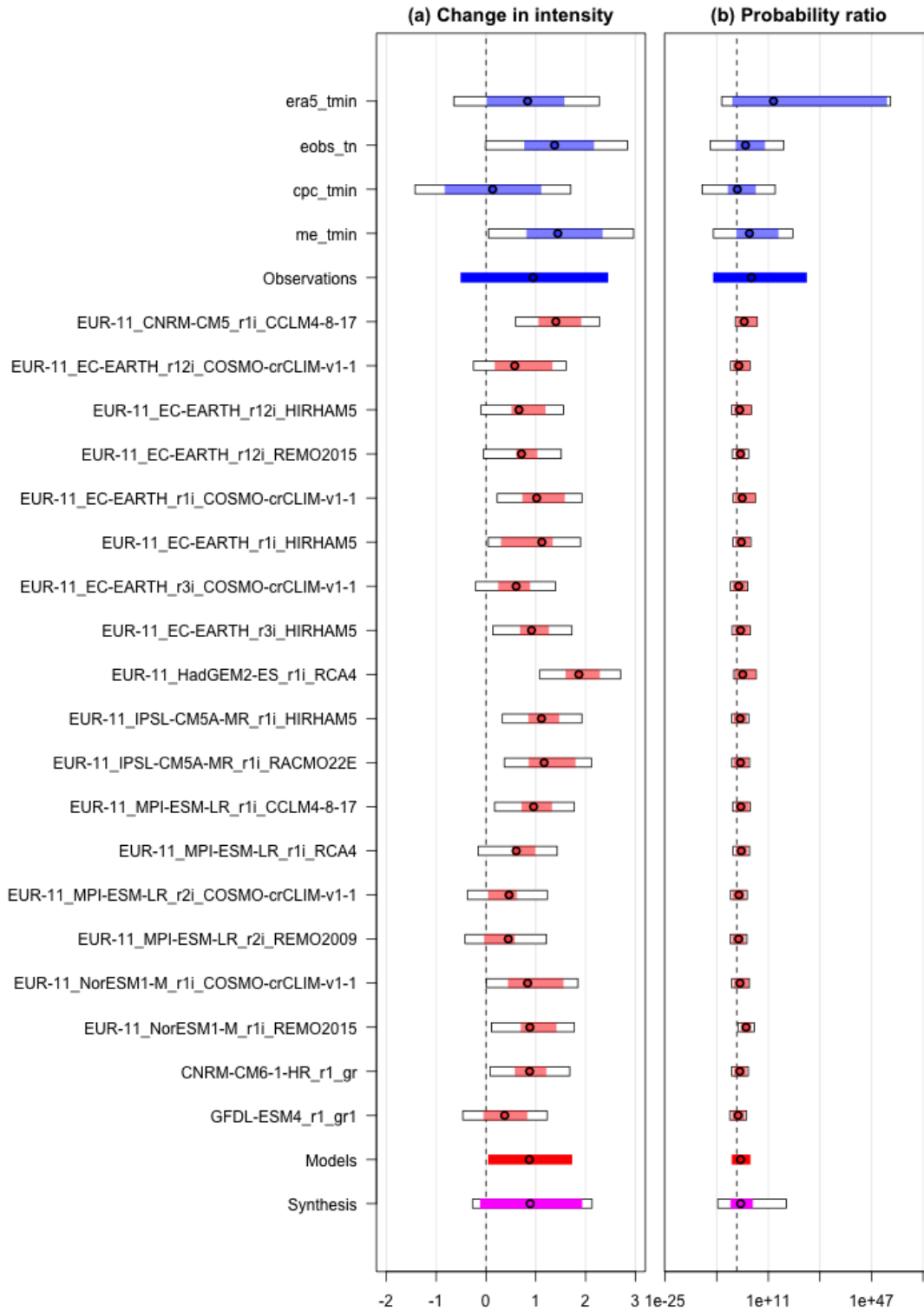


Figure 5.3: Synthesised changes for a 1-in-10-year (section 3.2) $T_{n2month}$ event due to GMST. Changes in intensity (left) and PR (right) are shown for a historical period comparing the past 1.1°C cooler climate with the 2018 climate.

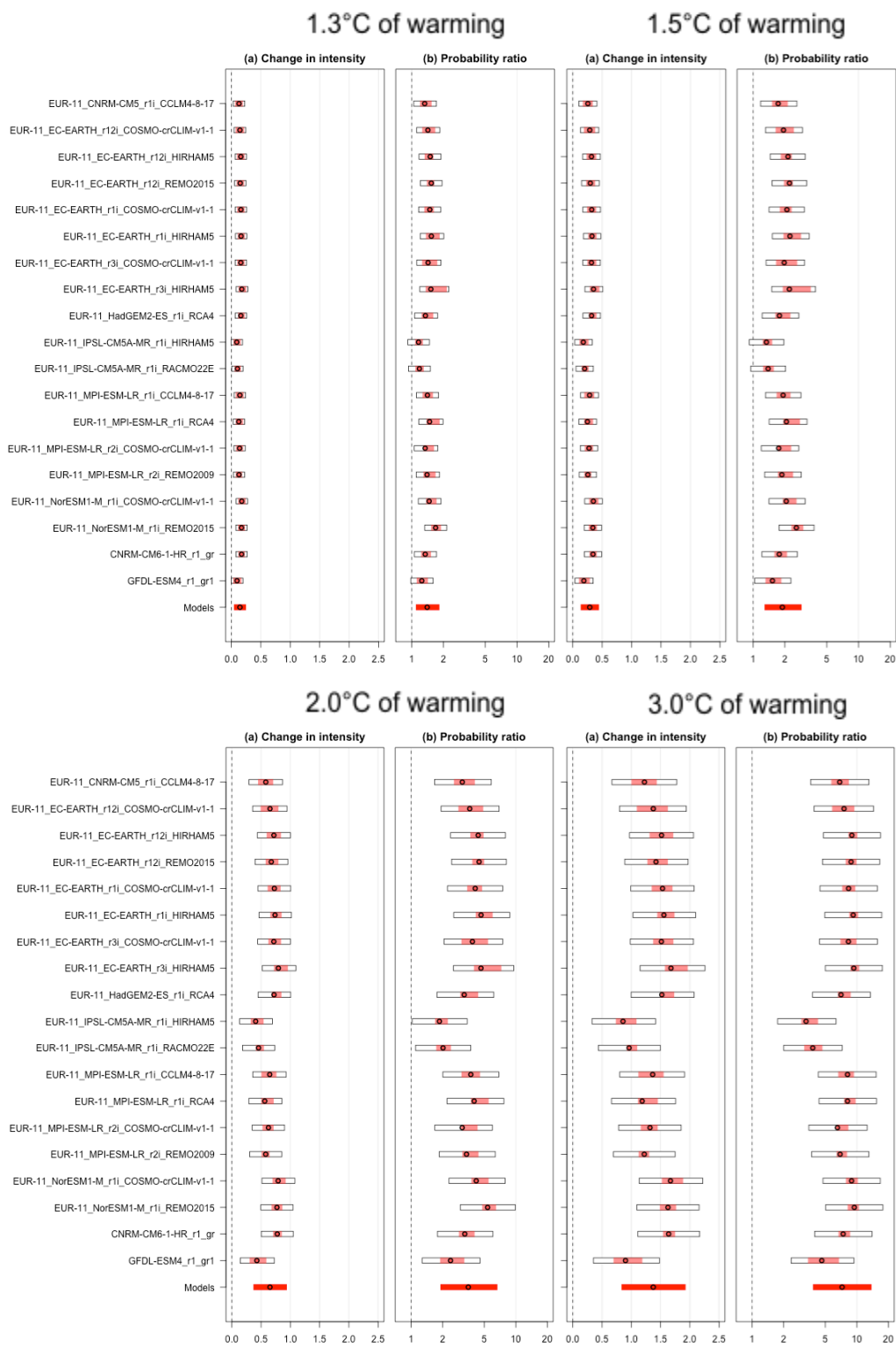


Figure 5.4: Synthesised changes for a 1-in-10-year (section 3.2) $T_{n2month}$ event due to GMST. Changes in intensity (left) and PR (right) are shown for the 2026 climate (1.3°C) and future periods, based on model projections only, comparing the 2018 climate to the 2026 climate and future climates.

Both observational and climate model results indicate a clear trend towards an increase in the intensity and frequency of a Tn2month event occurring in a 2018 climate when compared to the pre-industrial period. Model projections up until present (2026) and into the future (+1.5°C, +2.0°C & +3.0°C) further indicate a Tn2month event across June and July will become warmer and occur more frequently due to human induced climate change.

5.3 Rn30day - Attribution Analysis

The synthesised change in expected precipitation during the annual minimum 30-day period in June and July associated with 1.1°C of warming from the pre-industrial period to 2018, and further warming up to present day of 0.2°C (2026), followed by future warming of 0.4°C, 0.9°C and 1.9°C throughout the century can be seen in [Figure 5.5 - 5.6](#).

[Table 5.5](#) highlights how the annual minimum 30-day precipitation across June-July has been made 3.1% wetter compared to the pre-industrial climate. However, it should be noted that the observational data indicates a much larger increase in precipitation than the climate models. Although it is hard to say for certain, there is a possibility that these climate models have underpredicted the change in intensity. This might be a consequence of the climate models over estimating the amount of rainfall during June and July 2018. Under further warming up to present day (2026), this event has become 0.41% drier compared to 2018. This trend towards a drier extreme continues into the future where 1.5°C, 2°C and 3°C of warming are projected to make this event 0.82%, 1.89% and 4.16% drier respectively, compared to the 2018 climate. It must also be stressed that these are best estimates, and there is considerable uncertainty within the upper and lower bounds, allowing for the possibility of change in either direction. Why the observations (and to a lesser extent models) would imply a moistening that then reverses under further warming is unclear but may relate to changes in short lived climate forces and their direct and indirect effects on clouds.

The change in likelihood of this event happening can be seen in [Table 5.6](#). Under the 2018 climate (1.1°C warmer world), this event has become 0.66 times as likely (1 in 20 year event during pre-industrial) to occur compared to the pre-industrial climate. The warming from 2018 to 2026 has made this event a further 1.04 times more likely to occur. When we look at future climates, 1.5°C, 2°C and 3°C, this event will become 1.07, 1.17 and 1.37 times more likely than in 2018, making this a 1 in 28 year event, a 1 in 26 year event and a 1 in 22 year event respectively.

Table 5.5: Summary of synthesised changes in intensity for Rn30day, presented in Figures 5.5 and 5.6. The projected temperatures are for °C warmer than pre-industrial time (1.1°C cooler than 2018's climate). Statistically significant changes are highlighted in **bold**.

Rn30day	Change in precipitation (%)				
	2018 (+1.1°C)	2026 (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	35.41 (-28.81, 164.62)	-	-	-	-
Models	1.4 (-14.04, 19.29)	-0.41 (-2.11, 1.35)	-0.82 (-4.24, 2.74)	-1.89 (-9.59, 6.47)	-4.16 (-20.53, 15.23)
Synthesis	3.14 (-17.52, 29.33)	-	-	-	-

Table 5.6: Summary of synthesised changes in the probability ratio for Rn30day, presented in Figures 5.5 and 5.6. The projected temperatures are for °C warmer than pre-industrial time (1.1°C cooler than 2018's climate). Statistically significant changes are highlighted in **bold**.

Rn30day	Probability Ratio				
	2018 (+1.1°C)	2026 (+1.3°C)	Projected further change (+1.5°C)	Projected further change (+2.0°C)	Projected further change (+3.0°C)
Observations	0.29 (0, 4.38)	-	-	-	-
Models	0.83 (0.18, 4.66)	1.04 (0.88, 1.22)	1.07 (0.78, 1.48)	1.17 (0.57, 2.36)	1.37 (0.32, 5.59)
Synthesis	0.66 (0.08, 4.8)	-	-	-	-

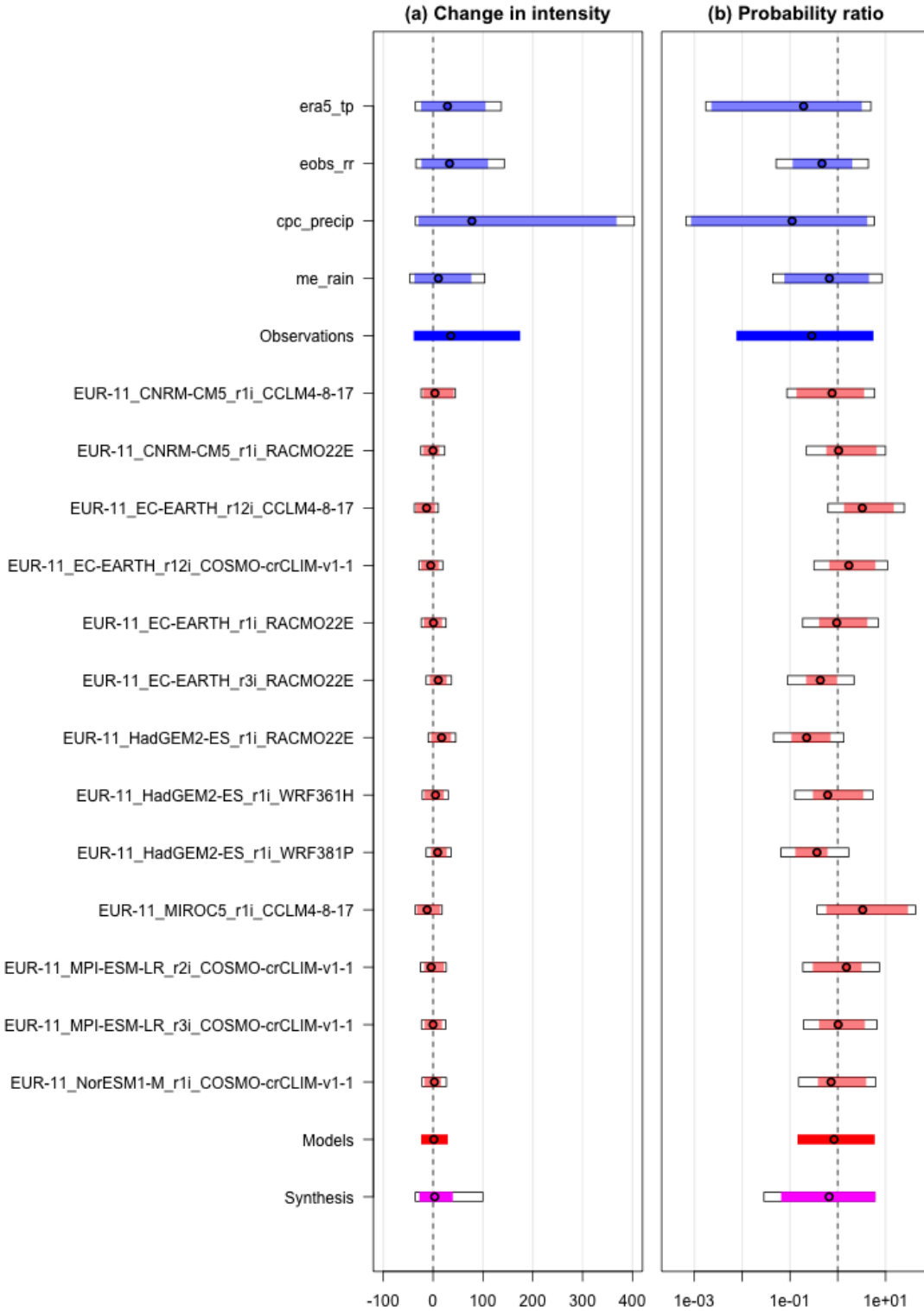


Figure 5.5: Synthesised changes for a 1-in-30-year (section 3.3) Rn30day event due to GMST. Changes in intensity (left) and PR (right) are shown for a historical period comparing the past 1.1°C cooler climate with the 2018 climate.

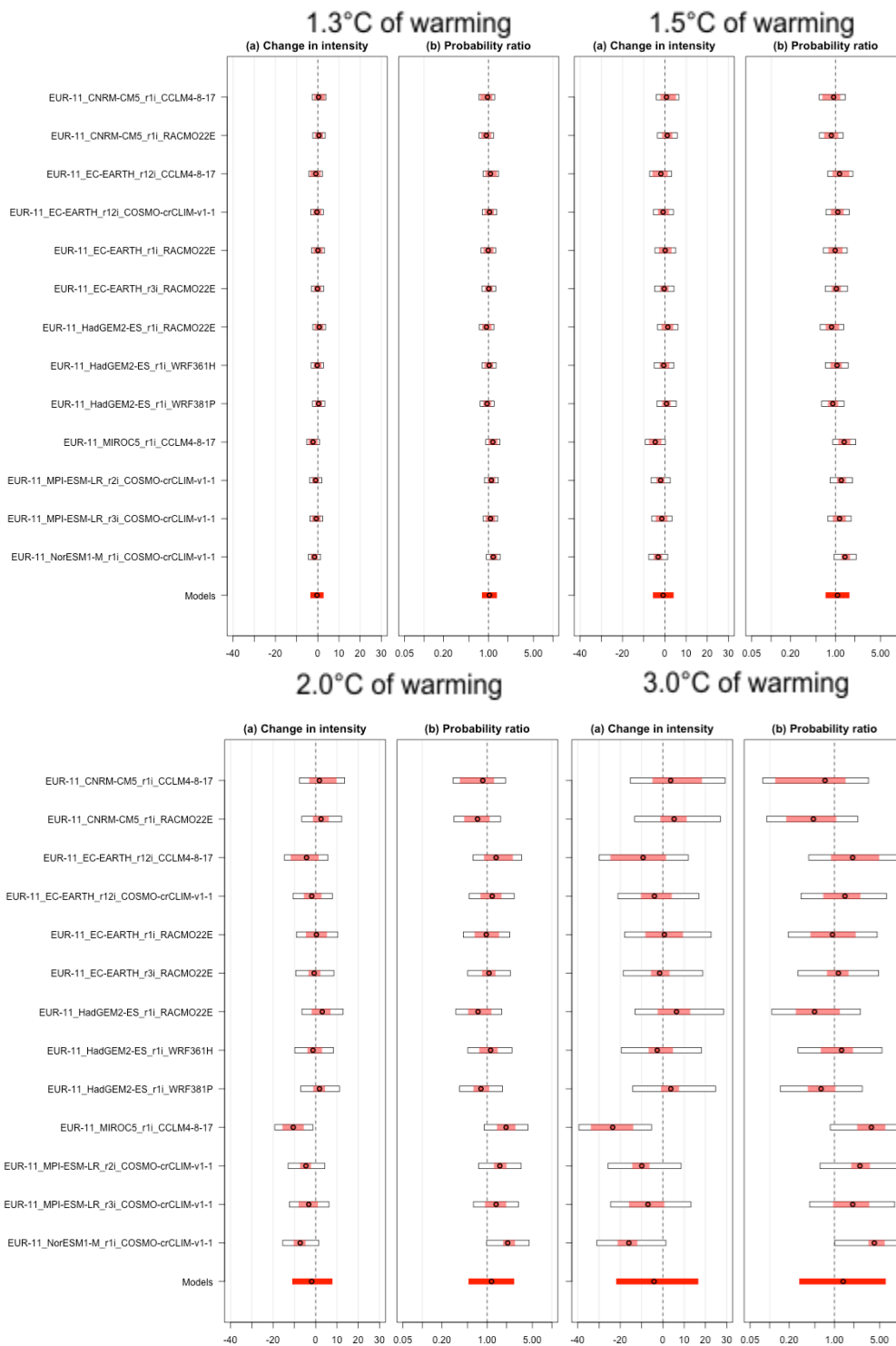


Figure 5.6: Synthesised changes for a 1-in-30-year (section 3.3) Rn30day event due to GMST. Changes in intensity (left) and PR (right) are shown for the 2026 climate (1.3°C) and future periods, based on model projections only, comparing the 2018 climate to the 2026 climate and future climates.

While observational results suggest a Rn30day event occurring in a 2018 climate has become much wetter and less likely to occur compared to a pre-industrial climate, the climate model results suggest a considerably smaller change in the event's intensity and frequency. Model projections from 2018 to 2026 and future warming of 1.5°C, 2.0°C and 3.0°C suggest an Rn30day event will become drier and more likely to occur with respect to a 2018 climate. A possible reason for this discrepancy between observational and climate model results is due to the climate models over estimating the amount of rainfall over June and July 2018. As there is no clear trend between observational and model results, changes in Rn30day discussed in this report are of low confidence and cannot be robustly attributed to human induced climate change.

6 Societal impacts

The high temperatures and low precipitation experienced across the summer months heavily impacted the health, water and agricultural sectors across Europe. In Ireland, [Boudou et al., \(2025\)](#) found that the unusually high temperatures were responsible for a minimum of 169 excess cases of campylobacteriosis and STEC in humans. These are both bacterial infections which are heavily linked to gastrointestinal illness, an illness projected to increase due to climate change. Heat related deaths were reported across Europe due to the extreme heatwave ([Met Eireann, 2020a](#)).

Fires were reported to have broken out across the country, with Wicklow County Council Fire services responding to 42 fires over a 2 day period ([RTE, 2018](#)). As the drought conditions began to set in, there was a serious reduction in vegetation growth all over the country ([Falzoi et al., 2019](#); [Noone et al., 2024](#)). Teagasc national grass growth curve highlighted the impact of summer 2018 on the growing season ([Figure 6.1](#)). In addition, the lack of precipitation proved detrimental for Ireland's water sector. The national water service, Irish Water, issued a 'National Water Conservation Order' on the 6th July 2018 for the entire country in an attempt to conserve water ([Augustenborg et al., 2022](#)). Inland Fisheries Ireland prompted people to keep an eye out for distressed fish due to the hot weather ([The Irish Times, 2018](#)), while dairy farmers struggled to keep their cattle cool and provide them with the large quantity of water and food they desperately need to remain healthy ([The Irish Examiner](#)).

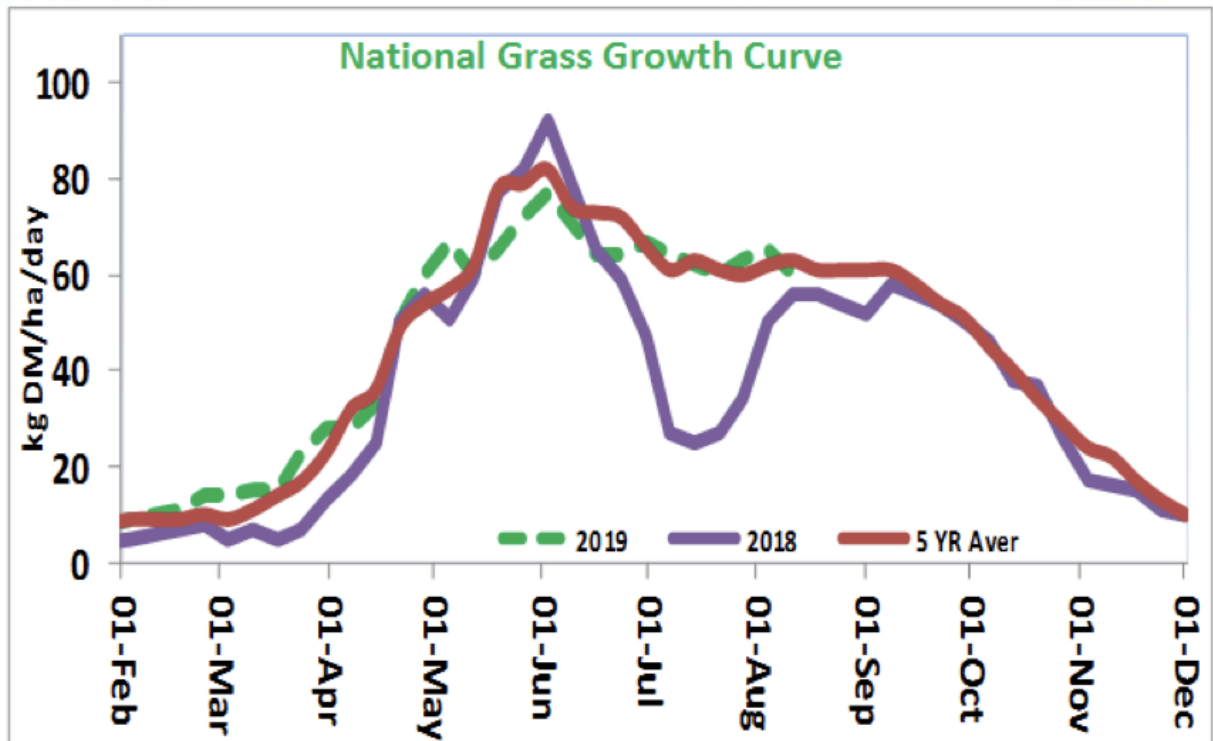


Figure 6.1: Teagasc National Grass Growth Curve. The purple line (2018) highlights the significant impact the heat and lack of precipitation had on the growing season. Source: [Teagasc](#)

7 Conclusion

June–July 2018 stood out for extreme daily maximum temperatures and exceptionally low 30-day precipitation, while daily minimum temperatures were not exceptional. Similarly extreme daily maximum and minimum temperatures had already become far more likely in 2018’s climate, with 2018’s maximum temperatures 6 times more likely and minimum temperatures 23 times more likely than in a pre-industrial (1.1°C cooler) climate. Similar extremes are projected to become increasingly frequent as warming continues, with similar daily maximum temperatures expected every few decades at 1.5°C–2°C of warming and every few years by 3°C, while daily minimum temperatures similar to 2018 will become almost routine under continued warming. Therefore, there is high confidence that human induced climate change has made and will continue to make average daily maximum and daily minimum temperature during June and July warmer and more frequent. In contrast, the low precipitation of 2018 shows only a small change in likelihood between 2018’s climate and future climates compared to pre-industrial times. While results are not statistically significant they do suggest this

precipitation event has become ~3% wetter compared to a pre-industrial climate. However, large differences between observational results (suggest a wetting trend between pre-industrial and 2018) and model results (suggest a drying trend in the future) lead to low confidence in the results. Therefore, the change in annual minimum 30-day precipitation across June-July cannot be robustly attributed to human induced climate change based on the findings of this report.

References

All references are given as hyperlinks in the text.

Appendix

Table A1: Evaluation results of the climate models considered for attribution analysis of Tx2month 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.

Model / Observations	Seasonal cycle	Spatial pattern	Sigma	Shape	Summary
era5_tmax			0.79 (0.6...0.98)	-0.07 (-0.32...0.17)	
eobs_tx			0.86 (0.67...1.08)	-0.1 (-0.38...0.11)	
cpc_tmax			0.91 (0.64...1.15)	-0.08 (-0.42...0.32)	
me_tmax			0.83 (0.65...1.05)	-0.03 (-0.34...0.22)	
EUR-11_CanESM2_r1i_REMO2015	good	good	1.28 (0.95...1.45)	-0.32 (-0.47...-0.2)	reasonable
EUR-11_CNRM-CM5_r1i_ALADIN63	reasonable	reasonable	0.84 (0.52...0.92)	-0.03 (-0.06...0.02)	reasonable
EUR-11_CNRM-CM5_r1i_CCLM4-8-17	good	good	0.92 (0.83...0.97)	-0.13 (-0.25...-0.12)	good
EUR-11_CNRM-CM5_r1i_HIRHAM5	good	reasonable	0.95 (0.75...0.85)	-0.17 (-0.21...0)	reasonable
EUR-11_CNRM-CM5_r1i_RACMO22E	bad	bad	0.87 (0.66...0.87)	-0.15 (-0.21...0.03)	bad
EUR-11_CNRM-CM5_r1i_RCA4	bad	bad	0.64 (0.59...0.68)	-0.15 (-0.49...-0.06)	bad
EUR-11_CNRM-CM5_r1i_REMO2015	good	good	0.97 (0.76...1.08)	-0.29 (-0.29...-0.09)	good
EUR-11_CNRM-CM5_r1i_WRF381P	good	good	1.21 (0.99...1.2)	-0.28 (-0.26...-0.04)	reasonable
EUR-11_EC-EARTH_r12i_CCLM4-8-17	reasonable	reasonable	0.99 (0.96...1.17)	0.06 (-0.15...0.02)	reasonable

EUR-11_EC-EARTH_r12i_COSMO-crCLIM-v1-1	reasonable	reasonable	0.88 (0.83...0.97)	-0.2 (-0.33...-0.19)	reasonable
EUR-11_EC-EARTH_r12i_HIRHAM5	bad	bad	0.78 (0.73...0.91)	-0.11 (-0.27...-0.07)	bad
EUR-11_EC-EARTH_r12i_RACMO22E	bad	bad	0.83 (0.69...0.97)	-0.1 (-0.32...0.08)	bad
EUR-11_EC-EARTH_r12i_RCA4	bad	bad	0.73 (0.64...0.72)	-0.13 (-0.19...-0.1)	bad
EUR-11_EC-EARTH_r12i_RegCM4-6	good	reasonable	0.81 (0.62...0.88)	0.06 (-0.04...0.18)	reasonable
EUR-11_EC-EARTH_r12i_REMO2015	good	good	1.02 (0.96...1.33)	-0.1 (-0.37...-0.07)	good
EUR-11_EC-EARTH_r12i_WRF361H	bad	bad	0.74 (0.68...0.71)	-0.09 (-0.23...-0.06)	bad
EUR-11_EC-EARTH_r12i_WRF381P	good	good	0.85 (0.72...0.95)	0.12 (-0.06...0.26)	good
EUR-11_EC-EARTH_r1i_COSMO-crCLIM-v1-1	good	good	0.85 (0.72...0.86)	-0.08 (-0.18...-0.05)	good
EUR-11_EC-EARTH_r1i_HIRHAM5	reasonable	bad	0.7 (0.6...0.77)	-0.07 (-0.28...-0.02)	bad
EUR-11_EC-EARTH_r1i_RACMO22E	bad	bad	0.62 (0.55...0.65)	0.23 (0.06...0.39)	bad
EUR-11_EC-EARTH_r1i_RCA4	bad	bad	0.57 (0.48...0.65)	0.02 (-0.11...0.28)	bad
EUR-11_EC-EARTH_r3i_COSMO-crCLIM-v1-1	good	good	0.9 (0.91...1.09)	-0.15 (-0.41...-0.15)	good
EUR-11_EC-EARTH_r3i_HIRHAM5	bad	bad	0.81 (0.74...0.95)	-0.14 (-0.2...-0.11)	bad
EUR-11_EC-EARTH_r3i_RACMO22E	bad	bad	0.87 (0.82...1)	-0.03 (-0.11...0.01)	bad
EUR-11_EC-EARTH_r3i_RCA4	bad	bad	0.65 (0.54...0.68)	-0.22 (-0.28...-0.2)	bad
EUR-11_HadGEM2-ES_r1i_ALADIN63	good	good	1.17 (0.99...1.26)	-0.44 (-0.5...-0.39)	bad
EUR-11_HadGEM2-ES_r1i_CCLM4-8-17	reasonable	reasonable	1.23 (1.12...1.29)	-0.24 (-0.39...-0.17)	bad
EUR-11_HadGEM2-ES_r1i_COSMO-crCLIM-v1-1	good	reasonable	1.23 (1.19...1.26)	-0.3 (-0.34...-0.25)	bad
EUR-11_HadGEM2-ES_r1i_HIRHAM5	good	good	1.01 (0.93...1.04)	-0.29 (-0.36...-0.24)	good
EUR-11_HadGEM2-ES_r1i_RACMO22E	good	good	1.13 (1.04...1.29)	-0.31 (-0.56...-0.22)	reasonable
EUR-11_HadGEM2-ES_r1i_RCA4	good	reasonable	1.02 (0.79...1.08)	-0.38 (-0.46...-0.04)	reasonable
EUR-11_HadGEM2-ES_r1i_RegCM4-6	good	good	0.92 (0.77...1.02)	-0.24 (-0.43...-0.07)	good
EUR-11_HadGEM2-ES_r1i_REMO2015	reasonable	bad	1.15 (0.92...1.18)	-0.31 (-0.36...-0.28)	bad

EUR-11_HadGEM2-ES_r1i_WRF361H	good	good	1.04 (0.87...1.06)	-0.29 (-0.35...-0.06)	good
EUR-11_HadGEM2-ES_r1i_WRF381P	good	good	1.1 (0.87...1.18)	-0.33 (-0.44...-0.18)	reasonable
EUR-11_IPSL-CM5A-MR_r1i_HIRHAM5	reasonable	bad	1.17 (0.98...1.32)	-0.14 (-0.36...-0.1)	bad
EUR-11_IPSL-CM5A-MR_r1i_RACMO22E	bad	bad	1.09 (0.85...1.19)	-0.09 (-0.27...0.01)	bad
EUR-11_IPSL-CM5A-MR_r1i_RCA4	bad	bad	0.99 (0.91...1.06)	0.02 (-0.14...0.19)	bad
EUR-11_IPSL-CM5A-MR_r1i_REMO2015	reasonable	reasonable	1.37 (1.2...1.5)	-0.22 (-0.48...-0.19)	bad
EUR-11_IPSL-CM5A-MR_r1i_WRF381P	bad	reasonable	1.5 (1.3...1.72)	-0.18 (-0.29...-0.08)	bad
EUR-11_MIROC5_r1i_CCLM4-8-17	good	good	1.02 (0.94...1.12)	-0.28 (-0.37...-0.16)	good
EUR-11_MIROC5_r1i_REMO2015	reasonable	good	1.12 (1.07...1.29)	-0.3 (-0.42...-0.27)	reasonable
EUR-11_MPI-ESM-LR_r1i_ALADIN63	good	bad	0.81 (0.77...0.84)	-0.26 (-0.23...-0.12)	bad
EUR-11_MPI-ESM-LR_r1i_CCLM4-8-17	reasonable	bad	0.81 (0.79...0.91)	-0.19 (-0.27...-0.1)	bad
EUR-11_MPI-ESM-LR_r1i_COSMO-crCLM-v1-1	good	good	0.77 (0.71...0.81)	-0.23 (-0.31...-0.14)	good
EUR-11_MPI-ESM-LR_r1i_HIRHAM5	reasonable	bad	0.77 (0.65...0.84)	-0.35 (-0.39...-0.26)	bad
EUR-11_MPI-ESM-LR_r1i_RACMO22E	bad	bad	0.79 (0.75...0.86)	-0.34 (-0.41...-0.28)	bad
EUR-11_MPI-ESM-LR_r1i_RCA4	bad	bad	0.67 (0.55...0.83)	-0.31 (-0.67...-0.12)	bad
EUR-11_MPI-ESM-LR_r1i_RegCM4-6	good	reasonable	0.8 (0.74...1.03)	-0.01 (-0.17...-0.02)	reasonable
EUR-11_MPI-ESM-LR_r1i_REMO2009	good	good	1 (0.84...1.17)	-0.39 (-0.5...-0.31)	bad
EUR-11_MPI-ESM-LR_r1i_WRF361H	reasonable	bad	0.66 (0.51...0.81)	-0.11 (-0.33...0.1)	bad
EUR-11_MPI-ESM-LR_r2i_COSMO-crCLM-v1-1	good	bad	0.99 (0.89...1.13)	-0.37 (-0.48...-0.26)	bad
EUR-11_MPI-ESM-LR_r2i_RCA4	bad	bad	0.88 (0.58...1.04)	-0.56 (-0.75...0.16)	bad
EUR-11_MPI-ESM-LR_r2i_REMO2009	good	good	1.19 (1.12...1.37)	-0.4 (-0.53...-0.28)	bad
EUR-11_MPI-ESM-LR_r3i_COSMO-crCLM-v1-1	good	good	0.8 (0.64...0.94)	-0.09 (-0.31...0)	good
EUR-11_MPI-ESM-LR_r3i_RCA4	bad	bad	0.85 (0.51...1.1)	-0.43 (-0.73...0.31)	bad
EUR-11_MPI-ESM-LR_r3i_REMO2015	good	good	0.98 (0.73...1.27)	-0.19 (-0.42...-0.12)	good

EUR-11_NorESM1-M_r1i_ALADIN63	reasonable	reasonable	0.65 (0.57...0.7)	-0.23 (-0.44...-0.12)	reasonable
EUR-11_NorESM1-M_r1i_COSMO-crCLIM-v1-1	good	good	0.75 (0.66...0.79)	-0.09 (-0.47...0.04)	good
EUR-11_NorESM1-M_r1i_HIRHAM5	reasonable	reasonable	0.71 (0.53...0.71)	-0.24 (-0.42...-0.05)	reasonable
EUR-11_NorESM1-M_r1i_RACMO22E	bad	bad	0.72 (0.59...0.72)	-0.42 (-0.45...-0.29)	bad
EUR-11_NorESM1-M_r1i_RCA4	bad	bad	0.65 (0.57...0.73)	-0.44 (-0.64...-0.35)	bad
EUR-11_NorESM1-M_r1i_RegCM4-6	good	good	0.62 (0.53...0.64)	-0.13 (-0.31...0.04)	reasonable
EUR-11_NorESM1-M_r1i_REMO2015	good	good	0.74 (0.62...0.97)	-0.06 (-0.32...0.22)	good
EUR-11_NorESM1-M_r1i_WRF381P	good	good	0.79 (0.66...0.87)	-0.01 (-0.14...0.1)	good
ACCESS-CM2_r1_gn	good	good	0.72 (0.47...0.77)	0.02 (-0.24...0.28)	good
AWI-CM-1-1-MR_r1_gn	good	good	0.85 (0.68...1.03)	-0.24 (-0.27...-0.12)	good
CanESM5_r1_gn	bad	bad	0.96 (0.75...0.99)	-0.28 (-0.33...-0.18)	bad
CMCC-ESM2_r1_gn	good	bad	0.75 (0.74...0.8)	-0.04 (-0.2...0)	bad
CNRM-CM6-1_r1_gr	good	good	1.21 (1.09...1.24)	-0.41 (-0.66...-0.23)	bad
CNRM-CM6-1-HR_r1_gr	good	good	1.03 (0.92...1.2)	-0.23 (-0.46...-0.15)	good
EC-Earth3-Veg-LR_r1_gr	good	reasonable	0.89 (0.74...0.96)	-0.14 (-0.22...-0.02)	reasonable
GFDL-ESM4_r1_gr1	good	good	0.91 (0.79...1.06)	-0.2 (-0.33...-0.12)	good
INM-CM4-8_r1_gr1	good	bad	1.4 (1.28...1.54)	-0.16 (-0.42...-0.1)	bad
INM-CM5-0_r1_gr1	reasonable	bad	1.05 (0.85...1.12)	0.02 (-0.12...0.16)	bad
KACE-1-0-G_r1_gr	good	bad	1.03 (0.94...1.13)	-0.13 (-0.3...-0.09)	bad
MIROC6_r1_gn	reasonable	bad	0.9 (0.73...0.94)	-0.18 (-0.26...-0.08)	bad
MPI-ESM1-2-LR_r1_gn	bad	reasonable	0.73 (0.65...0.79)	-0.18 (-0.36...-0.12)	bad
MRI-ESM2-0_r1_gn	good	good	0.93 (0.83...1.01)	-0.19 (-0.48...-0.01)	good
NorESM2-MM_r1_gn	good	reasonable	0.99 (0.96...1.07)	-0.17 (-0.32...-0.12)	reasonable

Table A2: Evaluation results of the climate models considered for attribution analysis of Tn2month 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.

Model / Observations	Seasonal cycle	Spatial pattern	Sigma	Shape	Summary
era5_tmin			0.58 (0.4...0.72)	-0.29 (-0.59...0)	
eobs_tn			0.53 (0.37...0.63)	-0.24 (-0.53...-0.03)	
cpc_tmin			0.64 (0.35...0.81)	-0.44 (-0.72...-0.02)	
me_tmin			0.54 (0.35...0.66)	-0.25 (-0.51...-0.02)	
EUR-11_CanESM2_r1i_REMO2015	reasonable	good	0.71 (0.43...0.82)	-0.27 (-0.47...-0.04)	reasonable
EUR-11_CNRM-CM5_r1i_ALADIN63	bad	reasonable	0.7 (0.57...0.68)	-0.14 (-0.37...-0.07)	bad
EUR-11_CNRM-CM5_r1i_CCLM4-8-17	good	good	0.53 (0.49...0.56)	-0.17 (-0.52...-0.17)	good
EUR-11_CNRM-CM5_r1i_HIRHAM5	reasonable	good	0.72 (0.41...0.65)	-0.2 (-0.22...0.25)	reasonable
EUR-11_CNRM-CM5_r1i_RCA4	reasonable	good	0.54 (0.48...0.6)	-0.22 (-0.42...-0.01)	reasonable
EUR-11_CNRM-CM5_r1i_REMO2015	good	good	0.46 (0.38...0.44)	-0.02 (-0.1...0.11)	reasonable
EUR-11_CNRM-CM5_r1i_WRF381P	bad	reasonable	0.94 (0.72...0.99)	-0.3 (-0.34...-0.11)	bad
EUR-11_EC-EARTH_r12i_CCLM4-8-17	reasonable	good	0.74 (0.68...0.87)	-0.1 (-0.32...-0.06)	reasonable
EUR-11_EC-EARTH_r12i_COSMO-crCLIM-v1-1	good	good	0.74 (0.65...0.84)	-0.23 (-0.57...-0.12)	good
EUR-11_EC-EARTH_r12i_HIRHAM5	good	good	0.57 (0.51...0.68)	-0.19 (-0.35...-0.1)	good
EUR-11_EC-EARTH_r12i_RACMO22E	bad	good	0.59 (0.5...0.64)	-0.17 (-0.46...-0.04)	bad
EUR-11_EC-EARTH_r12i_RCA4	bad	good	0.5 (0.37...0.44)	-0.08 (-0.18...-0.04)	bad
EUR-11_EC-EARTH_r12i_RegCM4-6	bad	reasonable	0.67 (0.48...0.66)	-0.1 (-0.13...0)	bad
EUR-11_EC-EARTH_r12i_REMO2015	good	good	0.56 (0.47...0.68)	-0.17 (-0.37...-0.08)	good
EUR-11_EC-EARTH_r12i_WRF361H	bad	reasonable	0.58 (0.46...0.55)	-0.15 (-0.39...-0.03)	bad
EUR-11_EC-EARTH_r12i_WRF381P	bad	reasonable	0.66 (0.58...0.75)	-0.05 (-0.33...-0.02)	bad
EUR-11_EC-EARTH_r1i_COSMO-crCLIM-v1-1	good	good	0.63 (0.5...0.71)	-0.32 (-0.49...-0.14)	good
EUR-11_EC-EARTH_r1i_HIRHAM5	good	good	0.48 (0.41...0.51)	-0.08 (-0.28...0.12)	good
EUR-11_EC-EARTH_r1i_RACMO22E	reasonable	good	0.55 (0.51...0.57)	-0.2 (-0.32...0.01)	reasonable
EUR-11_EC-EARTH_r3i_COSMO-crCLIM-v1-1	good	good	0.56 (0.51...0.63)	-0.1 (-0.24...-0.07)	good
EUR-11_EC-EARTH_r3i_HIRHAM5	good	good	0.55 (0.51...0.63)	-0.14 (-0.24...-0.12)	good
EUR-11_EC-EARTH_r3i_RACMO22E	bad	good	0.53 (0.49...0.6)	-0.08 (-0.18...-0.03)	bad
EUR-11_EC-EARTH_r3i_RCA4	bad	good	0.49 (0.43...0.49)	-0.28 (-0.51...-0.2)	bad
EUR-11_HadGEM2-ES_r1i_ALADIN63	reasonable	reasonable	0.69 (0.61...0.75)	-0.37 (-0.41...-0.36)	reasonable
EUR-11_HadGEM2-ES_r1i_CCLM4-8-17	bad	reasonable	0.77 (0.72...0.84)	-0.15 (-0.33...-0.07)	bad
EUR-11_HadGEM2-ES_r1i_COSMO-crCLIM-v1-1	bad	reasonable	0.78 (0.79...0.82)	-0.22 (-0.28...-0.16)	bad
EUR-11_HadGEM2-ES_r1i_HIRHAM5	bad	reasonable	0.69 (0.66...0.73)	-0.23 (-0.4...-0.17)	bad
EUR-11_HadGEM2-ES_r1i_RACMO22E	good	reasonable	0.82 (0.8...0.89)	-0.55 (-0.64...-0.48)	reasonable
EUR-11_HadGEM2-ES_r1i_RCA4	good	good	0.57 (0.49...0.66)	-0.09 (-0.3...0.15)	good

EUR-11_HadGEM2-ES_r1i_RegCM4-6	good	reasonable	0.63 (0.51...0.77)	-0.22 (-0.58...-0.16)	reasonable
EUR-11_HadGEM2-ES_r1i_WRF381P	reasonable	reasonable	0.83 (0.69...0.86)	-0.42 (-0.49...-0.34)	reasonable
EUR-11_IPSL-CM5A-MR_r1i_HIRHAM5	good	good	0.77 (0.7...0.83)	-0.16 (-0.41...-0.11)	good
EUR-11_IPSL-CM5A-MR_r1i_RACMO22E	good	good	0.68 (0.6...0.72)	-0.11 (-0.29...-0.01)	good
EUR-11_IPSL-CM5A-MR_r1i_RCA4	reasonable	good	0.65 (0.49...0.65)	0.05 (0.07...0.33)	bad
EUR-11_IPSL-CM5A-MR_r1i_REMO2015	good	good	0.9 (0.8...0.97)	-0.22 (-0.46...-0.17)	reasonable
EUR-11_IPSL-CM5A-MR_r1i_WRF381P	bad	reasonable	1.13 (1.05...1.28)	-0.26 (-0.37...-0.24)	bad
EUR-11_MIROC5_r1i_CCLM4-8-17	reasonable	good	0.66 (0.62...0.76)	-0.26 (-0.32...-0.17)	reasonable
EUR-11_MIROC5_r1i_REMO2015	reasonable	reasonable	0.7 (0.61...0.78)	-0.23 (-0.33...-0.11)	reasonable
EUR-11_MPI-ESM-LR_r1i_ALADIN63	reasonable	reasonable	0.5 (0.48...0.52)	-0.14 (-0.16...-0.02)	reasonable
EUR-11_MPI-ESM-LR_r1i_CCLM4-8-17	good	good	0.51 (0.41...0.54)	-0.12 (-0.1...0.06)	good
EUR-11_MPI-ESM-LR_r1i_COSMO-crCLIM-v1-1	reasonable	good	0.57 (0.51...0.64)	-0.22 (-0.43...-0.15)	reasonable
EUR-11_MPI-ESM-LR_r1i_HIRHAM5	reasonable	good	0.53 (0.44...0.61)	-0.31 (-0.52...-0.26)	reasonable
EUR-11_MPI-ESM-LR_r1i_RACMO22E	good	good	0.54 (0.45...0.61)	-0.34 (-0.57...-0.31)	good
EUR-11_MPI-ESM-LR_r1i_RCA4	good	good	0.55 (0.49...0.55)	-0.31 (-0.4...-0.2)	good
EUR-11_MPI-ESM-LR_r1i_RegCM4-6	reasonable	reasonable	0.44 (0.42...0.54)	-0.1 (-0.32...-0.05)	reasonable
EUR-11_MPI-ESM-LR_r1i_REMO2009	reasonable	reasonable	0.55 (0.45...0.63)	-0.33 (-0.48...-0.26)	reasonable
EUR-11_MPI-ESM-LR_r1i_WRF361H	bad	good	0.56 (0.52...0.63)	-0.29 (-0.5...-0.24)	bad
EUR-11_MPI-ESM-LR_r2i_COSMO-crCLIM-v1-1	good	good	0.69 (0.65...0.81)	-0.33 (-0.42...-0.22)	good
EUR-11_MPI-ESM-LR_r2i_RCA4	reasonable	good	0.6 (0.54...0.67)	-0.28 (-0.59...-0.06)	reasonable
EUR-11_MPI-ESM-LR_r2i_REMO2009	good	good	0.66 (0.6...0.77)	-0.26 (-0.52...-0.16)	good
EUR-11_MPI-ESM-LR_r3i_RCA4	reasonable	good	0.65 (0.45...0.81)	-0.33 (-0.61...0.26)	reasonable
EUR-11_NorESM1-M_r1i_ALADIN63	bad	reasonable	0.58 (0.41...0.66)	-0.23 (-0.32...-0.1)	bad
EUR-11_NorESM1-M_r1i_COSMO-crCLIM-v1-1	good	good	0.65 (0.43...0.62)	-0.2 (-0.28...0.11)	good
EUR-11_NorESM1-M_r1i_HIRHAM5	good	good	0.58 (0.44...0.53)	-0.37 (-0.38...-0.21)	good
EUR-11_NorESM1-M_r1i_RACMO22E	reasonable	good	0.62 (0.51...0.64)	-0.32 (-0.48...-0.27)	reasonable
EUR-11_NorESM1-M_r1i_RCA4	reasonable	good	0.58 (0.53...0.68)	-0.4 (-0.57...-0.31)	reasonable
EUR-11_NorESM1-M_r1i_RegCM4-6	reasonable	reasonable	0.57 (0.54...0.66)	-0.26 (-0.49...-0.17)	reasonable
EUR-11_NorESM1-M_r1i_REMO2015	good	good	0.5 (0.46...0.51)	-0.22 (-0.26...-0.04)	good
EUR-11_NorESM1-M_r1i_WRF381P	bad	reasonable	0.66 (0.49...0.74)	-0.09 (-0.33...0.04)	bad
ACCESS-CM2_r1_gn	reasonable	reasonable	0.6 (0.48...0.62)	-0.19 (-0.36...-0.15)	reasonable
AWI-CM-1-1-MR_r1_gn	bad	good	0.68 (0.57...0.75)	-0.27 (-0.31...-0.13)	bad
CanESM5_r1_gn	good	reasonable	0.81 (0.62...0.86)	-0.3 (-0.45...-0.15)	reasonable
CMCC-ESM2_r1_gn	good	bad	0.65 (0.6...0.77)	-0.2 (-0.67...-0.13)	bad
CNRM-CM6-1_r1_gr	bad	good	0.91 (0.85...0.91)	-0.28 (-0.48...-0.13)	bad
CNRM-CM6-1-HR_r1_gr	good	good	0.74 (0.65...0.78)	-0.31 (-0.37...-0.21)	good

EC-Earth3-Veg-LR_r1_gr	reasonable	reasonable	0.74 (0.66...0.77)	-0.2 (-0.23...-0.11)	reasonable
GFDL-ESM4_r1_gr1	good	good	0.71 (0.63...0.84)	-0.29 (-0.55...-0.18)	good
INM-CM4-8_r1_gr1	reasonable	reasonable	0.57 (0.52...0.56)	-0.15 (-0.31...-0.04)	reasonable
INM-CM5-0_r1_gr1	reasonable	reasonable	0.74 (0.6...0.75)	-0.29 (-0.41...-0.14)	reasonable
KACE-1-0-G_r1_gr	bad	good	0.44 (0.39...0.52)	-0.18 (-0.44...-0.15)	bad
MIROC6_r1_gn	bad	good	0.63 (0.54...0.69)	-0.22 (-0.28...-0.15)	bad
MPI-ESM1-2-LR_r1_gn	bad	good	0.57 (0.48...0.63)	-0.15 (-0.38...-0.08)	bad
MRI-ESM2-0_r1_gn	bad	good	0.72 (0.6...0.78)	-0.37 (-0.59...-0.25)	bad
NorESM2-MM_r1_gn	bad	good	0.69 (0.61...0.8)	-0.23 (-0.42...-0.14)	bad

Table A3: Evaluation results of the climate models considered for attribution analysis of Rn30day 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.

Model / Observations	Seasonal cycle	Spatial pattern	Sigma	Summary
era5_tp			1.09 (0.54...4.17)	
eobs_rr			2.2 (-1.65...13.16)	
cpc_precip			1.87 (-10.52...13.91)	
me_rain			1.97 (-7.46...13.32)	
EUR-11_CanESM2_r1i_CCLM4-8-17	reasonable	bad	0.35 (0.33...0.36)	bad
EUR-11_CanESM2_r1i_REMO2015	good	bad	0.26 (0.22...0.27)	bad
EUR-11_CNRM-CM5_r1i_ALADIN53	bad	good	0.17 (0.17...0.19)	bad
EUR-11_CNRM-CM5_r1i_ALADIN63	reasonable	reasonable	0.21 (0.18...0.24)	reasonable
EUR-11_CNRM-CM5_r1i_ALARO-0	reasonable	good	0.18 (0.14...0.19)	reasonable
EUR-11_CNRM-CM5_r1i_CCLM4-8-17	good	good	0.28 (0.26...0.28)	good
EUR-11_CNRM-CM5_r1i_HIRHAM5	good	reasonable	0.16 (0.15...0.17)	reasonable
EUR-11_CNRM-CM5_r1i_RACMO22E	good	good	0.17 (0.15...0.17)	good
EUR-11_CNRM-CM5_r1i_RCA4	bad	reasonable	0.13 (0.12...0.13)	bad
EUR-11_CNRM-CM5_r1i_REMO2015	good	bad	0.21 (0.19...0.22)	bad
EUR-11_CNRM-CM5_r1i_WRF381P	good	reasonable	0.18 (0.16...0.19)	reasonable
EUR-11_EC-EARTH_r12i_CCLM4-8-17	good	good	0.29 (0.24...0.32)	good
EUR-11_EC-EARTH_r12i_COSMO-crCLIM-v1-1	good	good	0.22 (0.19...0.24)	good
EUR-11_EC-EARTH_r12i_HIRHAM5	good	bad	0.22 (0.19...0.23)	bad
EUR-11_EC-EARTH_r12i_RACMO22E	reasonable	good	0.2 (0.17...0.22)	reasonable
EUR-11_EC-EARTH_r12i_RCA4	bad	good	0.16 (0.15...0.17)	bad
EUR-11_EC-EARTH_r12i_RegCM4-6	good	reasonable	0.23 (0.19...0.26)	reasonable
EUR-11_EC-EARTH_r12i_REMO2015	reasonable	bad	0.25 (0.21...0.29)	bad
EUR-11_EC-EARTH_r12i_WRF361H	reasonable	good	0.2 (0.18...0.21)	reasonable
EUR-11_EC-EARTH_r12i_WRF381P	good	reasonable	0.21 (0.15...0.22)	reasonable
EUR-11_EC-EARTH_r1i_COSMO-crCLIM-v1-1	reasonable	reasonable	0.27 (0.2...0.33)	reasonable
EUR-11_EC-EARTH_r1i_HIRHAM5	good	bad	0.27 (0.21...0.29)	bad

EUR-11_EC-EARTH_r1i_RACMO22E	good	good	0.25 (0.18...0.29)	good
EUR-11_EC-EARTH_r1i_RCA4	reasonable	good	0.23 (0.18...0.28)	reasonable
EUR-11_EC-EARTH_r3i_COSMO-crCLIM-v1-1	reasonable	bad	0.26 (0.24...0.29)	bad
EUR-11_EC-EARTH_r3i_HIRHAM5	reasonable	reasonable	0.22 (0.18...0.23)	reasonable
EUR-11_EC-EARTH_r3i_RACMO22E	good	good	0.24 (0.22...0.27)	good
EUR-11_EC-EARTH_r3i_RCA4	reasonable	good	0.18 (0.17...0.2)	reasonable
EUR-11_HadGEM2-ES_r1i_ALADIN63	reasonable	good	0.22 (0.21...0.23)	reasonable
EUR-11_HadGEM2-ES_r1i_CCLM4-8-17	reasonable	good	0.27 (0.25...0.29)	reasonable
EUR-11_HadGEM2-ES_r1i_COSMO-crCLIM-v1-1	reasonable	bad	0.28 (0.25...0.32)	bad
EUR-11_HadGEM2-ES_r1i_HIRHAM5	good	bad	0.21 (0.2...0.22)	bad
EUR-11_HadGEM2-ES_r1i_RACMO22E	good	good	0.2 (0.18...0.22)	good
EUR-11_HadGEM2-ES_r1i_RCA4	reasonable	reasonable	0.19 (0.16...0.21)	reasonable
EUR-11_HadGEM2-ES_r1i_RegCM4-6	good	reasonable	0.2 (0.18...0.23)	reasonable
EUR-11_HadGEM2-ES_r1i_REMO2015	good	bad	0.21 (0.2...0.22)	bad
EUR-11_HadGEM2-ES_r1i_WRF361H	good	good	0.21 (0.19...0.22)	good
EUR-11_HadGEM2-ES_r1i_WRF381P	good	good	0.17 (0.15...0.18)	good
EUR-11_IPSL-CM5A-MR_r1i_HIRHAM5	good	bad	0.22 (0.18...0.23)	bad
EUR-11_IPSL-CM5A-MR_r1i_RACMO22E	good	good	0.18 (0.17...0.2)	good
EUR-11_IPSL-CM5A-MR_r1i_RCA4	reasonable	good	0.16 (0.14...0.17)	reasonable
EUR-11_IPSL-CM5A-MR_r1i_REMO2015	good	bad	0.18 (0.15...0.19)	bad
EUR-11_IPSL-CM5A-MR_r1i_WRF381P	reasonable	good	0.22 (0.2...0.22)	reasonable
EUR-11_MIROC5_r1i_CCLM4-8-17	good	good	0.26 (0.23...0.3)	good
EUR-11_MIROC5_r1i_REMO2015	reasonable	bad	0.22 (0.2...0.24)	bad
EUR-11_MIROC5_r1i_WRF361H	bad	bad	0.24 (0.21...0.26)	bad
EUR-11_MPI-ESM-LR_r1i_ALADIN63	reasonable	good	0.21 (0.21...0.24)	reasonable
EUR-11_MPI-ESM-LR_r1i_CCLM4-8-17	reasonable	good	0.2 (0.18...0.21)	reasonable
EUR-11_MPI-ESM-LR_r1i_COSMO-crCLIM-v1-1	reasonable	good	0.2 (0.17...0.22)	reasonable
EUR-11_MPI-ESM-LR_r1i_HIRHAM5	reasonable	bad	0.2 (0.16...0.21)	bad
EUR-11_MPI-ESM-LR_r1i_RACMO22E	reasonable	good	0.19 (0.16...0.22)	reasonable
EUR-11_MPI-ESM-LR_r1i_RCA4	bad	good	0.17 (0.17...0.19)	bad
EUR-11_MPI-ESM-LR_r1i_RegCM4-6	reasonable	bad	0.2 (0.19...0.22)	bad
EUR-11_MPI-ESM-LR_r1i_REMO2009	reasonable	bad	0.21 (0.19...0.23)	bad
EUR-11_MPI-ESM-LR_r2i_COSMO-crCLIM-v1-1	good	good	0.23 (0.2...0.23)	good
EUR-11_MPI-ESM-LR_r2i_RCA4	bad	good	0.14 (0.13...0.15)	bad
EUR-11_MPI-ESM-LR_r2i_REMO2009	reasonable	bad	0.17 (0.15...0.17)	bad
EUR-11_MPI-ESM-LR_r3i_COSMO-crCLIM-v1-1	good	good	0.19 (0.18...0.24)	good
EUR-11_MPI-ESM-LR_r3i_RCA4	bad	good	0.15 (0.15...0.17)	bad
EUR-11_MPI-ESM-LR_r3i_REMO2015	reasonable	bad	0.2 (0.15...0.22)	bad
EUR-11_NorESM1-M_r1i_ALADIN63	bad	good	0.15 (0.15...0.19)	bad
EUR-11_NorESM1-M_r1i_COSMO-crCLIM-v1-1	good	good	0.17 (0.16...0.18)	good
EUR-11_NorESM1-M_r1i_HIRHAM5	good	bad	0.17 (0.16...0.18)	bad
EUR-11_NorESM1-M_r1i_RACMO22E	reasonable	good	0.16 (0.14...0.17)	reasonable
EUR-11_NorESM1-M_r1i_RCA4	reasonable	reasonable	0.13 (0.12...0.14)	reasonable
EUR-11_NorESM1-M_r1i_RegCM4-6	bad	bad	0.14 (0.12...0.16)	bad
EUR-11_NorESM1-M_r1i_REMO2015	reasonable	good	0.17 (0.17...0.19)	reasonable
EUR-11_NorESM1-M_r1i_WRF381P	reasonable	reasonable	0.17 (0.16...0.19)	reasonable

Table A4: Event magnitude, probability ratio and change in intensity for 70-year return period for Tx2month for observational datasets and each model that passed the evaluation tests. (a) from pre-industrial to 2018's climate, from 2018's climate to present day (2026) of 1.3°C above pre-industrial climate (c) from 2018's climate to 1.5°C above pre-industrial climate (d) from 2018's climate to 2.0°C above pre-industrial climate, and (e) from 2018's climate to 3.0°C above pre-industrial climate.

		Preindustrial - 2018 (1.1 °C)		2018 - Present (1.3 °C)		2018 - Future (1.5 °C)		2018 - Future (2.0 °C)		2018 - Future (3.0 °C)	
Model / Observations	Threshold for return period 70 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 [%]	Probability ratio PR [-]	Change in intensity ΔI [%]
era5_tmax	20.08°C	1.83 (0.33...Inf)	0.35 (-0.6...1.43)								
eobs_tx	21.23°C	4.56 (0.83...Inf)	0.79 (-0.2...2.21)								
cpc_tmax	20.8°C	18.24 (1.38...Inf)	1.8 (0.47...3.57)								
me_tmax	21.78°C	6.13 (1.54...Inf)	1.28 (0.44...2.73)								
EUR-11_CNRM-CM5_r1i_CCLM4-8-17	20.18°C	13.67 (3.75...43.84)	1.2 (0.71...1.8)	1.23 (1.14...1.26)	0.11 (0.07...0.13)	1.5 (1.29...1.56)	0.23 (0.14...0.26)	2.41 (1.74...2.6)	0.51 (0.3...0.58)	5.64 (3.06...6.34)	1.07 (0.64...1.22)
EUR-11_CNRM-CM5_r1i_REMO2015	20.05°C	Inf (Inf...Inf)	1.6 (1.49...2.28)	1.44 (1.32...2.31)	0.14 (0.1...0.19)	2.01 (1.7...4.19)	0.28 (0.19...0.38)	4.13 (2.98...11.23)	0.63 (0.44...0.86)	12.18 (7.25...32.03)	1.33 (0.92...1.81)
EUR-11_EC-EARTH_r12i_REMO2015	19.94°C	1.79 (1.39...27.57)	0.3 (0.13...0.73)	1.36 (1.27...1.52)	0.15 (0.13...0.16)	1.81 (1.6...2.2)	0.29 (0.25...0.32)	3.45 (2.77...4.68)	0.65 (0.57...0.72)	9.8 (7.23...13.65)	1.38 (1.2...1.51)
EUR-11_EC-EARTH_r12i_WRF381P	20.86°C	1.94 (2.31...37.76)	0.76 (0.73...1.31)	1.19 (1.14...1.39)	0.15 (0.14...0.17)	1.41 (1.29...1.89)	0.29 (0.27...0.34)	2.16 (1.79...3.76)	0.66 (0.61)	4.99 (3.48...11.44)	1.4 (1.29)

									...0.76)		...1.61)
EUR-11_EC-EARTH_r1i_COSMO-crCLIM-v1-1	19.61°C	5.77 (2.36...3 5.08)	0.93 (0.56... 1.52)	1.41 (1.29... 1.48)	0.14 (0.1...0. 18)	1.95 (1.63... 2.13)	0.28 (0.19... 0.37)	3.97 (2.79...4 .82)	0.63 (0.43 ...0.83)	12.19 (6.69... 17.5)	1.32 (0.9... 1.75)
EUR-11_EC-EARTH_r3i_COSMO-crCLIM-v1-1	19.58°C	3.25 (1.07...7 497.34)	0.48 (0.04... 0.91)	1.38 (1.24... 1.65)	0.13 (0.12... 0.16)	1.85 (1.53... 2.53)	0.27 (0.23... 0.31)	3.62 (2.51...5 .96)	0.61 (0.53 ...0.71)	10.62 (6.01... 19)	1.28 (1.11... 1.49)
EUR-11_HadGEM2-ES_r1i_HIRHAM5	21.19°C	Inf (Inf...Inf)	1.32 (0.82... 1.83)	1.54 (1.41... 1.89)	0.17 (0.16... 0.2)	2.27 (1.94... 3.18)	0.34 (0.31... 0.39)	5.1 (3.96...8 .39)	0.76 (0.7... 0.88)	16.34 (12.25 ...27.21)	1.6 (1.47 ...1.86)
EUR-11_HadGEM2-ES_r1i_RegCM4-6	21.36°C	35135.1 3 (33.82...l nf)	1.23 (0.56... 1.94)	1.28 (1.22... 1.34)	0.15 (0.14... 0.16)	1.63 (1.49... 1.76)	0.29 (0.28... 0.32)	2.89 (2.42...3 .28)	0.66 (0.63 ...0.72)	7.9 (6.2...9. 24)	1.4 (1.33 ...1.53)
EUR-11_HadGEM2-ES_r1i_WRF361H	20.46°C	Inf (17.08...l nf)	1.26 (1.19... 1.89)	1.33 (1.25... 1.41)	0.12 (0.12... 0.14)	1.74 (1.56... 1.94)	0.25 (0.25... 0.29)	3.19 (2.62...3 .94)	0.55 (0.56 ...0.64)	8.65 (6.61... 12.08)	1.17 (1.18 ...1.36)
EUR-11_MIROC5_r1i_CCLM4-8-17	21.5°C	4.77 (3.41...3 79.26)	0.79 (0.43... 1.73)	1.37 (1.2...1. 51)	0.22 (0.18... 0.24)	1.86 (1.44... 2.22)	0.44 (0.36... 0.49)	3.73 (2.27...5 .24)	1 (0.8... 1.09)	12.13 (5.52... 19.84)	2.11 (1.69 ...2.3)
EUR-11_MPI-ESM-LR_r1i_COSMO-crCLIM-v1-1	19.2°C	13.9 (2.63...ln f)	0.58 (0.18... 0.9)	1.32 (1.32... 1.68)	0.11 (0.12... 0.16)	1.73 (1.73... 2.64)	0.23 (0.25... 0.32)	3.16 (3.18...6 .7)	0.51 (0.55 ...0.72)	8.57 (8.78... 23.88)	1.08 (1.17 ...1.51)
EUR-11_MPI-ESM-LR_r3i_COSMO-crCLIM-v1-1	19.65°C	8.54 (2.15...1 09.34)	0.79 (0.32... 0.81)	1.54 (1.45... 1.71)	0.15 (0.14... 0.17)	2.28 (2.04... 2.68)	0.3 (0.28... 0.34)	5.23 (4.34...6 .46)	0.69 (0.63 ...0.76)	17.61 (13.93 ...21.48)	1.45 (1.33 ...1.61)
EUR-11_MPI-ESM-LR_r3i_REMO2015	20.01°C	17.74 (4.24...ln f)	0.72 (0.29... 1.04)	1.49 (1.38... 1.59)	0.13 (0.11... 0.13)	2.14 (1.85... 2.37)	0.25 (0.21... 0.25)	4.55 (3.53...5 .26)	0.57 (0.47 ...0.57)	13.64 (9.74... 15.72)	1.2 (1...1. 2)
EUR-11_NorESM1-M_r1i_COSMO-crCLIM-v1-1	19.72°C	2.88 (1.35...ln f)	0.5 (0.08... 1.82)	1.49 (1.42... 1.76)	0.17 (0.16... 0.2)	2.17 (1.97... 2.91)	0.35 (0.33... 0.41)	5.05 (4.25...8 .28)	0.78 (0.73	19.11 (15.34	1.65 (1.55

									...0.92)	...33.64)	...1.94)
EUR-11_NorESM1-M_r1i_REMO2015	20°C	1.86 (1.14...1 4548964 49.48)	0.32 (0.03... 1.66)	1.58 (1.34... 1.75)	0.19 (0.16... 0.19)	2.4 (1.78... 2.82)	0.37 (0.32... 0.38)	5.99 (3.5...7. 3)	0.84 (0.72 ...0.87)	23.51 (11.76 ...25.99)	1.78 (1.53 ...1.83)
EUR-11_NorESM1-M_r1i_WRF381P	19.99°C	3.53 (2.77...1 3.72)	0.78 (0.62... 1.41)	1.25 (1.19... 1.37)	0.15 (0.13... 0.17)	1.56 (1.42... 1.85)	0.3 (0.26... 0.34)	2.67 (2.19...3 .71)	0.67 (0.59 ...0.76)	7.41 (5.19... 12.3)	1.42 (1.25 ...1.6)
ACCESS-CM2_r1_gn	19.98°C	66.56 (12.47... 1530.53)	1.53 (1.27... 1.68)	1.51 (1.43... 1.53)	0.21 (0.2...0. 21)	2.23 (2.01... 2.27)	0.41 (0.39... 0.42)	5.35 (4.41...5 .51)	0.93 (0.88 ...0.95)	21.26 (16.33 ...21.94)	1.95 (1.85 ...2.01)
AWI-CM-1-1-MR_r1_gn	19.05°C	7.05 (3.27...2 21.47)	0.6 (0.48... 0.98)	1.67 (1.49... 2.11)	0.2 (0.18... 0.23)	2.64 (2.17... 3.86)	0.39 (0.36... 0.46)	6.95 (4.94...1 1.84)	0.88 (0.8... 1.03)	26.88 (17.81 ...42.26)	1.87 (1.69 ...2.17)
CNRM-CM6-1-HR_r1_gr	20.13°C	4.83 (2.4...12. 08)	0.83 (0.5...1. 09)	1.27 (1.22... 1.28)	0.17 (0.15... 0.17)	1.61 (1.49... 1.64)	0.34 (0.31... 0.35)	2.83 (2.43...2 .94)	0.76 (0.69 ...0.78)	7.92 (6.28... 8.53)	1.61 (1.46 ...1.65)
GFDL-ESM4_r1_gr1	19.56°C	235.59 (4.95...3 3470187 1604.66)	1.05 (0.58... 1.56)	1.39 (1.29... 1.68)	0.16 (0.13... 0.2)	1.91 (1.64... 2.67)	0.31 (0.26... 0.39)	3.88 (2.88...7 .05)	0.71 (0.59 ...0.88)	12.45 (7.69... 27.18)	1.49 (1.24 ...1.86)
MRI-ESM2-0_r1_gn	21.04°C	17.33 (7.09...1 42.81)	1.08 (0.97... 1.42)	1.33 (1.27... 1.41)	0.15 (0.14... 0.16)	1.74 (1.61... 1.95)	0.3 (0.29... 0.32)	3.28 (2.8...3. 98)	0.68 (0.65 ...0.72)	9.69 (7.63... 12.3)	1.44 (1.36 ...1.53)

Table A5: Event magnitude, probability ratio and change in intensity for 10-year return period for Tn2month for observational datasets and each model that passed the evaluation tests. (a) from pre-industrial to 2018's climate, from 2018's climate to present day (2026) of 1.3°C above pre-industrial climate (c) from 2018's climate to 1.5°C above pre-industrial climate (d) from 2018's climate to 2.0°C above pre-industrial climate, and (e) from 2018's climate to 3.0°C above pre-industrial climate.

		Preindustrial - 2018 (1.1 °C)		2018 - Present (1.3 °C)		2018 - Future (1.5 °C)		2018 - Future (2.0 °C)		2018 - Future (3.0 °C)	
Model / Observations	Threshold for return period 10yr	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 [%]	Probability ratio PR [-]	Change in intensity ΔI [%]
era5_tmin	12.55 °C	Inf (1.64...Inf)	0.84 (0.11...1.47)								
eobs_tn	11.45 °C	1117.2 (22.99...Inf)	1.38 (0.87...2.07)								
cpc_tmin	11.59 °C	1.61 (0.04...Inf)	0.13 (-0.73...1.01)								
me_tmin	11.29 °C	26592 (42.39...Inf)	1.44 (0.91...2.24)								
EUR-11_CNRM-CM5_r1i_CCLM4-8-17	11.74 °C	402.09 (50.68...Inf)	1.4 (1.15...1.81)	1.33 (1.28...1.45)	0.13 (0.11...0.15)	1.73 (1.61...2)	0.26 (0.22...0.29)	3.08 (2.73...3.8)	0.58 (0.5...0.66)	6.86 (6.08...7.87)	1.23 (1.05...1.39)
EUR-11_EC-EARTH_r12i_COSMO-cr CLIM-v1-1	11.19 °C	5.26 (1.99...520.5)	0.58 (0.28...1.23)	1.42 (1.34...1.57)	0.14 (0.12...0.17)	1.94 (1.74...2.28)	0.29 (0.24...0.33)	3.63 (3.01...4.57)	0.65 (0.54...0.75)	7.55 (6.19...8.88)	1.38 (1.14...1.58)
EUR-11_EC-EARTH_r12i_HIRHAM5	11.44 °C	10.57 (5.91...1626.71)	0.66 (0.61...1.1)	1.5 (1.41...1.51)	0.16 (0.14...0.18)	2.14 (1.95...2.18)	0.32 (0.29...0.35)	4.37 (3.92...4.61)	0.72 (0.65...0.79)	8.97 (8.86...9.5)	1.52 (1.36...1.67)
EUR-11_EC-EARTH_r12i_REMO2015	11.24 °C	19.45 (19.87...Inf)	0.71 (0.71...0.93)	1.53 (1.48...1.54)	0.15 (0.14...0.17)	2.21 (2.09...2.23)	0.3 (0.28...0.33)	4.45 (4.09...4.67)	0.67 (0.63...0.75)	8.81 (8.36...9.33)	1.42 (1.33...1.57)
EUR-11_EC-EARTH_r1i_COSMO-cr CLIM-v1-1	11.29 °C	77.71 (9.18...Inf)	1.02 (0.83...1.48)	1.48 (1.4...1.52)	0.16 (0.15...0.17)	2.09 (1.91...2.18)	0.32 (0.29...0.35)	4.09 (3.66...4.46)	0.73 (0.66...0.78)	8.35 (7.74...9.06)	1.53 (1.4...1.65)

EUR-11_EC-EARTH_r1i_HIRHAM5	11.74°C	41.41 (16...Inf)	1.12 (0.4...1.24)	1.53 (1.45...1.73)	0.16 (0.16...0.18)	2.23 (2.07...2.67)	0.33 (0.31...0.36)	4.65 (4.42...5.63)	0.74 (0.71...0.8)	9.24 (9.03...9.65)	1.56 (1.49...1.69)
EUR-11_EC-EARTH_r3i_COSMO-crCLIM-v1-1	11.29°C	4.63 (2.13...Inf)	0.61 (0.35...0.78)	1.43 (1.34...1.64)	0.16 (0.15...0.18)	1.97 (1.76...2.45)	0.32 (0.3...0.35)	3.85 (3.23...5.09)	0.72 (0.67...0.79)	8.31 (7.44...9.32)	1.51 (1.42...1.67)
EUR-11_EC-EARTH_r3i_HIRHAM5	11.71°C	20.61 (7.36...Inf)	0.92 (0.78...1.16)	1.52 (1.45...2.02)	0.18 (0.17...0.2)	2.21 (2.04...3.31)	0.35 (0.34...0.4)	4.64 (4.25...6.82)	0.8 (0.77...0.91)	9.36 (9.27...9.89)	1.68 (1.63...1.92)
EUR-11_HadGEM2-ES_r1i_RCA4	12.7°C	121.48 (13.43...Inf)	1.87 (1.7...2.18)	1.35 (1.33...1.5)	0.16 (0.16...0.18)	1.78 (1.73...2.12)	0.32 (0.33...0.35)	3.21 (3.13...4.09)	0.72 (0.73...0.8)	7.06 (7.03...8.2)	1.52 (1.55...1.68)
EUR-11_IPSL-CM5A-MR_r1i_HIRHAM5	12.65°C	15.8 (4.39...59.67)	1.11 (0.95...1.37)	1.16 (1.15...1.2)	0.09 (0.08...0.11)	1.34 (1.31...1.42)	0.18 (0.17...0.22)	1.86 (1.8...2.1)	0.41 (0.37...0.49)	3.27 (3.15...4)	0.86 (0.79...1.04)
EUR-11_IPSL-CM5A-MR_r1i_RACMO22E	11.11°C	19.46 (4.97...206.13)	1.17 (0.96...1.7)	1.18 (1.15...1.22)	0.1 (0.1...0.11)	1.39 (1.33...1.47)	0.2 (0.2...0.22)	2.01 (1.85...2.25)	0.46 (0.46...0.5)	3.79 (3.35...4.4)	0.96 (0.97...1.05)
EUR-11_MPI-ESM-LR_r1i_CCLM4-8-17	11.96°C	25.44 (19.21...376.73)	0.96 (0.81...1.23)	1.41 (1.35...1.49)	0.14 (0.12...0.16)	1.92 (1.78...2.12)	0.29 (0.25...0.32)	3.71 (3.23...4.27)	0.65 (0.55...0.71)	8.15 (7.09...8.8)	1.37 (1.17...1.5)
EUR-11_MPI-ESM-LR_r1i_RACMO22E	11.24°C	Inf (Inf...Inf)	0.88 (0.82...1.16)	1.48 (1.35...1.66)	0.13 (0.11...0.14)	2.08 (1.77...2.48)	0.26 (0.22...0.29)	4.05 (3.15...4.91)	0.59 (0.5...0.65)	8.26 (6.78...8.89)	1.25 (1.05...1.37)
EUR-11_MPI-ESM-LR_r1i_RCA4	10.99°C	37.13 (25.06...Inf)	0.61 (0.63...0.89)	1.48 (1.47...1.72)	0.12 (0.12...0.15)	2.07 (2.06...2.61)	0.25 (0.25...0.3)	4 (3.97...5.16)	0.56 (0.55...0.67)	8.15 (8.06...9.13)	1.19 (1.16...1.4)
EUR-11_MPI-ESM-LR_r2i_COSMO-crCLIM-v1-1	12.06°C	5.64 (1.82...12.73)	0.46 (0.14...0.52)	1.34 (1.38...1.52)	0.14 (0.13...0.15)	1.75 (1.83...2.15)	0.28 (0.26...0.3)	3.07 (3.3...4.04)	0.63 (0.57...0.66)	6.53 (6.87...7.79)	1.32 (1.21...1.4)

EUR-11_MPI-ESM-LR_r2i_REMO2009	12.12°C	4.25 (1.29...12.53)	0.45 (0.06...0.48)	1.4 (1.38...1.58)	0.13 (0.12...0.13)	1.87 (1.83...2.24)	0.26 (0.25...0.26)	3.38 (3.28...4.12)	0.58 (0.56...0.59)	6.92 (6.85...7.55)	1.22 (1.18...1.26)
EUR-11_NorESM1-M_r1i_COSMO-crCLIM-v1-1	12.39°C	13.57 (5.51...Inf)	0.84 (0.54...1.46)	1.46 (1.46...1.61)	0.18 (0.17...0.19)	2.06 (2.04...2.42)	0.35 (0.33...0.39)	4.18 (4.02...5.15)	0.79 (0.75...0.87)	8.91 (8.4...9.59)	1.67 (1.57...1.84)
EUR-11_NorESM1-M_r1i_HIRHAM5	12.17°C	Inf (Inf...Inf)	1.05 (0.9...1.55)	1.59 (1.6...1.66)	0.18 (0.16...0.19)	2.38 (2.39...2.54)	0.35 (0.31...0.37)	5.11 (5...63)	0.8 (0.7...0.83)	9.59 (9.31...9.86)	1.69 (1.47...1.76)
EUR-11_NorESM1-M_r1i_REMO2015	12.12°C	1745.94 (1624.26...Inf)	0.88 (0.8...1.32)	1.68 (1.63...1.78)	0.17 (0.16...0.18)	2.57 (2.46...2.81)	0.34 (0.32...0.36)	5.37 (5.08...6.07)	0.77 (0.73...0.81)	9.46 (8.72...9.83)	1.63 (1.54...1.72)
CNRM-CM6-1-HR_r1_gr	11.2°C	11.53 (6.29...46.53)	0.88 (0.68...1.11)	1.34 (1.31...1.43)	0.17 (0.17...0.18)	1.77 (1.7...1.96)	0.35 (0.34...0.36)	3.25 (3.05...3.78)	0.78 (0.75...0.8)	7.41 (7.13...8.09)	1.64 (1.59...1.7)
GFDL-ESM4_r1_g_r1	12.43°C	2.99 (1.14...11.54)	0.38 (0.05...0.73)	1.24 (1.19...1.33)	0.09 (0.08...0.12)	1.52 (1.4...1.73)	0.19 (0.16...0.24)	2.38 (2.02...3.02)	0.43 (0.35...0.54)	4.62 (3.64...6.33)	0.9 (0.75...1.14)

Table A6: Event magnitude, probability ratio and change in intensity for 30-year return period for Rn30day for observational datasets and each model that passed the evaluation tests. (a) from pre-industrial to 2018's climate, from 2018's climate to present day (2026) of 1.3°C above pre-industrial climate (c) from 2018's climate to 1.5°C above pre-industrial climate (d) from 2018's climate to 2.0°C above pre-industrial climate, and (e) from 2018's climate to 3.0°C above pre-industrial climate.

		Preindustrial - 2018 (1.1 °C)	2018 - Present (1.3 °C)	2018 - Future (1.5 °C)	2018 - Future (2.0 °C)	2018 - Future (3.0 °C)

Model/ Observations	Threshold for return period 30 yr	Probabili ty ratio PR [-]	Change in intensity ΔI [%]	Probabi lity ratio PR [-]	Chang e in intensit y ΔI [%]	Probabi lity ratio PR [-]	Change in intensity ΔI [%]	Probabil ity ratio PR [-]	Change in intensity ΔI [%]	Probabi lity ratio PR [-]	Change in intensity ΔI [%]
era5_tp	0.42	0.19 (0...2.51)	28.84 (-14.17 ...95.01)								
eobs_rr	0.55	0.47 (0.15...1 .58)	32.9 (-13.47 ...100.18)								
cpc_precip	0.48	0.11 (0...3.25)	77.73 (-19.41 ...358.17)								
me_rain	0.53	0.67 (0.1...3. 54)	10.49 (-27.55 ...66.62)								
EUR-11_CNRM- CM5_r1i_CCLM4 -8-17	0.81	0.76 (0.17...2 .8)	3.55 (-10.36 ...31.01)	0.97 (0.84... 1.03)	0.39 (-0.36 ...1.94)	0.93 (0.69 ...1.07)	0.78 (-0.73... 3.85)	0.86 (0.42... 1.15)	1.75 (-1.65... 8.45)	0.72 (0.14... 1.34)	3.66 (-3.51... 16.96)
EUR-11_CNRM- CM5_r1i_RACM O22E	1.12	1.04 (0.74...5 .09)	-0.3 (-9.88... 2.23)	0.93 (0.86... 1)	0.57 (0.02... 1.08)	0.86 (0.74 ...0.99)	1.14 (0.05... 2.15)	0.71 (0.49... 0.98)	2.54 (0.1...4. 76)	0.47 (0.2...0. 96)	5.29 (0.21...9 .79)
EUR-11_EC-EAR TH_r12i_CCLM4 -8-17	0.62	3.25 (1.72...1 1.67)	-13.22 (-24.47 ...-6.19)	1.08 (1...1.2 2)	-0.94 (-2.22 ...0.01)	1.15 (1...1. 47)	-1.89 (-4.48... 0.02)	1.37 (0.99... 2.25)	-4.3 (-10.39 ...0.04)	1.92 (0.98... 4.43)	-9.29 (-23.27 ...0.07)
EUR-11_EC-EAR TH_r12i_COSM O-crCLIM-v1-1	0.77	1.7 (0.85...4 .8)	-4.91 (-13.98 ...1.57)	1.04 (0.97... 1.1)	-0.41 (-0.91 ...0.3)	1.08 (0.94 ...1.2)	-0.82 (-1.82... 0.59)	1.2 (0.87... 1.5)	-1.85 (-4.14... 1.33)	1.46 (0.75... 2.27)	-3.95 (-8.95... 2.78)
EUR-11_EC-EAR TH_r1i_RACMO 22E	0.93	0.95 (0.52...3 .26)	0.57 (-8.58... 7.81)	0.99 (0.93... 1.08)	0.08 (-0.7... 0.88)	0.99 (0.86 ...1.16)	0.15 (-1.41... 1.76)	0.97 (0.71... 1.38)	0.34 (-3.19... 3.91)	0.94 (0.47... 1.92)	0.72 (-6.86... 8.07)

EUR-11_EC-EARTH_r3i_RACMO22E	0.96	0.43 (0.28...0.76)	10.29 (3.37...17.26)	1.02 (0.98...1.04)	-0.16 (-0.43...0.18)	1.03 (0.97...1.09)	-0.32 (-0.87...0.36)	1.07 (0.93...1.21)	-0.72 (-1.97...0.81)	1.15 (0.85...1.49)	-1.52 (-4.2...1.71)
EUR-11_HadGEM2-ES_r1i_RACMO22E	1.02	0.22 (0.14...0.55)	17.02 (6.11...25.74)	0.93 (0.89...1.01)	0.69 (-0.11...1.27)	0.87 (0.78...1.02)	1.38 (-0.22...2.52)	0.72 (0.57...1.05)	3.09 (-0.5...5.59)	0.49 (0.28...1.09)	6.4 (-1.06...11.43)
EUR-11_HadGEM2-ES_r1i_WRF361H	1.11	0.62 (0.38...0.69)	4.79 (-7.52...11.21)	1.03 (0.96...1.06)	-0.28 (-0.55...0.36)	1.06 (0.93...1.13)	-0.55 (-1.09...0.71)	1.13 (0.84...1.31)	-1.25 (-2.48...1.6)	1.29 (0.69...1.74)	-2.66 (-5.3...3.33)
EUR-11_HadGEM2-ES_r1i_WRF381P	1.08	0.37 (0.17...0.48)	9.03 (5.95...17.22)	0.95 (0.92...0.99)	0.4 (0.06...0.67)	0.91 (0.85...0.99)	0.8 (0.11...1.34)	0.8 (0.68...0.97)	1.79 (0.25...2.98)	0.62 (0.43...0.93)	3.74 (0.53...6.18)
EUR-11_MIROC5_r1i_CCLM4-8-17	0.79	3.32 (0.74...3.1)	-12.01 (-22.61...-3.99)	1.17 (1.11...1.24)	-2.25 (-3...-1.51)	1.36 (1.23...1.53)	-4.56 (-6.09...-3.05)	1.96 (1.58...2.46)	-10.55 (-14.23...-6.98)	3.73 (2.5...5.52)	-23.58 (-32.45...-15.32)
EUR-11_MPI-ESM-LR_r2i_COSMO-crCLIM-v1-1	0.98	1.52 (0.38...0.46)	-3.99 (-7.58...11.39)	1.11 (1.08...1.15)	-1 (-1.29...-0.78)	1.23 (1.17...1.31)	-2.01 (-2.6...1.57)	1.57 (1.41...1.79)	-4.58 (-5.95...3.58)	2.48 (2.03...3.18)	-9.91 (-12.97...-7.7)
EUR-11_MPI-ESM-LR_r3i_COSMO-crCLIM-v1-1	1.05	1.02 (0.52...0.89)	-0.15 (-7.36...7.81)	1.08 (1.01...1.14)	-0.72 (-1.43...-0.07)	1.16 (1.01...1.3)	-1.44 (-2.89...-0.15)	1.38 (1.03...1.77)	-3.26 (-6.62...0.33)	1.92 (1.06...3.11)	-7.01 (-14.49...-0.7)
EUR-11_NorESM1-M_r1i_COSMO-crCLIM-v1-1	1.13	0.72 (0.49...0.8)	2.56 (-7.41...5.67)	1.19 (1.17...1.23)	-1.57 (-1.93...-1.33)	1.4 (1.36...1.51)	-3.17 (-3.89...-2.69)	2.08 (1.96...2.42)	-7.26 (-8.97...6.15)	4.14 (3.74...5.38)	-15.96 (-19.89...-13.42)

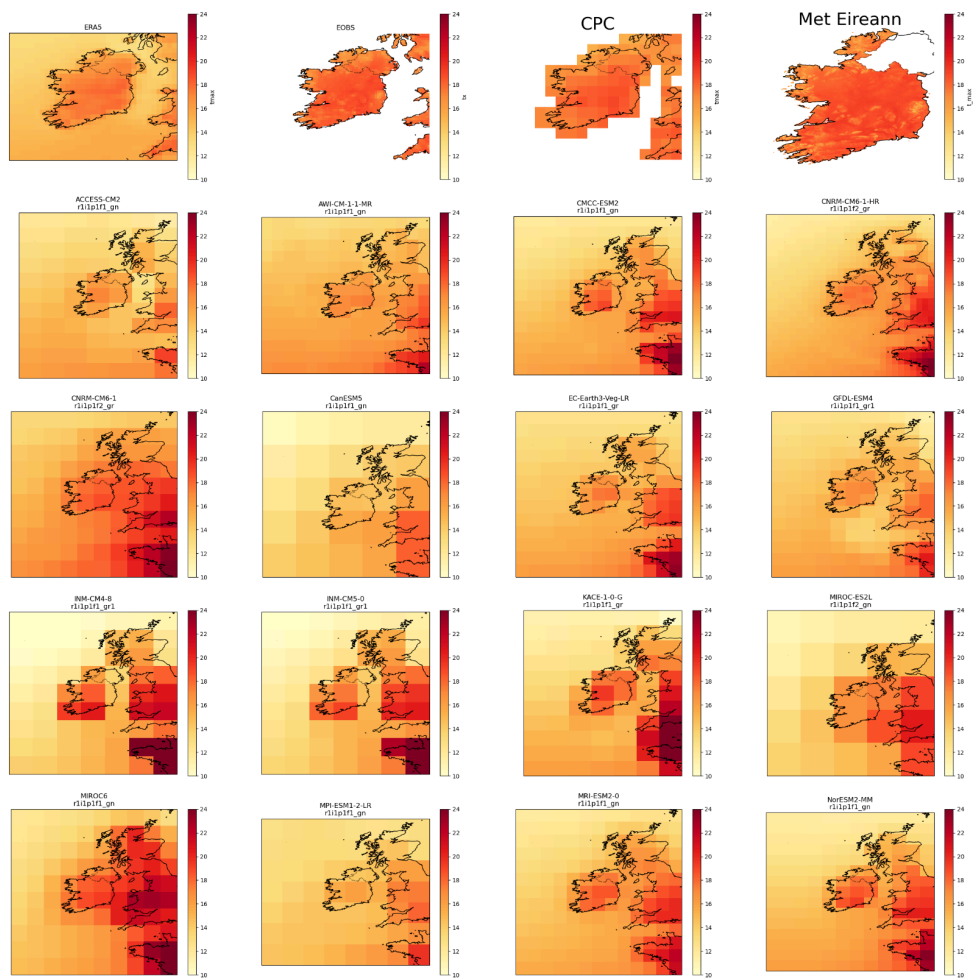
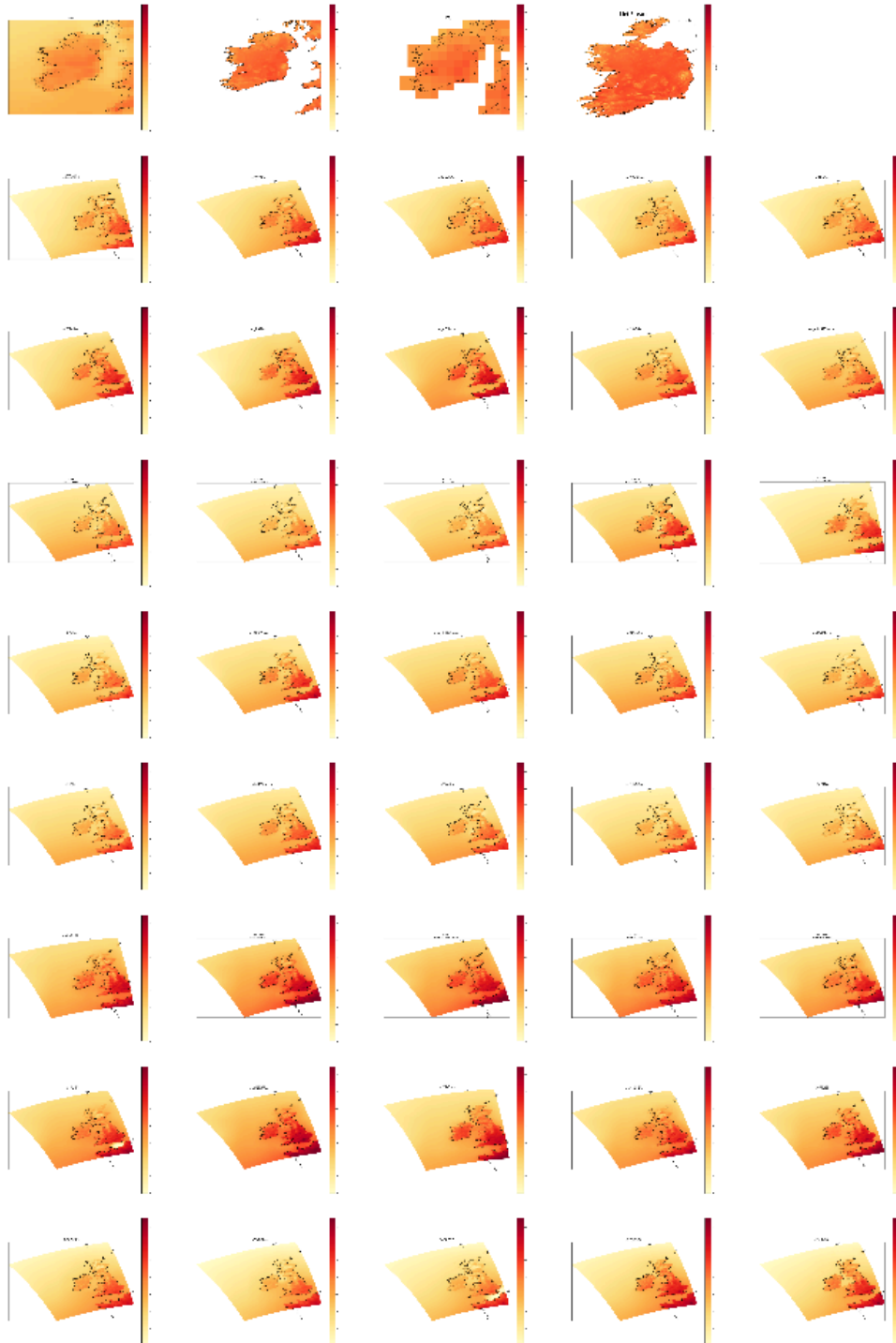


Figure A1: Spatial patterns of daily maximum temperatures in observations and CMIP6 models.



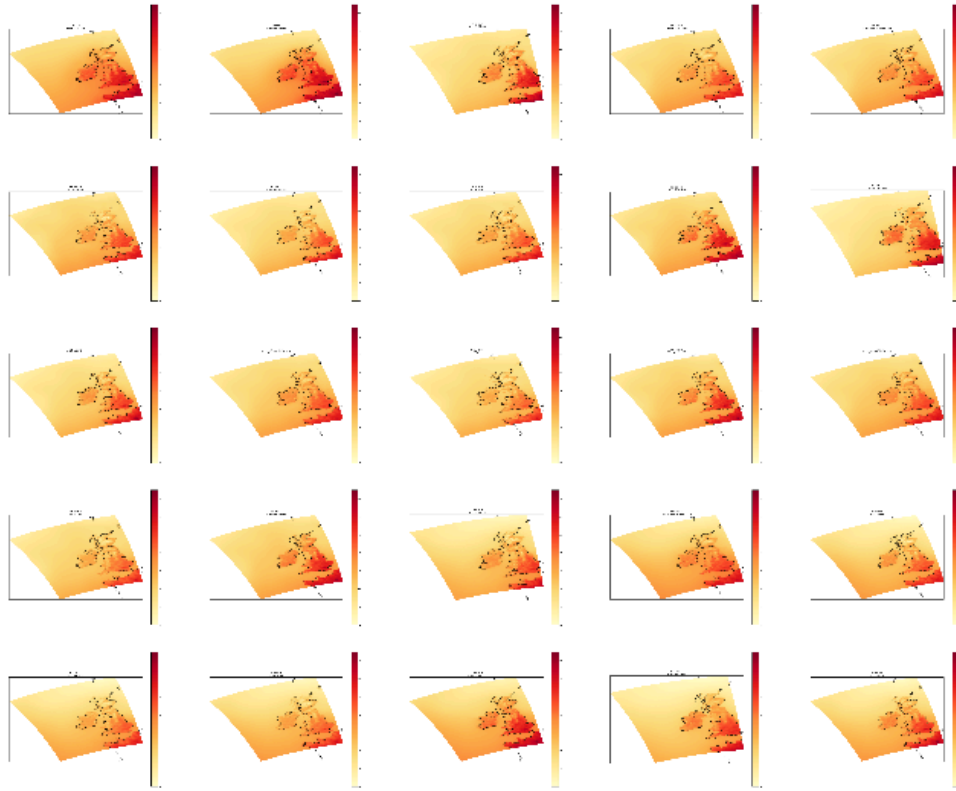


Figure A2: Spatial patterns of daily maximum temperatures in observations and CORDEX models.

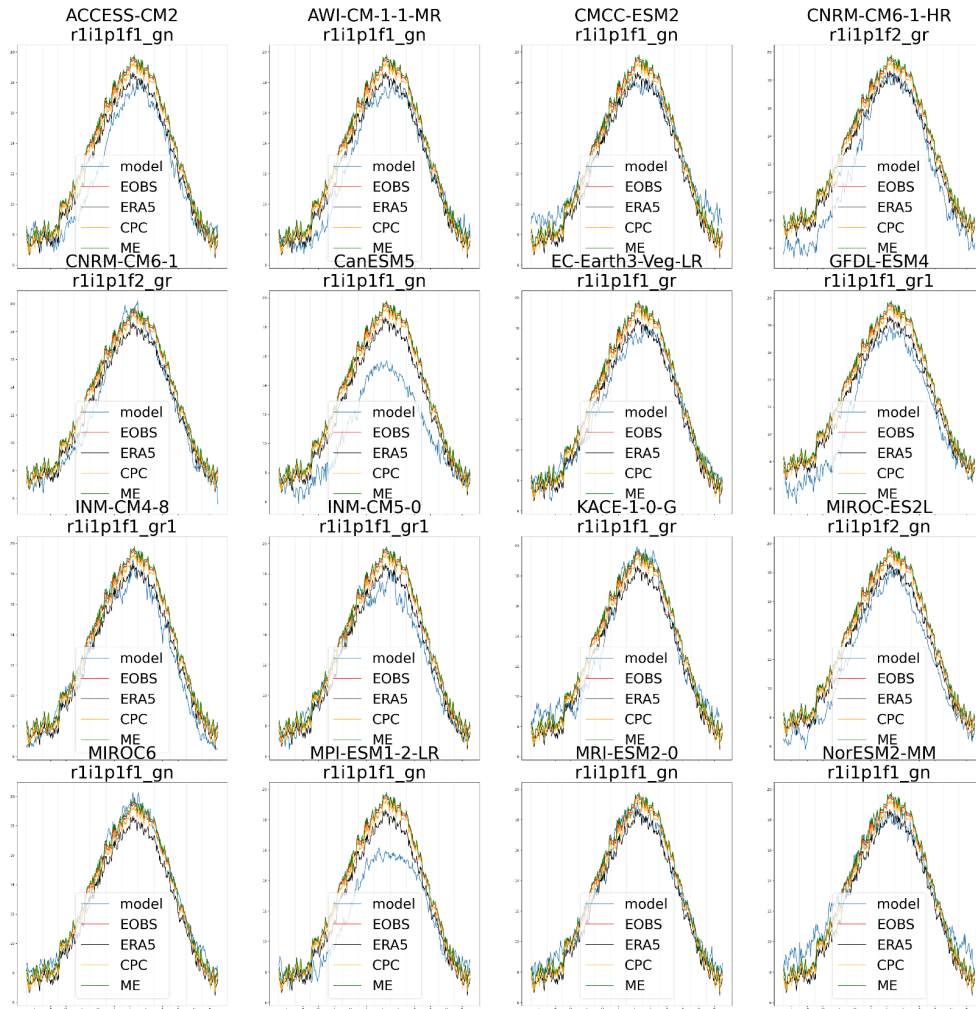
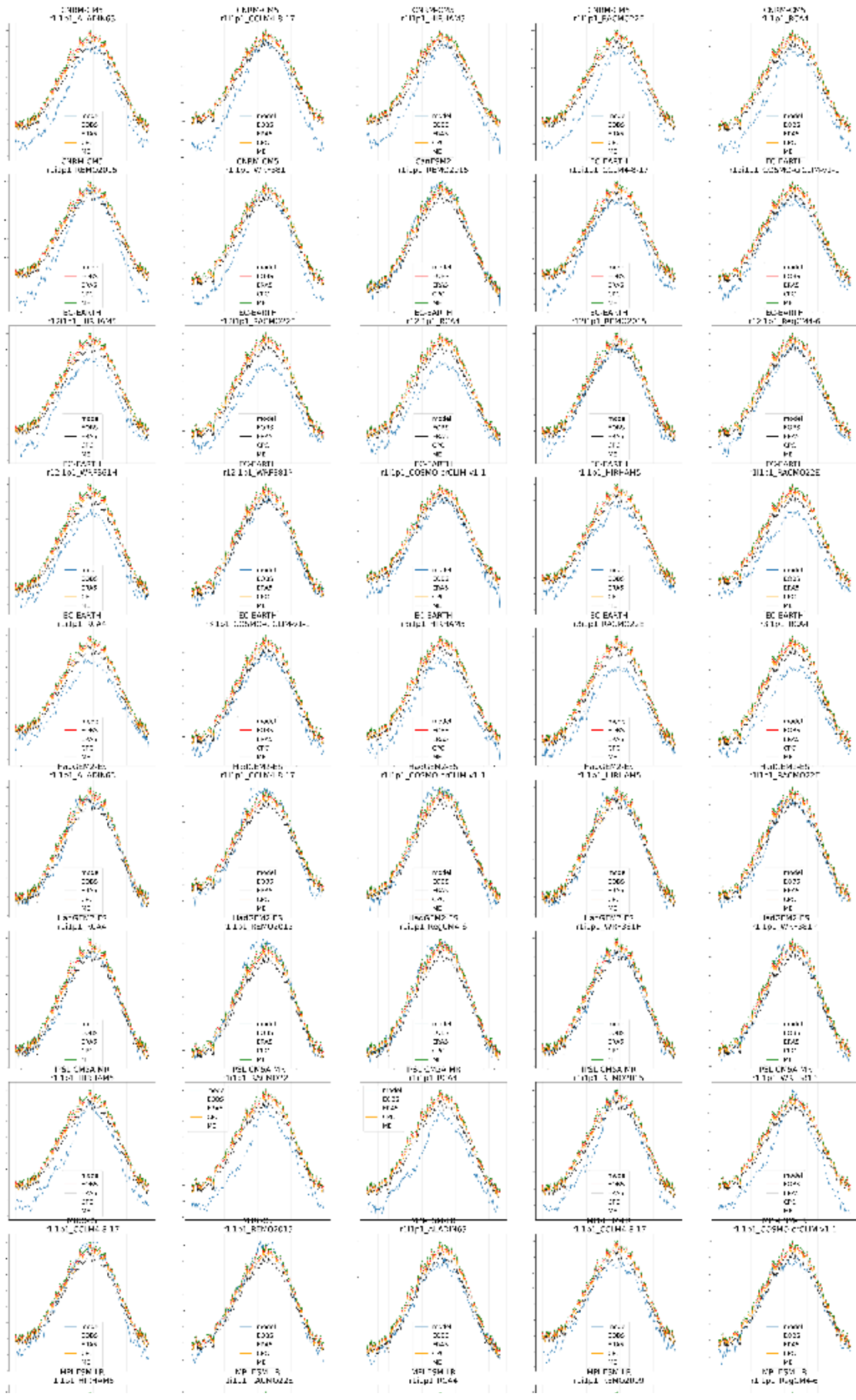


Figure A3: Seasonal cycles of daily maximum temperatures in observations, EOBS shown in red, ERA5 shown in black, CPC in yellow, Met Éireann in green, and CMIP6 models, shown in blue.



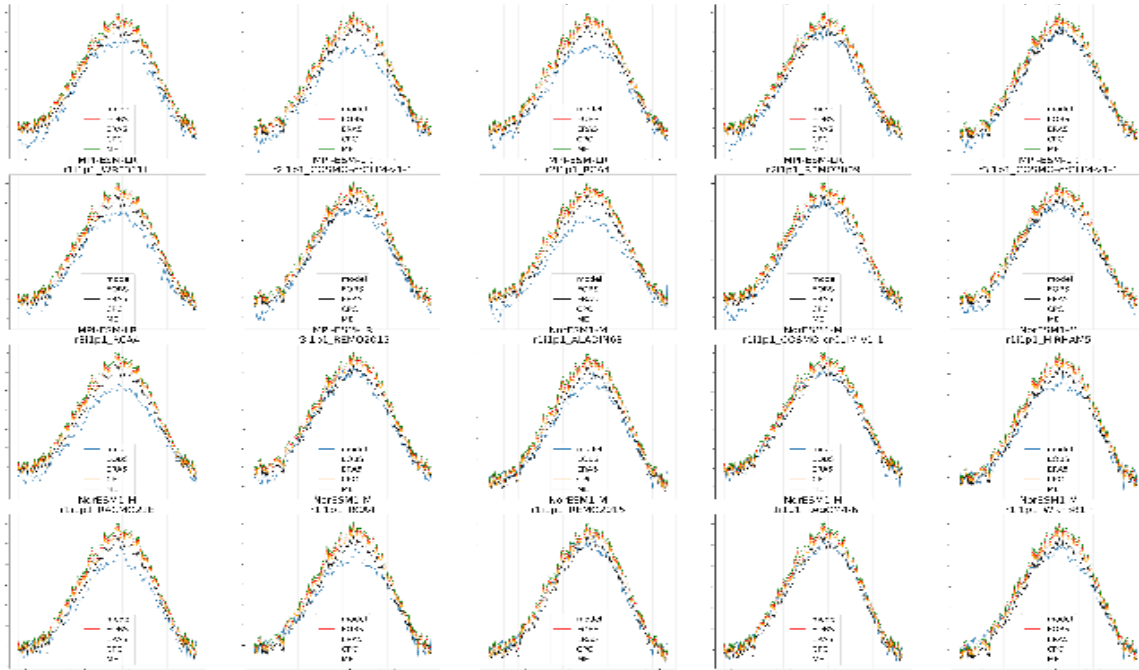


Figure A4: Seasonal cycles of daily maximum temperatures in observations, EOBS shown in red, ERA5 shown in black, CPC in yellow, Met Éireann in green, and CORDEX models, shown in blue.

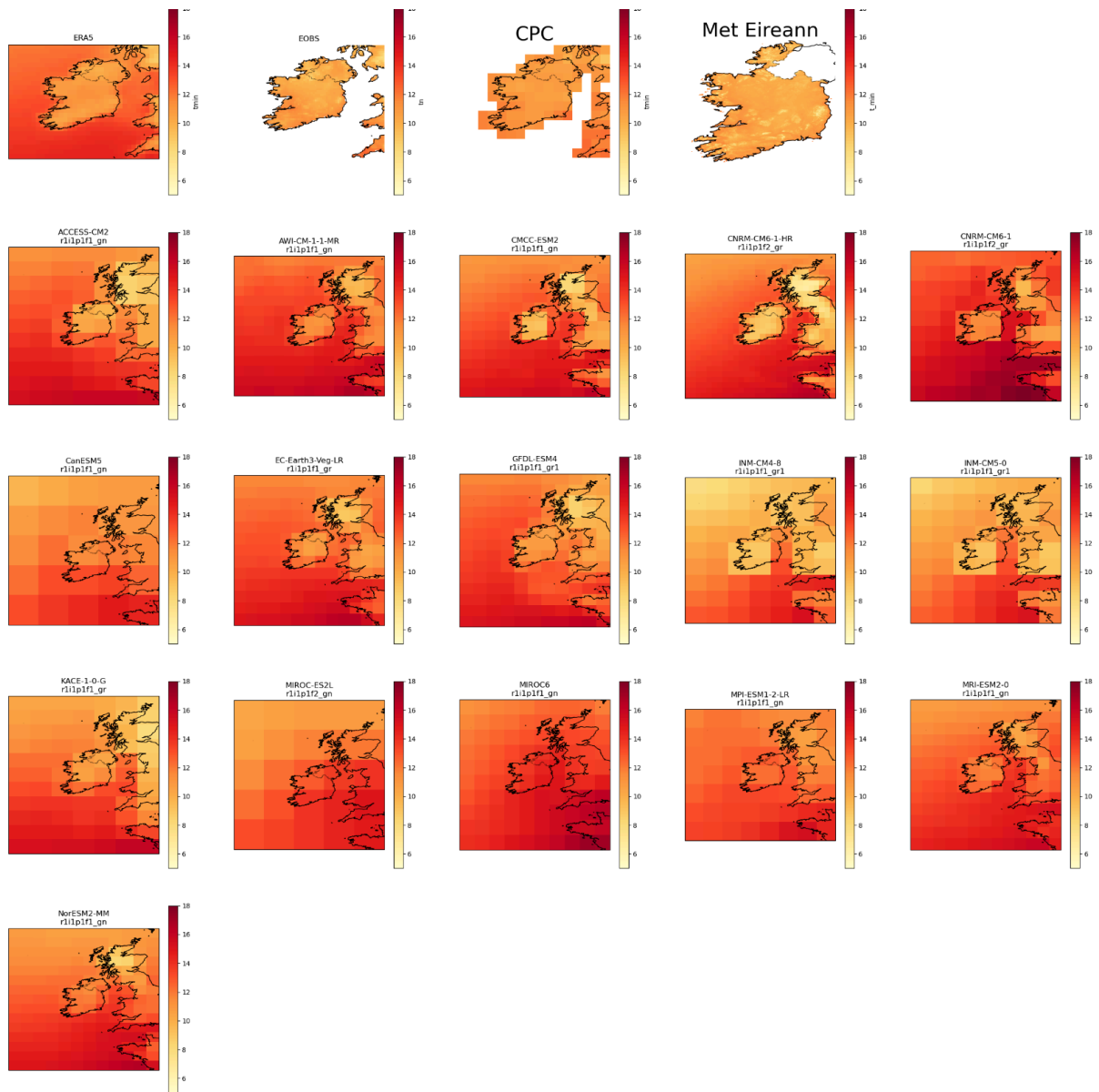


Figure A5: Spatial patterns of daily minimum temperatures in observations and CMIP6 models.



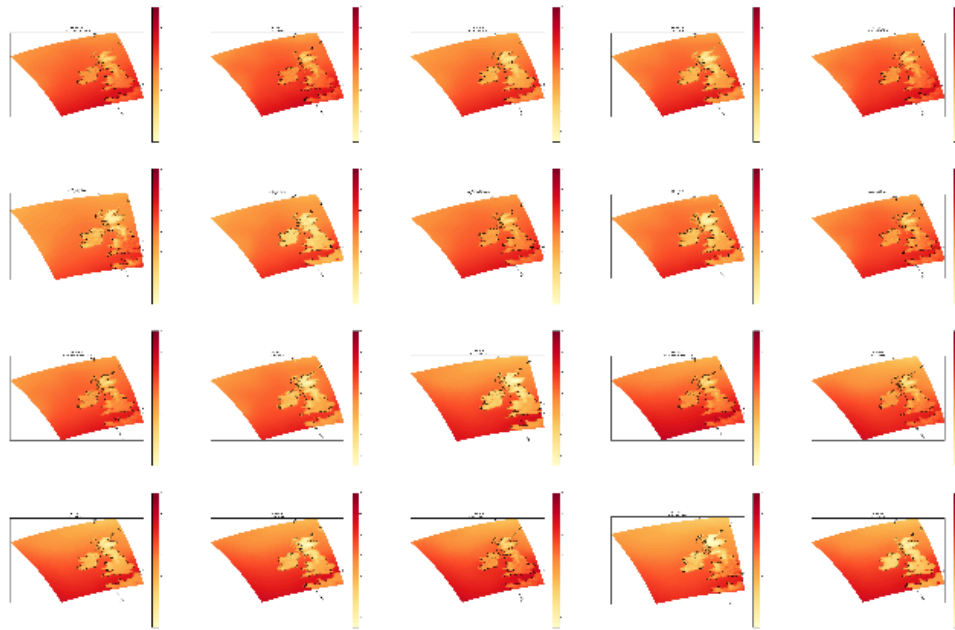


Figure A6: Spatial patterns of daily minimum temperatures in observations and CORDEX models.

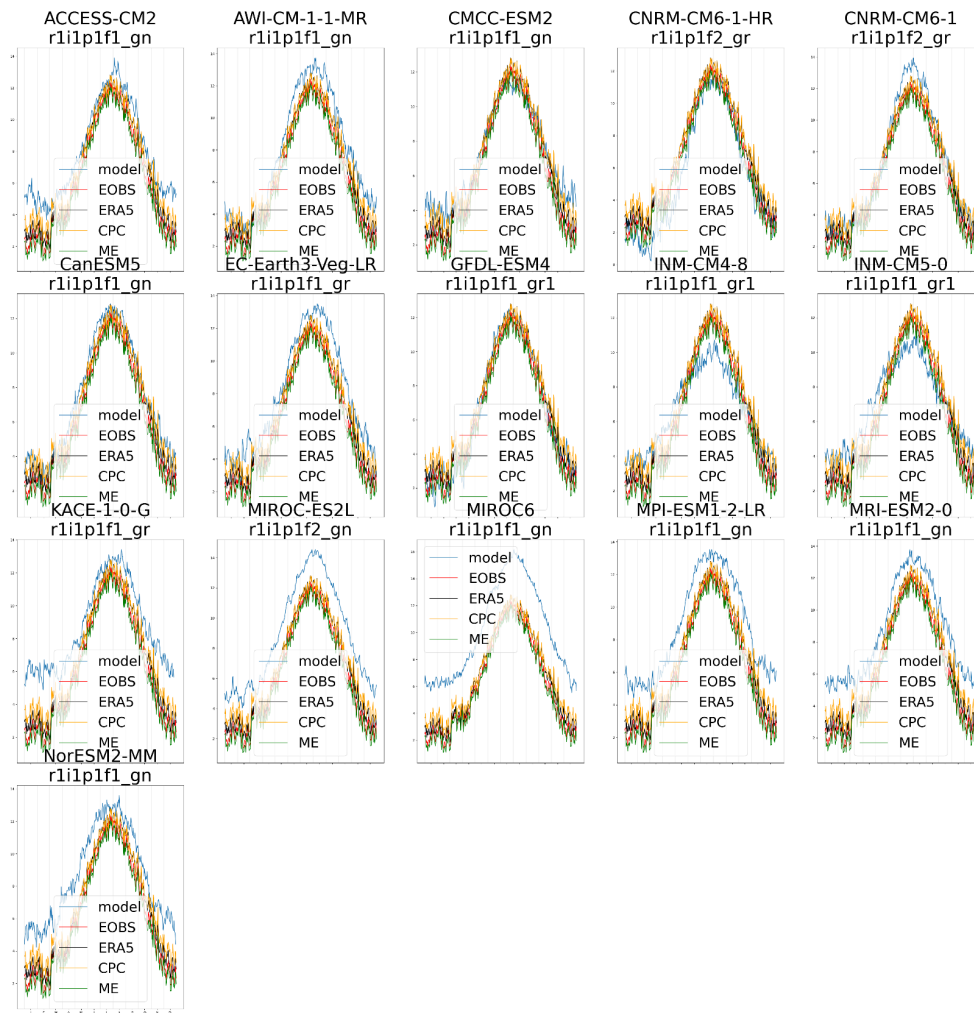


Figure A7: Seasonal cycles of daily minimum temperatures in observations, EOBS shown in red, ERA5 shown in black, CPC in yellow, Met Éireann in green, and CMIP6 models, shown in blue.



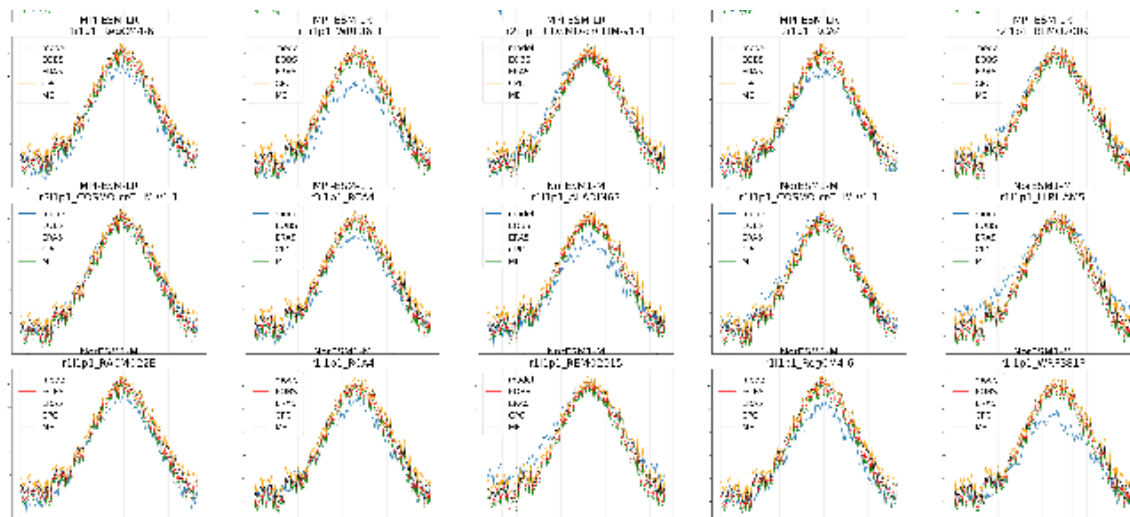


Figure A8: Seasonal cycles of daily minimum temperatures in observations, EObs shown in red, ERA5 shown in black, CPC in yellow, Met Éireann in green, and CORDEX models, shown in blue.



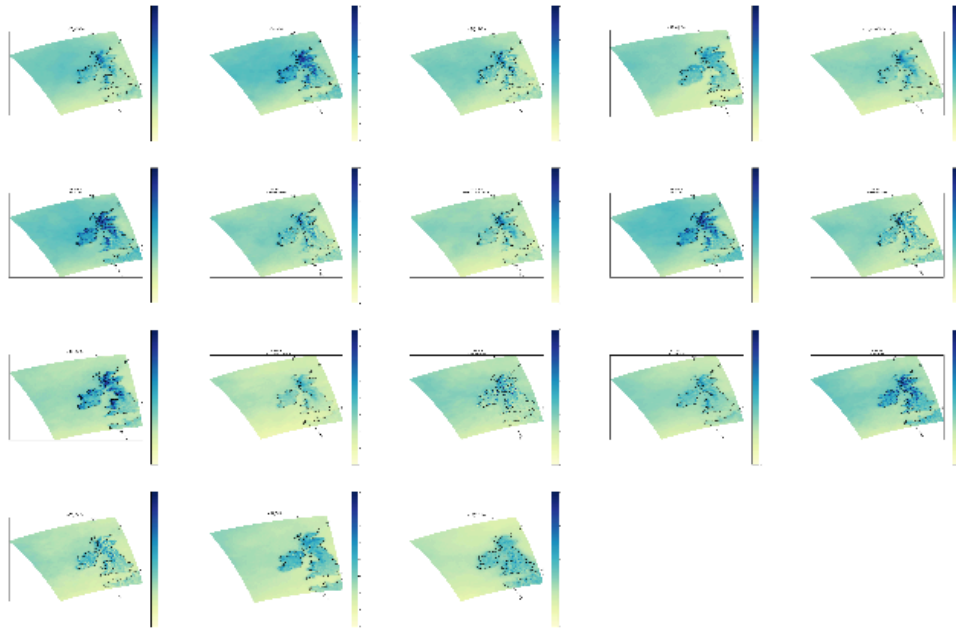
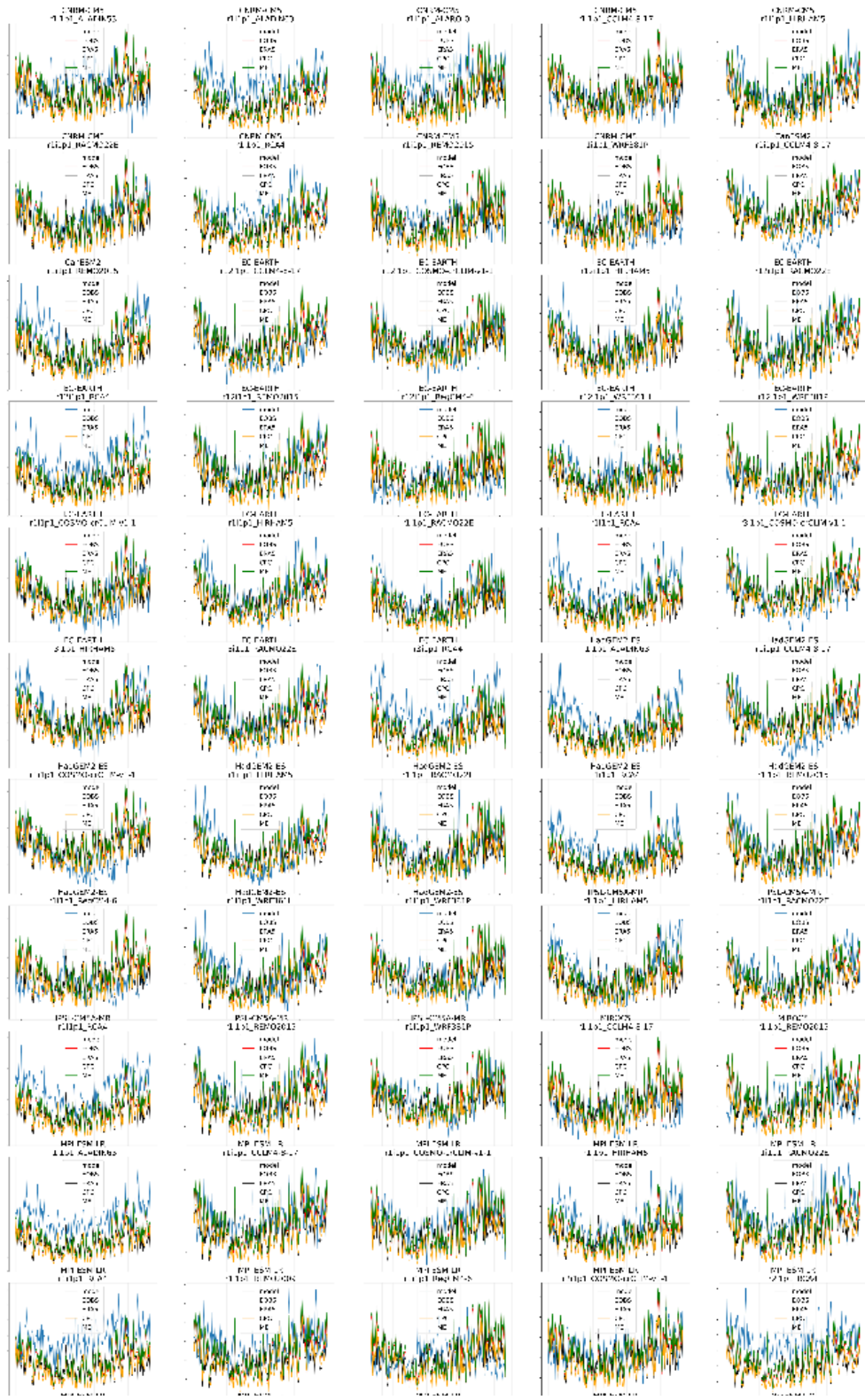


Figure A9: Spatial patterns of daily precipitation in observations and CORDEX models.



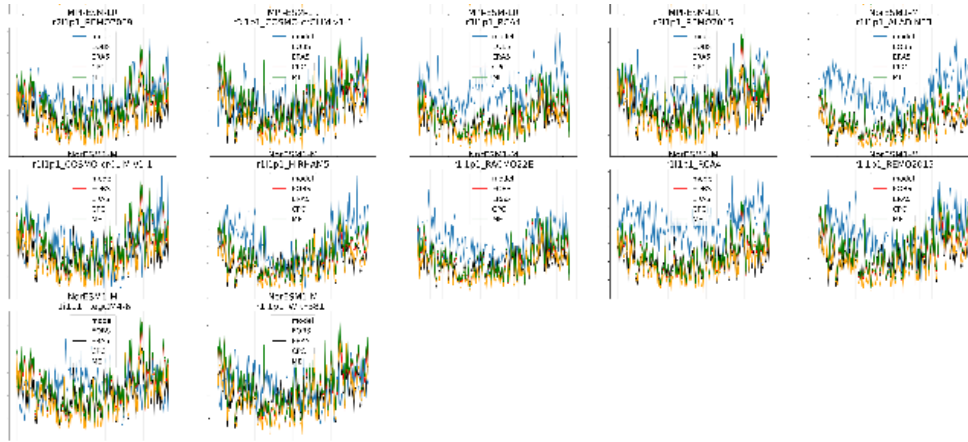


Figure A10: Seasonal cycles of daily precipitation in observations, EOBS shown in red, ERA5 shown in black, CPC in yellow, Met Éireann in green, and CORDEX models, shown in blue.