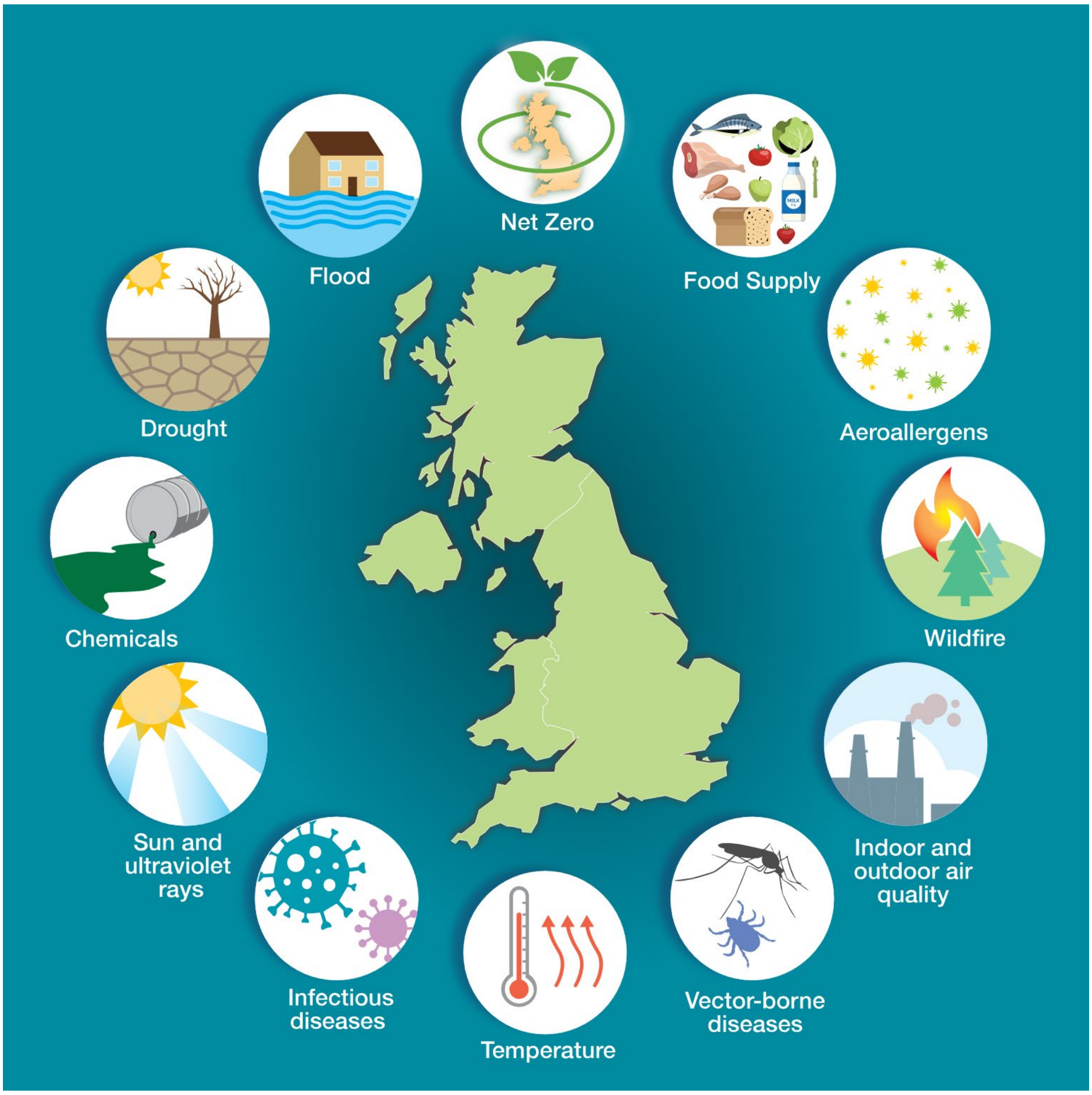
UK Health Security Agency

Health Effects of Climate Change (HECC) in the UK: 2023 report

Chapter 1. State of the past and future UK climate



Summary

This chapter provides an overview of how the UK climate is changing and will change over the coming decades, setting the scene and providing the context for the rest of the report. The chapter was led by experts at the Met Office with academic affiliations at the University of Leeds and University of Bristol. Projecting how the climate will change in the UK is complex, not least because of the uncertainty around how rapidly nations around the world will decarbonise their economies and societies, which will determine the amount of warming that the UK will experience. Climate science thus uses a range of 'possible futures' based on scenarios of different levels of greenhouse gas emissions. Successful global decarbonisation aims to limit warming and ideally keep global average temperatures well below 2°C and ideally below 1.5°C above pre-industrial averages. Current global policy commitments are more likely to give a median warming of 2°C to 3°C, and median global warming over 4°C is increasingly considered 'high end' warming (reasonable worst-case scenario). Currently, we have reached in excess of 1.1°C above pre-industrial temperatures.

While this chapter provides updated synthesis of climate projections using the most recent climate science, headline messages from climate observations and projections have not changed substantially since previous reports. The current UK climate is warmer, wetter and sunnier than was typical during the 20th century, with average annual temperatures over the whole of the UK increasing and sea levels rising. In the future, there will be a greater chance of warmer, wetter winters and hotter, drier summers with sea levels continuing to rise. However, there will still be cold snaps and cool summers or winters as weather varies year to year and around the UK. By the end of the 21st century, all areas of the UK are projected to be warmer, particularly in the summer. Despite overall trends towards hotter and drier summers, climate projections anticipate future increases in the intensity of short-lived heavy summer rainfall events.

The updated climate projections for the UK presented in this chapter have 4 major implications for public health. Firstly, they indicate that temperatures at mid-century (that is, during the 2050s and 2060s) will almost certainly be warmer than today, with their precise level determined not by emissions in a single year but the total greenhouse gas emissions over time. This means that children born today will likely bear a greater burden of climate change impacts on health. Additionally, the current generation of working-age adults who will become the older-age population by mid-century, will be at greatest risk of heat-health harms. Health interventions and adaptations should take into account these timescales to minimise risk for the next and subsequent generations. Secondly, the adverse impacts of climate change on health will vary greatly depending on how much warming the UK experiences. Health interventions that are effective and feasible at 1.5°C of warming may be ineffective, unfeasible, or inappropriate at +3°C. Assessments, interventions and adaptation plans should explicitly consider whether a particular approach will remain appropriate as the UK warms, and attention should be given to flexible adaptation approaches. Finally, existing climate risk assessment tools (such as models) are poorly equipped to integrate adaptation interventions. This means that many risk

assessment tools don't take adaptation into account even where effective adaptations exist. A priority is to bring together risk assessment approaches with planning and assessment of adaptation pathways to enable an integrated approach to public health interventions.

This chapter highlights a number of other research gaps and priorities, including the need to:

- develop models at higher (finer) spatial resolution that enable health risk assessments
- develop metrics and indicators of climate-health risk for use by local authorities and other organisations with a role in adaptation and improve access to relevant and actionable data sets and visualisations
- improve projections of health impacts by developing models that better integrate epidemiological and behavioural science insights
- improve data science tools and methods (such as machine-learning) to facilitate more automated modelling of climate risks to health

Since the early 1990s, the UK has developed its own sets of national climate projections based on the latest developments in climate science. UKHSA works closely with the Met Office to integrate climate science and modelling into health impact assessments and weather-health alerts and guidance. In June 2023, UKHSA launched an impact-based Weather-Health Alerting system in collaboration with the Met Office that uses consistent methods between the Met Office's National Severe Weather Warning Service (NSWWS) and UKHSA's Adverse Weather and Health Plan (AWHP) (see Chapter 2).

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Chapter 1. State of the past and future UK climate

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Acknowledgements

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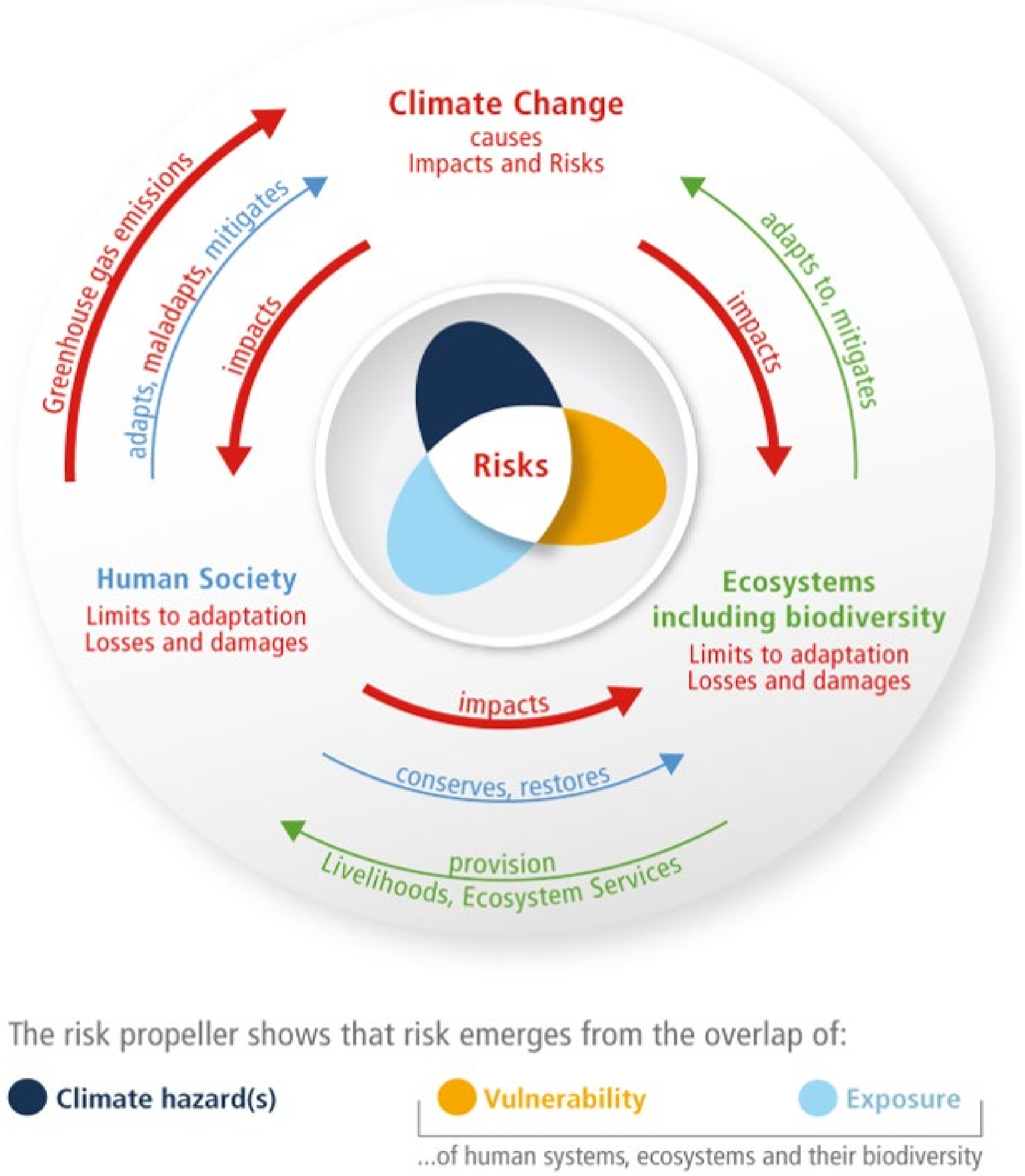
1. Changing climate drivers of human health risks

Since 2002, the UK has experienced its 10 warmest years on record (1). In 2022, the Met Office issued its first ever red warning for exceptional heat which was accompanied by a Heat Health Warning of level 4 by the UK Health Security Agency (UKHSA), which triggered a series of actions set by the Heatwave Plan for England (2). On 19 July 2022, a new temperature record was set at Coningsby, Lincolnshire, where 40.3°C was recorded, exceeding the previous record from 2019 (3). The summer of 2022 saw 3 heatwaves in the UK and initial estimates are that there were an estimated 2,839 excess deaths for those aged 65 and over (4). A climate change attribution study found that human-caused climate change made the heatwave at least 10 times more likely (5). These types of extreme heat events will likely become more frequent as "global surface temperature continue to increase until at least mid-century under all emissions scenarios considered" and "global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas (GHG) emissions occur in the coming decades" (6).

The scientific community is now able to detect, attribute, and project anthropogenic climate change. However, while an increasing trend in temperature has been one of the more direct signals of a warming climate in recent years in the UK, the effects of climate change on human health manifest via multiple and complex pathways. These include life-threatening extreme events such as floods (see Chapter 3) and windstorms and their long-term effect on human health during the recovery process (7). Additionally, climate change could provide the conditions for the spread of infectious diseases (see Chapter 7), exacerbate the effects of air pollution (see Chapter 4) in our urban areas as well as energy poverty (8). In this chapter, we focus on the climate hazard component of climate change risk. Risk is defined as the overlap of the climate hazard, vulnerability and exposure (see Figure 1). This framework is used in both the 'Third UK Climate Change Risk Assessment (CCRA3)' (9) and the Intergovernmental Panel on Climate Change's (IPCC) 'Sixth Assessment Report' (6). The climate hazard is determined from climate variables that are measured, as well as simulated using climate models. They include temperature, precipitation, sunshine, humidity, snowfall and wind speed. A climate hazard will usually require a combination of multiple variables as well as an analysis of the magnitude and frequency of occurrence. For example, the Met Office defines a heatwave as a period of at least 3 consecutive days with daily maximum temperatures meeting or exceeding a county-based temperature threshold. However, the risk to human health of such a climate hazard will also depend on relative humidity, wind speed and sunshine for thermal comfort or for those working outside, as well as underlying health of the population and effectiveness of response plans.

In this chapter, the key concepts of climate change are summarised, including the global context and emissions scenarios. These are then outlined using the available historical observations and future climate model projections for the UK as well as how the data have been processed and translated into products to support health impacts and risks to be assessed. The chapter then looks at recent advances in climate science which could provide the basis for climate information that may be useful for future work to determine the health impacts of climate change.

Figure 1. Components of climate risk and the interactions between climate change, human society and ecosystems (adapted from Figure TS.2 (10))



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The diagram shows the interaction of 3 elements: human society, climate change and ecosystems, including diversity. It shows in schematic form how human society causes climate change. Climate change, through hazards, exposure and vulnerability generates impacts and risks that can surpass limits to adaptation and result in losses and damages. Human society can adapt to, maladapt and mitigate climate change; ecosystems can adapt and mitigate within limits. Ecosystems and their biodiversity provision livelihoods and ecosystem services. Human society impacts ecosystems and can restore and conserve them.

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2. The global context

It is now clear from observations that the global climate has changed over the past century or more. Global average near surface temperature for the last decade (2011 to 2020) was between 1.1ºC and 1.2ºC above pre-industrial levels, taken as the 1850 to 1900 period (Figure 2), with some individual years now exceeding 1.2ºC. Compared to earlier periods the rate of change has been rapid, and the most recent IPCC assessment report highlights that the global mean surface temperatures during 2011 to 2020 are above those of the most recent multi-century warm period, around 6,500 years ago (6). Alongside the changes in temperature there are also large-scale changes in the hydrological cycle, including rainfall. Looking beyond the land, sea-levels have risen around coastal areas globally, with more rapid rates of increase since the early 1990s. There have been observed decreases in the extent of sea ice in the Arctic (11), which has warmed nearly 4 times faster than the global average (12).

Many of the types of weather and climate hazards that can impact on health are associated with extremes. There is growing evidence from attribution studies, which look at how long-term climate change driven by human causes alters the risk of extreme events, of a clear human fingerprint in many temperature and heavy rainfall extremes, and common metrics of drought. The prevalence of the impact of human influence on warming is shown in Figure 3. For the UK and the wider European region, there are now multiple event attribution studies also showing the influence of human activity on increasing heavy precipitation. In some parts of Europe, especially in the south, there is some evidence of climate change influence on drought events, although this is not as strong as that for temperature and heavy precipitation.

Figure 2. Global mean temperature relative to a pre-industrial baseline period of 1850 to 1900 from the HadCRUT5 data set and several other alternative estimates

All of the models show that temperatures have increased over time, with the most rapid warming occurring since the 1970s (Crown copyright. Source: The Met Office).

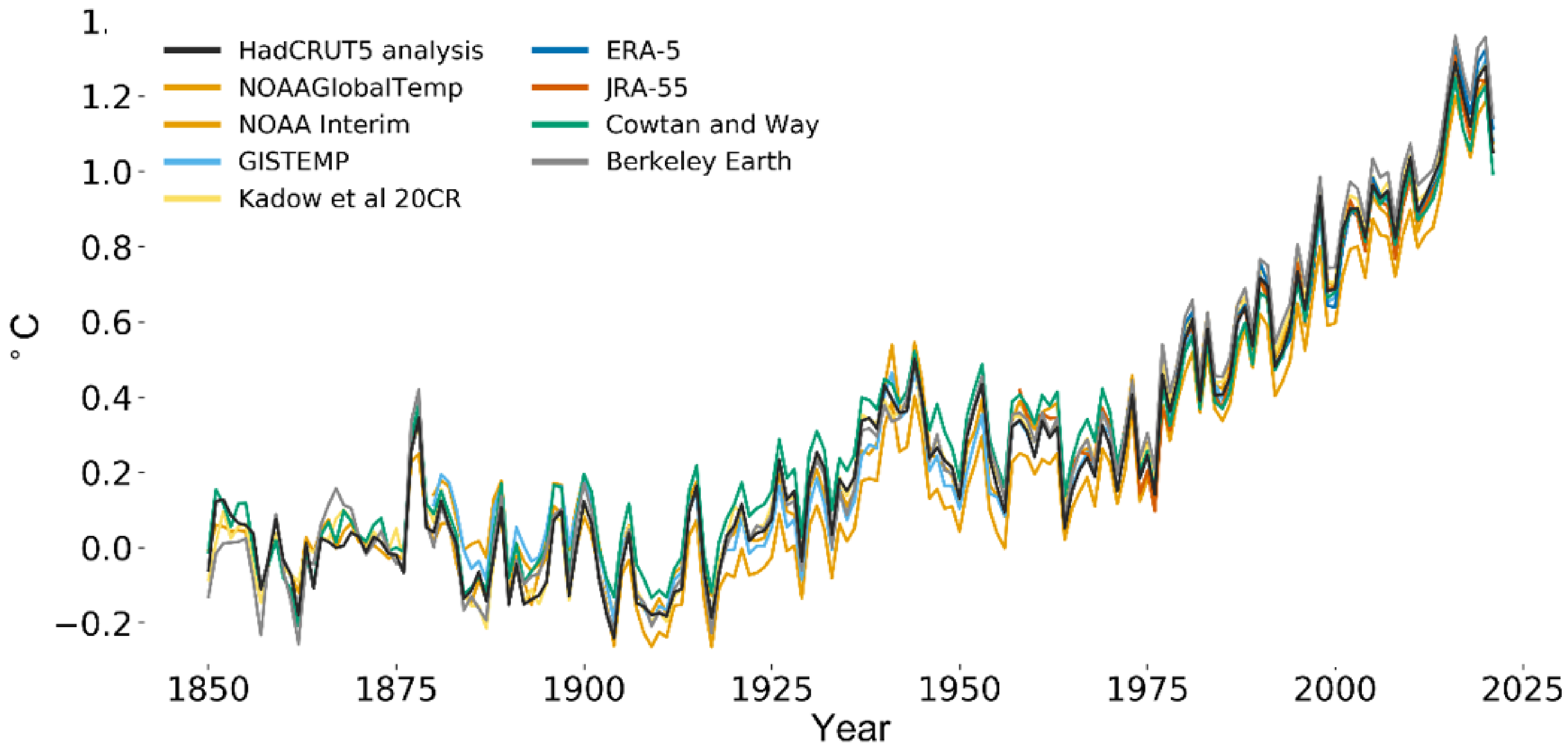
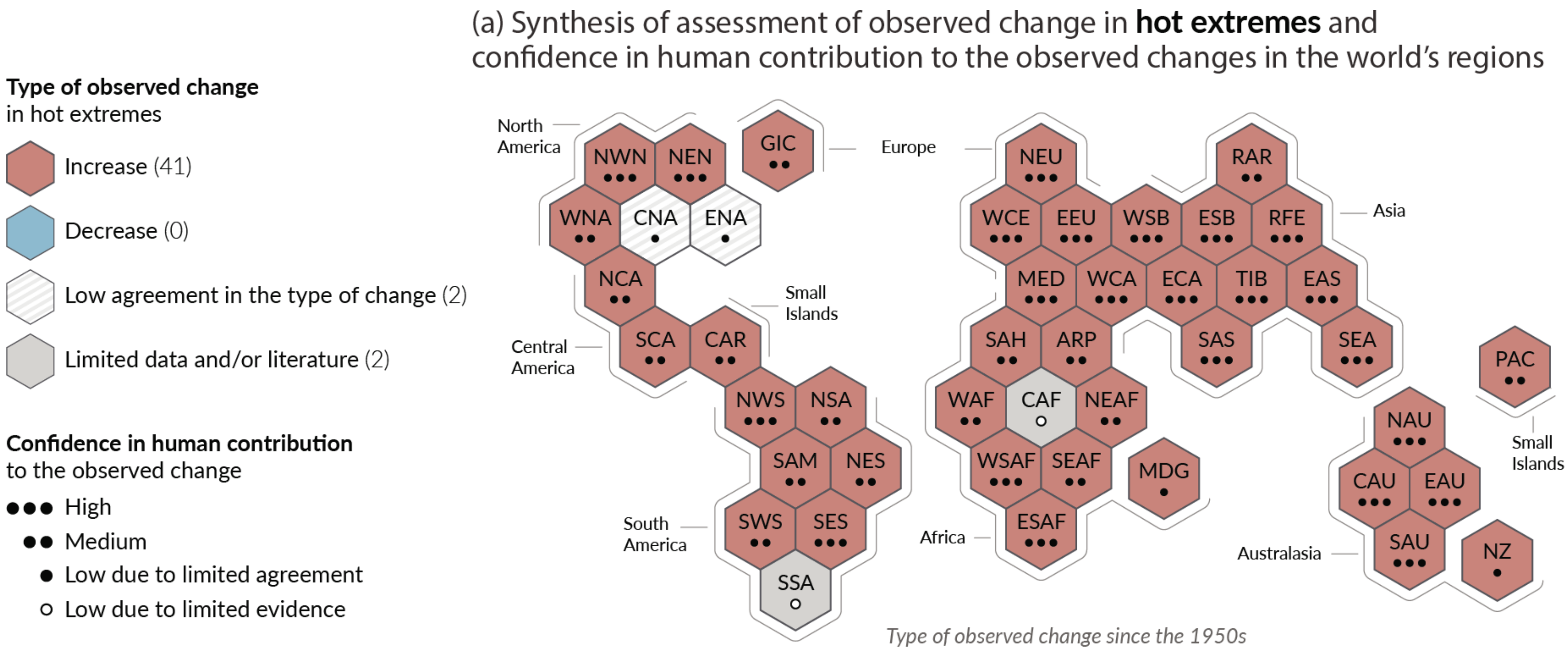


Figure 3. Schematic representation of the map for the world, showing influence of climate change on hot extremes using event attribution approaches

The UK is located in box NEU (North East Europe) (6).



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All regions of the world show observed increase in hot extremes – medium or high confidence for all regions except Madagascar and New Zealand. There is low agreement in type of change in eastern North America. The evidence is too limited in southern South America and Central Africa to make an assessment.

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Future global mean warming depends on both the future GHG emissions and the sensitivity of the climate system to emissions. Whilst it is possible to rule out some future emission pathways as neither economically nor technically feasible, there is still a wide range of potential emissions over the years to 2100. The emissions pathway followed will depend on political choices made by nations around the world, with the United Nations Framework Convention on Climate Change (UNFCCC) providing a forum for negotiating emission reduction commitments.

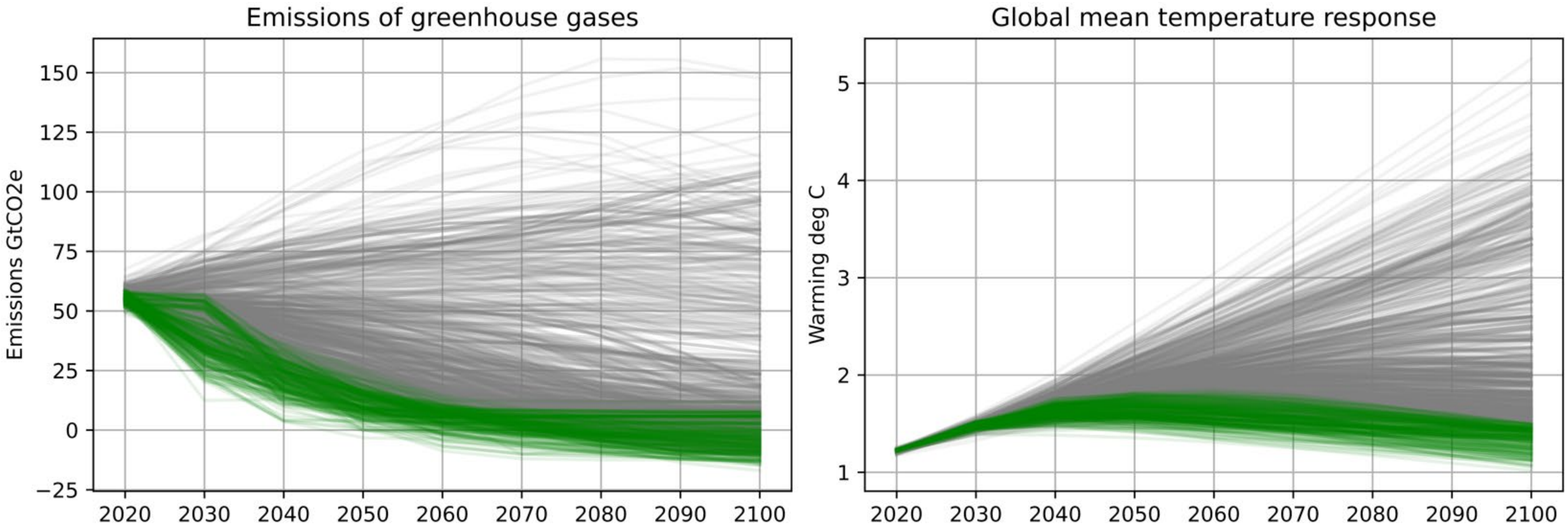
The IPCC process has reported a large number of emission futures derived from integrated assessment models (IAMs). These models draw on a range of estimates of future population growth, economic changes, technology development and resource demand assumptions. The experimental designs of IAMs account for a range of policy choices ranging from back-tracking on current emission pledges made through the Paris Agreement process to a significant increase in global mitigation, with many nations committing to net zero futures. Between these extremes are pathways that include recent mitigation pledges. Figure 4 summarises over 1,000 emission pathways used in the IPCC 'Sixth Assessment Report' (13), showing their GHG emissions and their median temperature response.

It is clear from Figure 4 that there are pathways that limit peak warming to below 1.5°C above pre-industrial levels, and a wider set that have warming below 1.5°C at 2100, but with some temporary overshooting of the level earlier in the century. These strong mitigation pathways all show rapid and large-scale global reductions in emissions, with GHG reaching net zero towards the middle of the century and in most cases becoming negative in the second half of the century. These negative emissions will require active removal of extra GHGs from the atmosphere on a large scale.

The highest emission pathways typically require emissions to increase beyond current policy pledges, and the likelihood of this in the real world has been questioned (14). Many of these pathways have a median warming of more than 4°C above pre-industrial levels, with a subset exceeding 5°C by the end of the century. These are sometimes referred to as back-tracking scenarios.

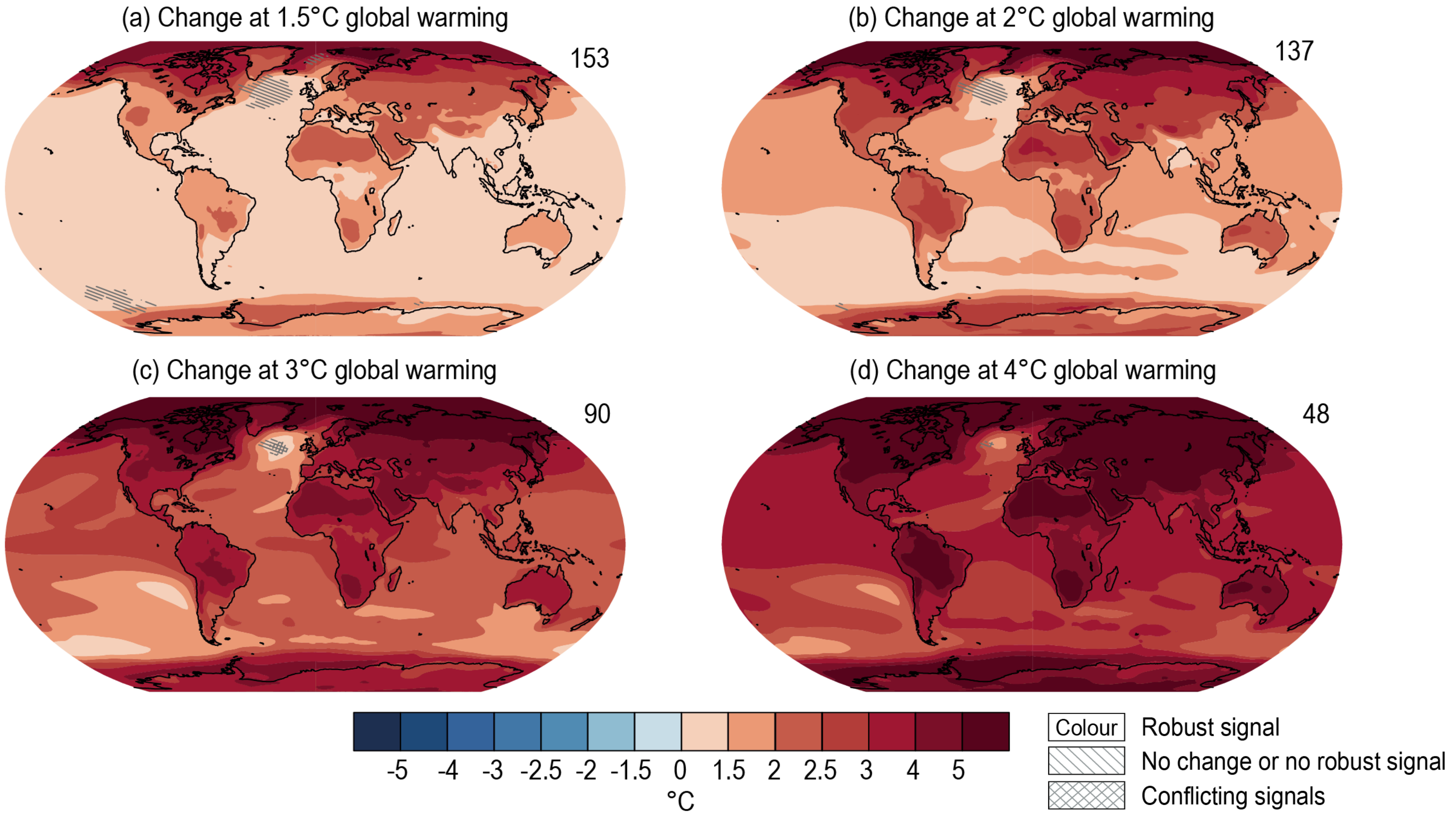
Taking account of pre-COP27, estimates of the emission pledges typically leads to pathways with a median global warming of around 2.4°C to 2.8°C (15), although some estimates have produced slightly lower numbers. This is partly because of differences when interpreting policy pledges, and partly due to technical differences between studies. Often these scenarios are referred to as Nationally Determined Contributions (NDCs) or current policy scenarios.

Figure 4. Greenhouse gas emissions and median global mean temperature response for pathways in the IPCC 'Sixth Assessment Report' Temperature estimates were derived by a version of the MAGICC simple climate model. The green lines have a median warming of response for each scenario that is below 1.5°C at 2100. The grey lines show alternative scenarios with a larger warming response.



Another feature of Figure 4 is that even in very strong mitigation cases there is a high probability of some further warming beyond the present day, meaning that to avoid adverse impacts, both mitigation and adaptation will be required. The estimates in Figure 4 focus on the warming for a median climate system response, meaning for any particular pathway there is 50% chance that greater warming will be experienced. Elsewhere in this chapter, a range of emission scenarios from the representative concentration pathway (RCP) set are referred to, as these were used within the UKCP18 project which provides information on UK climate variability and change. RCP2.6 is a mitigation scenario that gives a median warming of below around 2°C by 2100. RCP8.5 is a back-tracking scenario with a median warming above 4°C. Intermediate scenarios of RCP4.5 and RCP6.0 give intermediate temperature responses in the region of the NDCs. It is possible to recast the results from higher emission scenarios onto levels of global mean warming ranging from 1.5°C up to 4°C or higher. This can be useful because it enables the high emission scenario (RCP8.5) experiments to also provide useful information for lower levels of warming.

Figure 5. Projected spatial patterns of change in annual average near-surface temperature (°C) at different levels of warming (6)
Figures a, b, c and d show spatial patterns of change in annual average surface temperatures at 1.5°C, 2°C, 3°C and 4°C, respectively, of warming compared to the period 1850 to 1900 (6).

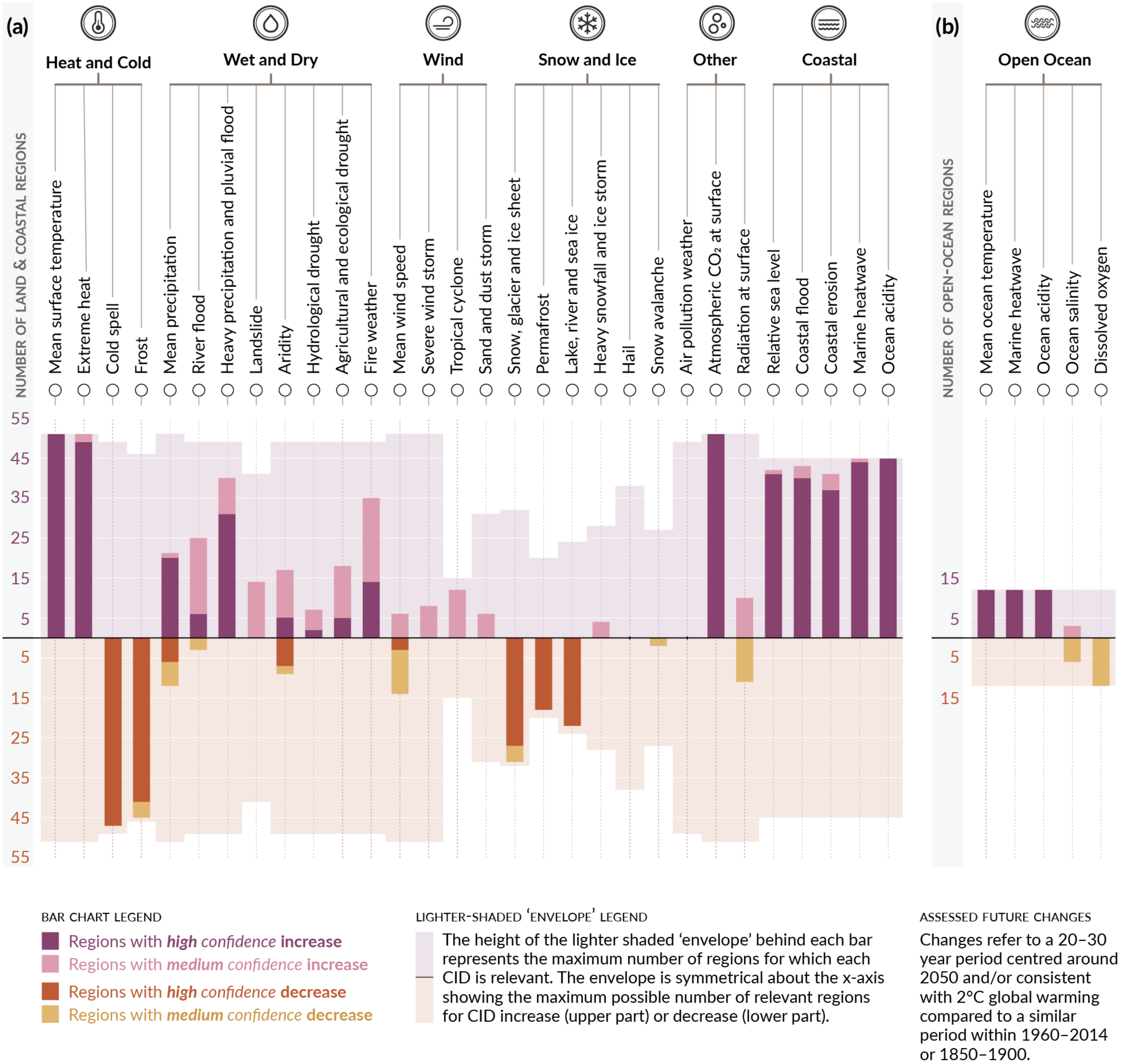


From an impact perspective, it is regional warming that becomes important. Figure 5 shows the spatial pattern of warming for global warming levels of 1.5°C to 4°C above pre-industrial levels. It is clear that land areas warm more than the ocean, with amplification especially evident at high northern latitudes. Some land areas also show enhanced warming at other latitudes, because of feedback in the climate system, including those associated with reduced surface moisture. The increases in global warming and higher radiative forcing will drive a wide range of other climate system changes, including precipitation, tropical cyclone characteristics and sea-level rise. From a health perspective, it is useful to consider the concept of climate impact drivers.

There is now growing evidence that a wide range of these hazards will change in the future over large parts of the world, and these are shown in Figure 6.

For land areas, there is high confidence that mean surface temperatures, extreme heat and atmospheric CO2 at the surface will increase for all areas. For almost all coastal regions there is high confidence for increased relative sea level, coastal flooding, coastal erosion, marine heatwaves and ocean acidity. There is high confidence that cold spells and snow, glacier and snow sheet coverage and depth will decrease for land and coastal regions. For precipitation, there is high confidence in most regions for increased heavy precipitation, whereas for mean precipitation, there is high confidence for only about half of the regions for an increase and a couple of regions for a decrease. There is medium confidence in most regions for increases in fire weather and for half in increased river flood. For a few regions, there is also medium confidence for increased agricultural and ecological drought, aridity and landslides.

Figure 6. Number of land and coastal regions (i) and open-ocean regions (ii) where each climate-impact drivers are projected to increase (purple) or decrease (orange), with high confidence (dark shade) or medium confidence (light shade) shown ([16](#))



In summary, the global climate has undergone detectable changes over the last century or more and there is very strong evidence that many of these changes have been influenced by human emissions of GHG. Further changes in the future are almost certain to occur, but the amount of global warming and climate change depends on the size of future global GHG emissions. Future global changes in the climate system will influence many drivers of health-related climate impacts, including higher temperatures, flooding, drought and a greater number of the most intense tropical cyclones.

3. Past and future climate change information in the UK

Past and future climate information is vital at each stage of the climate change adaptation management cycle. Historical climate observations provide us the means to raise awareness of how our organisations have been impacted by weather events, which could start us on our adaptation journey. They also provide data to support the analysis of our current climate change risks. Future climate model projections provide us with the tools to explore our future risks for different mitigation pathways and inform our adaptation measures. The monitoring of our current climate is also essential to understand when to implement these adaptation measures and evaluate their efficacy.

3.1. Observing climate in the UK

The National Climate Information Centre at the Met Office publishes the 'State of the UK Climate Report' annually, presenting statistics based on long historical records, such as monthly rainfall that goes back to 1836. This report and its underpinning data provide the evidence to evaluate our current risks. The 'State of the UK Climate 2021' reports that "the UK's climate is continuing to change, recent decades have been warmer, wetter and sunnier than the 20th century" (1).

The report also provides information on both long-term climate statistics, as well as descriptions of the processes underlying recent extreme events such as the hot day of 31 July 2021 when temperatures reached 37.8°C at Heathrow, Greater London. In addition, they also report on metrics such as heating and cooling degree days, which indicate, for example, energy requirements for buildings to maintain comfortable temperatures (17) as well as vector-borne disease transmission (18). These metrics re-emphasise the warming of the UK during the past 80 years, with the lowest 10 heating degree day years occurring since 1999.

The 'State of the UK Climate' report is based on the HadUK-Grid data set that covers the UK at 1km x 1km spatial resolution. These are derived from the network of land surface observations and include daily precipitation, maximum and minimum temperatures as well as a large set of monthly mean variables: temperature, precipitation, sunshine duration mean wind speed, sea level pressure, relative humidity, vapour pressure, days of ground frost and lying snow as well as maximum and minimum temperatures. The reports include other metrics including heating, cooling or growing degree days, providing information on potential energy costs and growing season patterns. Information on coastal areas is also provided, including annual mean sea-surface temperature and sea level.

In 2018, an extremes supplement was published (19), some components of which are now included in the annual 'State of the UK Climate' report. Climate extremes are reported here on temperature and rainfall-based metrics including highest or lowest recorded maximum or minimum daily temperatures, tropical nights and icing days.

3.2 Modelling future climate for the UK

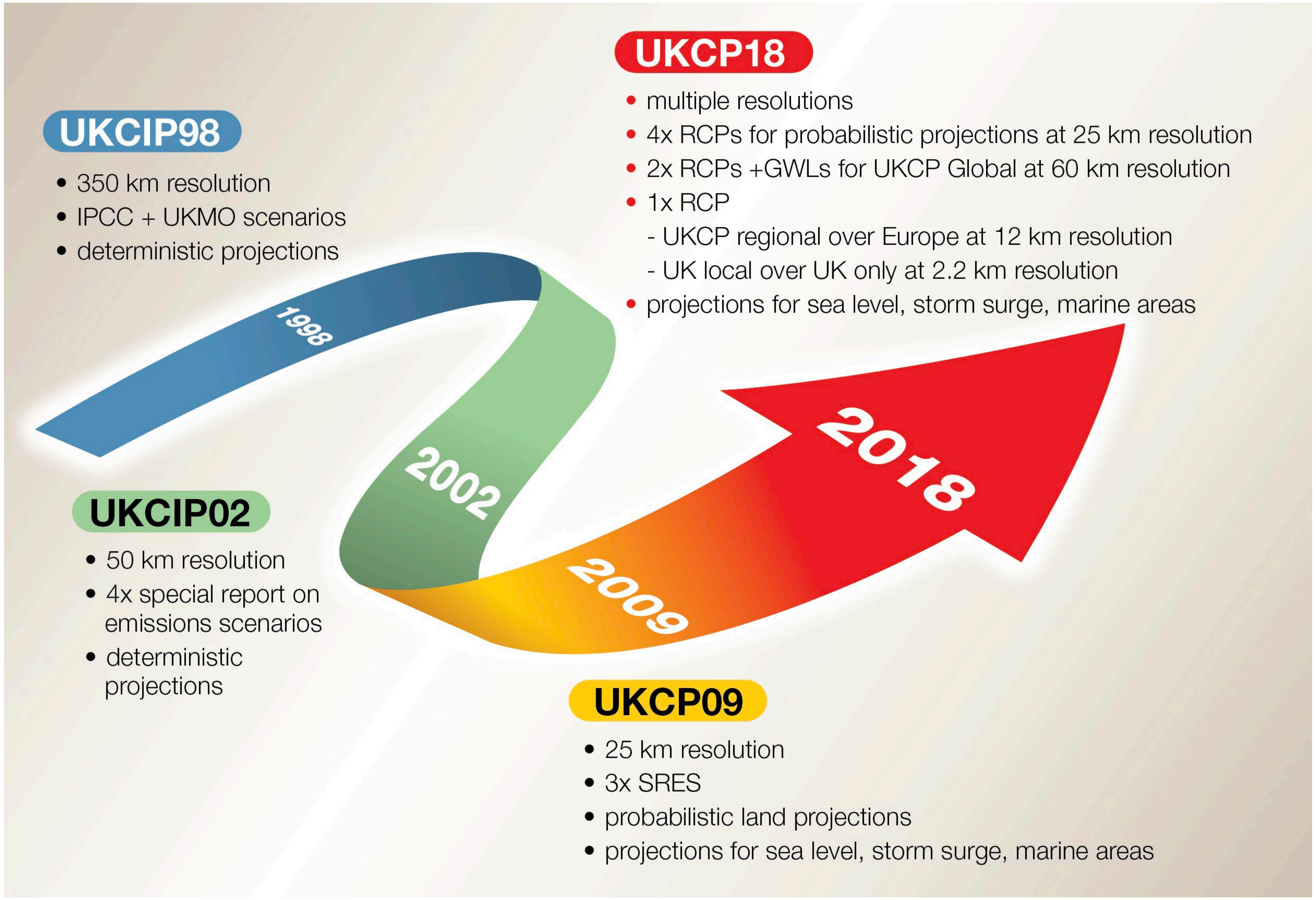
To support the understanding of our future risks, the UK has developed its own set of national climate projections since the early 1990s, based on the latest developments of climate science. With each iteration of the climate projections, climate models have improved in their representation of climate processes as well as provided broader assessments of uncertainty[1] and finer spatial detail (Figure 7). The projections provide a range of tools to support risk assessment based on our latest understanding of how the climate may unfold throughout the 21st century. However, the headline message from these climate projections has not changed: warmer, wetter winters and hotter, drier summers are expected, with sea levels continuing to rise

Since the Climate Change Act 2008, the UK Climate Projections (UKCPs) have formed the basis of national climate risk assessments (in 2012, 2017 and 2022) as well as previous iterations of the 'Health Effects of Climate Change in the UK (HECC)' reports (20 to 22). As part of this current report, UKCP18 climate projections are being used to provide the most up-to-date information on future climate change for the UK as a basis for understanding potential health impacts.

[1] Uncertainties include those from emissions scenarios, internal climate variability and differences between different climate models.

Figure 7. A history of developing UK climate projections

In the diagram, resolution refers to the horizontal spatial resolution. IPCC is the Intergovernmental Panel on Climate Change. UKMO is the UK Met Office. RCP refers to representative concentration pathways. GWLs are global warming levels and SRES is the 'Special Report on Emissions Scenarios'.



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Since 1998, the UK Climate Projections have been updated 3 times: 2002, 2009 and 2018. The resolution has increased with every release: it started at 350km and is now available at multiple resolutions down to 2.2km. From the 2009 release, both probabilistic and deterministic projections have been included, as well as projections of sea level and storm surge.

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The different components included in the climate projections through its history, with UKCP18 preserving and updating the probabilistic projections, sea level and storm surge from UKCP09, are shown in Figure 7. Whilst the probabilistic projections approach can provide a broad estimate of the uncertainties in climate modelling, the method is unable to provide information required for impact studies where sub-monthly (such as daily or hourly) data or spatial coherence[2] are important. The UKCP09 probabilistic projections were based on a set of regional climate models but these were not brought to the forefront at the time.

In UKCP18, in addition to the components described above, a new modelling system was used which provided a chain of climate models at a number of resolutions that explore uncertainty: UKCP Global (60km), Regional (12km) and Local (2.2km). These resolutions were not available in UKCP09, meaning that UKCP18 provides more detailed information at the global, European and UK level that is spatially coherent. However, they are only available for a small number of future emissions scenarios.

UKCP Global (60km) provides the widest assessment of uncertainty out of these 3 climate model products where information is provided at a high emissions scenario (RCP8.5), low emissions scenario (RCP2.6), and 2 global warming levels (+2°C and +4ºC compared to pre-industrial levels). UKCP Global comprises of 2 sets of climate models: one based on variants of a Met Office Hadley Centre climate model (Global-PPE), and the other based on climate models produced by other international climate modelling centres based on the Climate Model Intercomparison Project (CMIP5) (Global-CMIP5, see (23) for more information). For applications where large-scale climate patterns are sufficient for understanding the climate risks, such as whole UK or national assessments, then UKCP Global offers the broadest range of outcomes (except for a small number of situations, such as convective storms that can cause heavy rainfall events experienced during the UK summer).

As spatial resolution increases, climate models can better represent smaller-scale features such as summer rainfall extremes, the diurnal cycle, sea-land interactions at the coast and the effect of mountains. However, higher resolution requires more computer resources to not only run the climate model, but also generate and store large volumes of data. At launch, UKCP18 provided data for only the high emissions scenario (RCP8.5) for UKCP Regional and UKCP Local using

[2] Spatial coherence is where weather events happening simultaneous in 2 different locations is important, for example, whether a heat wave is happening in both London and Belfast at the same time.

Met Office climate models. The latter was also only available for 3 20-year time slices (1981 to 2000, 2021 to 2040, and 2061 to 2080). UKCP Local and Regional often provide the detail required by impact scientists to carry out their analysis; UKCP Local is also the first set of national climate projections at 2.2km resolution[3] providing hourly data. However, some care must be taken to understand whether the increase in resolution and processing is warranted for the climate impacts of interest and how to use the increased spatial resolution appropriately (24).

In UKCP and climate science more generally, a large effort is aimed at assessing uncertainties from different sources including emissions scenario, natural variability in the climate system and climate models' performance. There are other sources of data that could complement the suite of data that UKCP provides. For example, the EURO-CORDEX model experiments (25), which are at the same spatial resolution as UKCP Regional, provide a large ensemble that can support the assessment of uncertainties across different climate modelling centres, although this does mean adding to the data volume. Barnes and colleagues processed this data set into the same format as UKCP Regional, effectively making it easier to compare EUROCORDEX and UKCP18 (26).

Note that since UKCP18 was released, CCRA3 defined its future scenarios as emission pathways that reach +2°C and +4°C at the end of the century compared to preindustrial levels rather scenarios at these global warming levels. Further processing of the UKCP data sets were required to use this framing and examples are included in the supporting research reports (27, 28).

There are other relevant model intercomparison initiatives such as CMIP6 (29) and HighResMIP which informed the IPCC's 'Sixth Assessment Report'. The latter explores the impacts of spatial resolution on the uncertainty range with a notable project PRIMAVERA. However, these data sources are aimed at advanced users, presuming they have familiarity with coding and dealing with large climate data sets. In addition to the above, the Copernicus Climate Change Service offers a data portal to access a range of climate model and climate impact model results which includes the UK.

[3] At 2.2km spatial resolution, climate models are able to simulate 'convection', that is an atmospheric process that can cause small-scale intensive rainstorms. This capability is often referred to as 'convection-permitting'.

4. Recent changes in UK climate

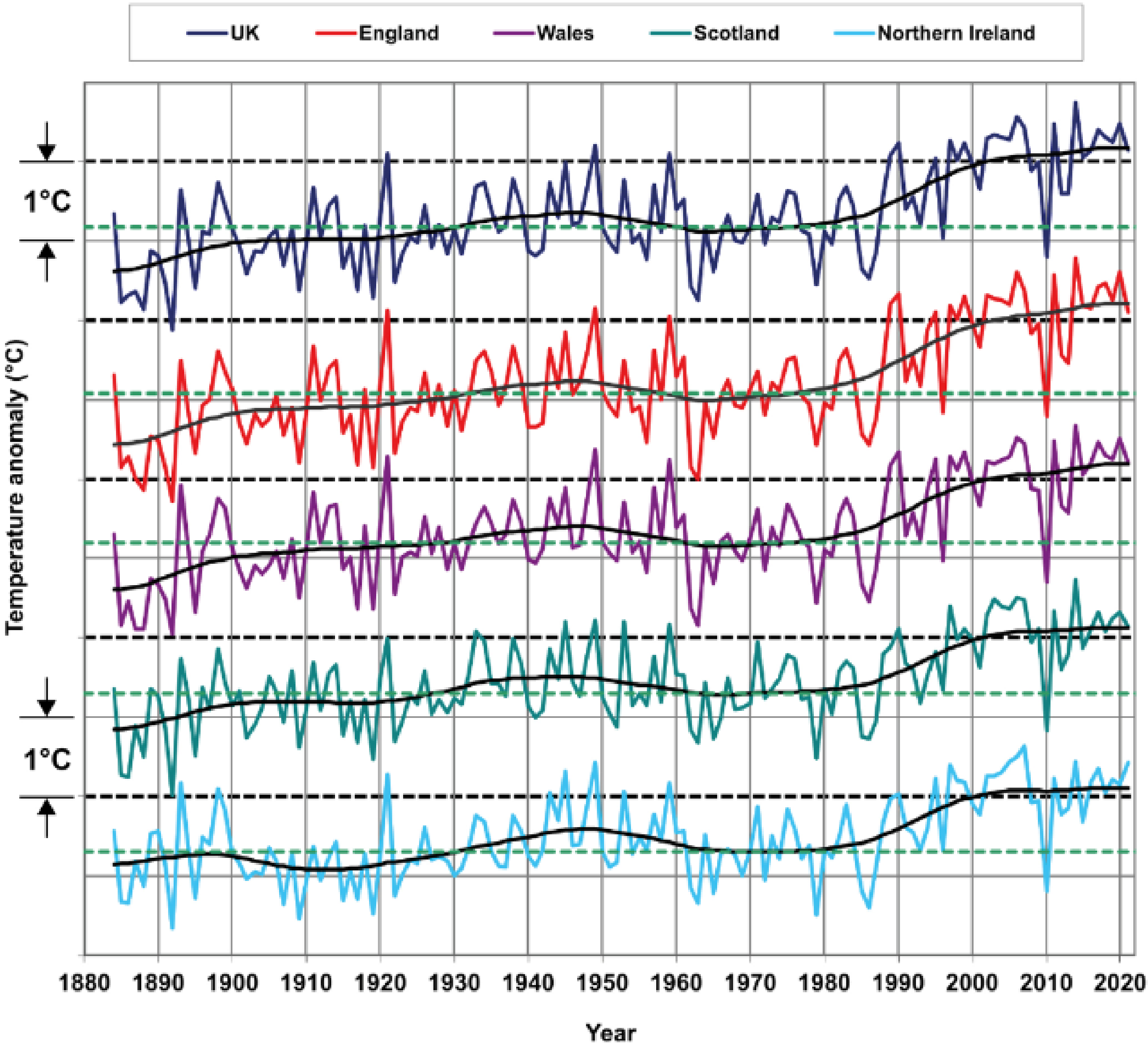
In the HECC report of 2012, Vardoulakis and colleagues stated that the UK temperatures have been increasing since pre-industrial times with the number of hot days (daily mean temperature above 20°C) increasing and the number of cold days (daily mean temperature below 0°C) decreasing (20). Since 2012, UK temperatures have continued to increase, and other climate metrics are also changing in a manner consistent with a warmer climate. The results presented here are primarily selected from the latest version of the 'State of the UK Climate Report' published in 2022 (1). While mean annual temperatures over the whole of the UK are increasing, the magnitude of these varies geographically (Table 1) and seasonally (Figure 8). For example, Figure 8 shows that winter, spring and summer mean temperature has increased by nearly 1°C, and autumn slightly less.

Table 1. Average annual surface air temperature (°C) for different geographical regions, reproduced from Figure 8 of (1)

Geographical area	1961 to 1990 average	1991 to 2020 average	2012 to 2021 average
UK	8.3	9.1	9.3
England	9.0	10.0	10.2
Wales	8.6	9.4	9.6
Scotland	7.0	7.7	7.8
Northern Ireland	8.4	9.1	9.5

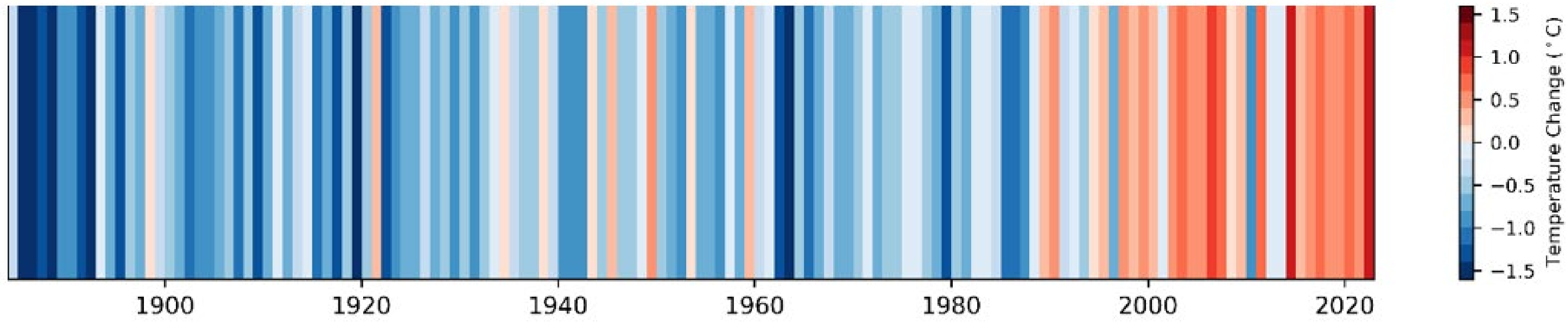
Figure 8. Seasonal mean air temperature (°C) for the UK, 1884 to 2021. The hatched black line is the 1991 to 2021 long-term average

The lower hatched green line is the 1961 to 1990 long-term average. Light grey gridlines represent anomalies of ±1°C (1).



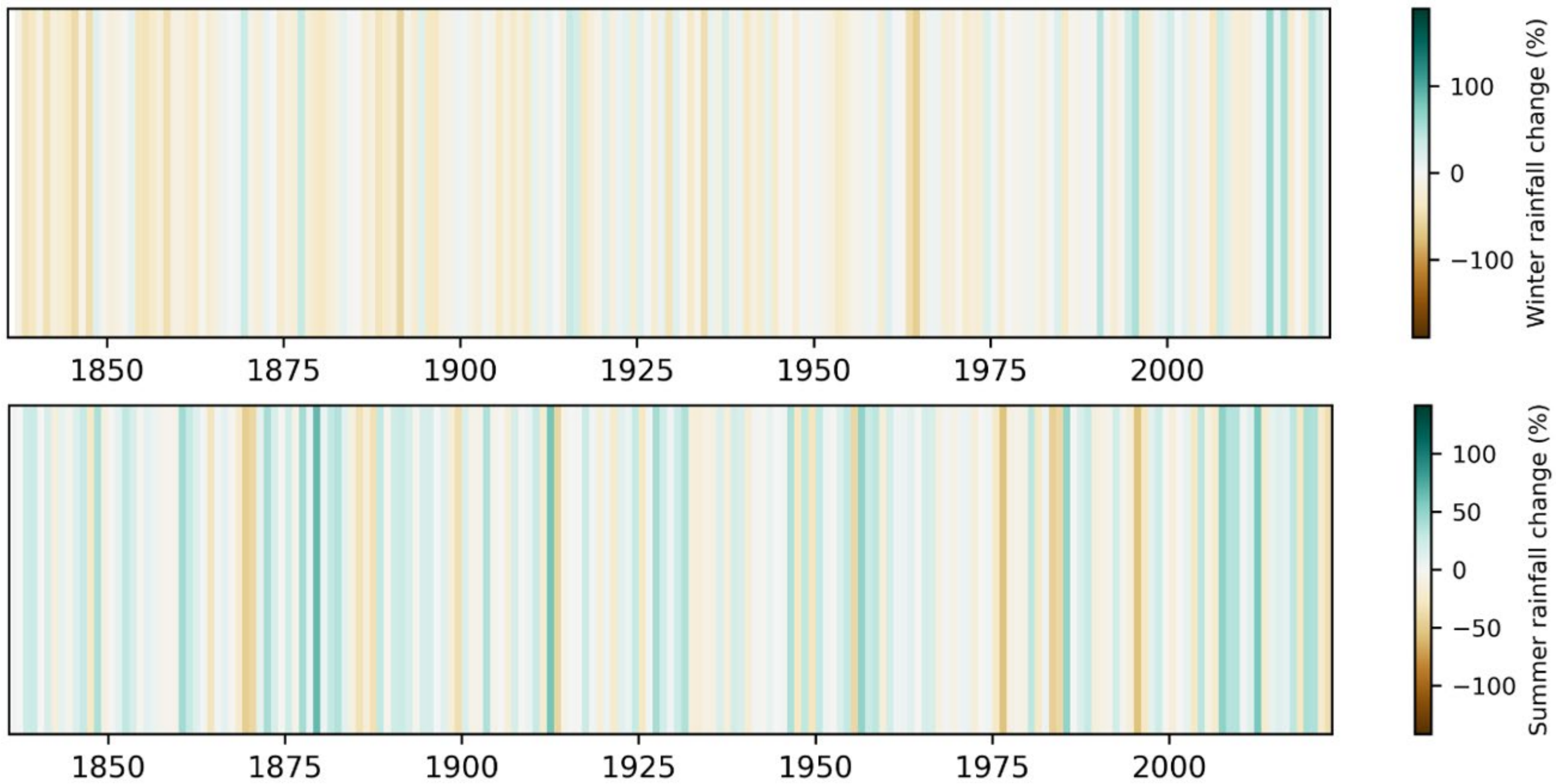
Mean annual temperatures have increased in the most recent decade (2010 to 2019) by an average of 0.3°C compared to 1981 to 2010 (Figure 9), with the 10 warmest years occurring since 2002. Daily maximum and minimum temperatures have also increased with a great warming in the former. Of particular note since 2012 are the heatwaves of 2018 and 2022, with temperatures exceeding 30°C across parts of Highland Scotland, North Wales and Northern Ireland on 28 June 2018, and fairly widely across England through the rest of the summer. The 2018 heatwave presented major negative impacts across the UK and particularly on rural sectors (such as lower crop yields and feed shortages), as well as transport (such as rail buckling) and water infrastructure (for example, increase in water demand) (30). In July 2022, the Met Office triggered a red Extreme Heat warning for the first time ever.

Figure 9. Changes in UK mean annual temperature compared to 1981 to 2010 based on HadUK-Grid (31)
The colour scale indicates temperature change from the baseline period 1981 to 2010.



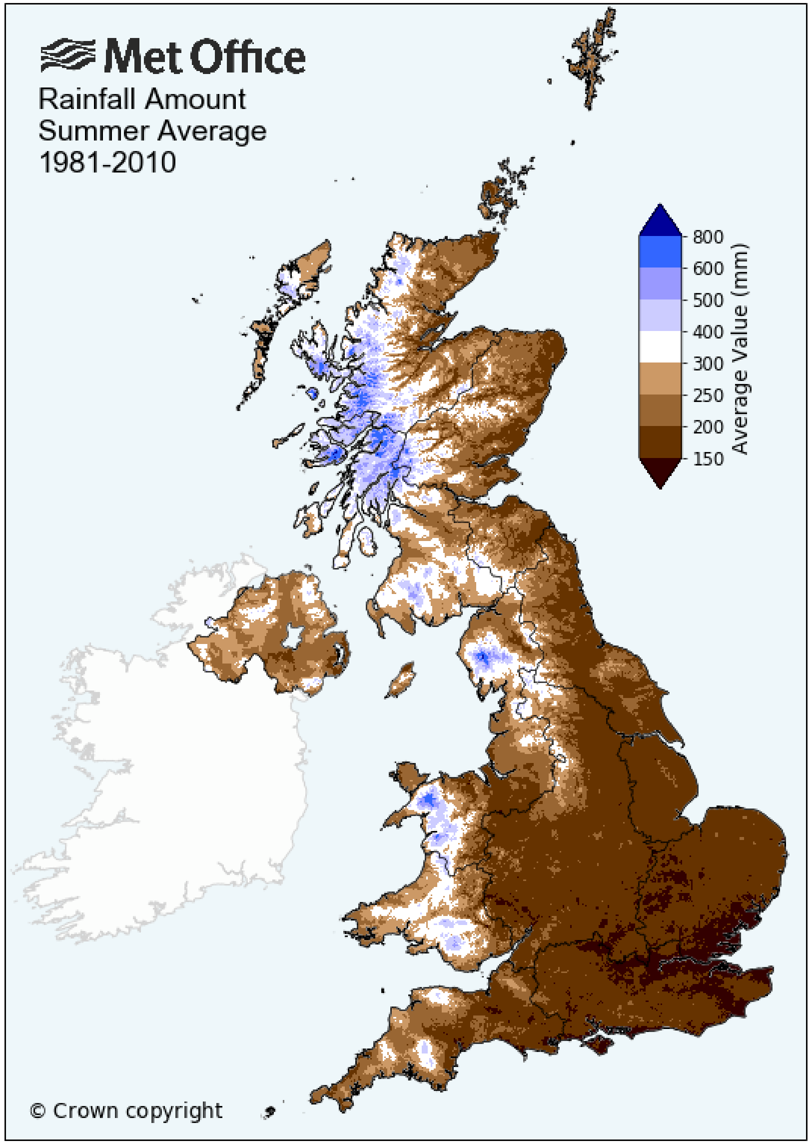
Despite increases in mean annual temperatures, the UK still experiences cold snaps such as in 2021, which saw its coldest winter in Scotland since 2011 (1). Cold temperatures can have several detrimental health impacts, including as a result of ground frosts and the lack of access to energy required for heating buildings. During the period 2010 to 2019, there were 6% fewer days of air frost, 10% fewer days of ground frost and 4% fewer heating degree days (a measure of how cold the temperature is on a given day that may have implications on energy demands) compared to the average baseline during 1981 to 2010 (32). Snow events have occurred in 2009, 2010, 2013 and 2018, but their number and severity have generally declined since the 1960s (33).

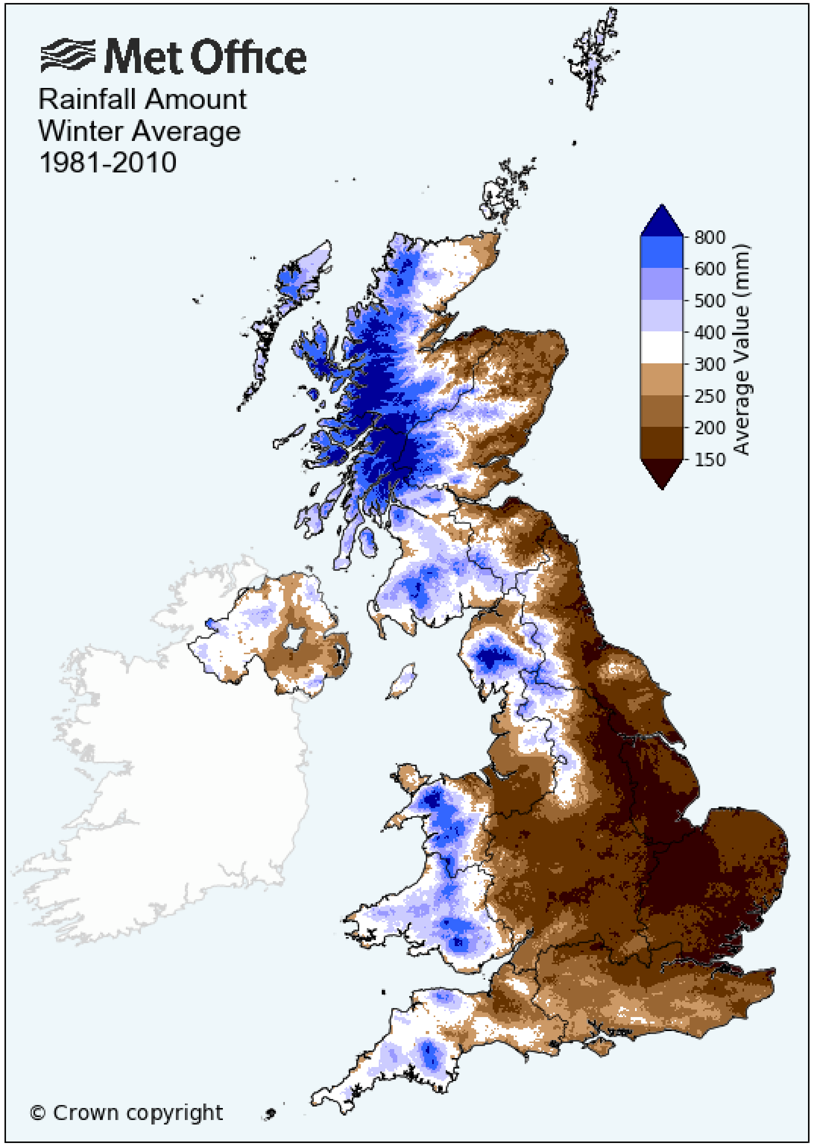
Figure 10. Changes in winter (top) and summer (bottom) UK rainfall during 1836 to 2022 (using 1981 to 2010 as the baseline) based on HadUK-Grid. Each stripe represents one year in the time series.



HadUK-Grid data have shown that since 1836, 5 of the 10 wettest years for the UK have occurred since 1998. During the most recent decade (2010 to 2019), UK summers were 11% wetter and UK winters were 4% wetter on average compared with 1981 to 2010 (Figure 10). The magnitude of these changes is even larger when compared to 1961 to 1990. While the changes are similar across the UK, the actual distribution of summer and winter rainfall is highly heterogenous, although there are generally higher rainfall amounts along the west coast with highest amounts in west Scotland (Figure 11). Note that the year-to-year variability in rainfall is high, making the detection of a climate change signal against background noise difficult. Estimates are that climate change may be detectable only by the 2040s (winter) and 2080s (summer) for short-duration rainfall events and 10 to 15 years later for daily rainfall (34).

Figure 11. Maps of summer and winter rainfall amounts across the UK for 1981 to 2010

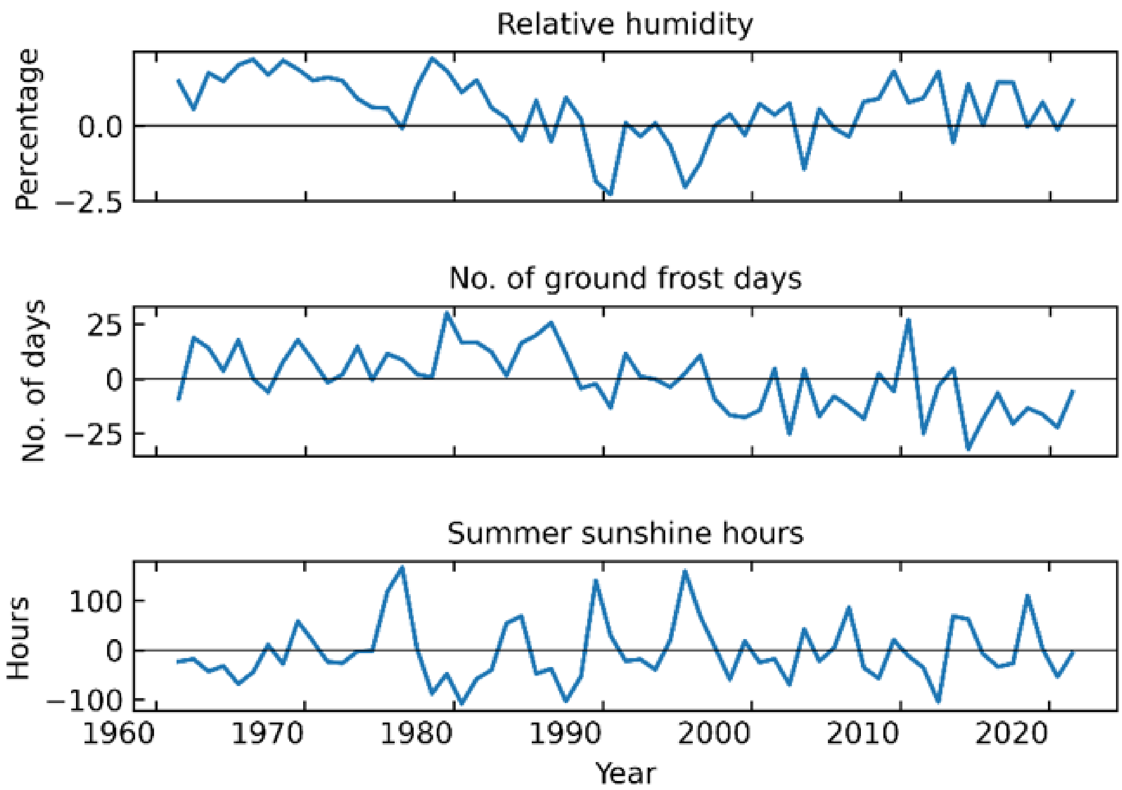




Significant flood events have happened since 2012, including the series of storms that hit the UK during the winter 2013 to 2014. These events started with a storm surge along the north-east coast of the UK on 4 and 5 December 2013, which was followed by a series of deep pressure systems that caused widespread flooding, coastal erosion and wind damage (35). A recent study investigating the Yorkshire floods in November 2019, found that there was a long-term increase in daily rainfall totals, suggesting that the frequency of such floods have increased due to climate change (36). Other significant flood events include the Cumbria floods in December 2015, as well as Storm Ciara and Storm Dennis in February 2020. On the other side of the spectrum, in 2022, the record high temperatures in combination with the driest summer in 50 years resulted in the National Drought Group meeting on 12 August 2022 to discuss their response to the drought.

As with rainfall, detecting trends in windstorms is difficult where observations are also sparse and short. Even if data was available, the year-to-year variability in windstorms is large and the impacts of storms vary greatly on location, thus point-based trend detection would remain very difficult. One measure of large-scale storm systems that the Met Office's National Climate Information Centre uses is the number of days each year on which at least 20 stations recorded wind gusts exceeding 40, 50 or 60 Knots. They observed a decrease in occurrences of these events during the past 2 decades as well as a decreasing trend in the UK annual mean wind speed for the period 1961 to 2021 (1). There are other climate variables of relevance for health impacts, including relative humidity, where very small fluctuations from the mean (82%) were observed during 1981 to 2010 (Figure 12). Similarly, number of sunshine hours has also been related to health, and year-to-year variability in sunshine hours is large, with very little trend seen since 1961 (Figure 12).

Figure 12. UK-averaged mean annual absolute changes in climate variables (relative humidity, ground frost days and summer sunshine hours) related to health impacts compared to 1981 to 2010 based on HadUK-Grid (31)

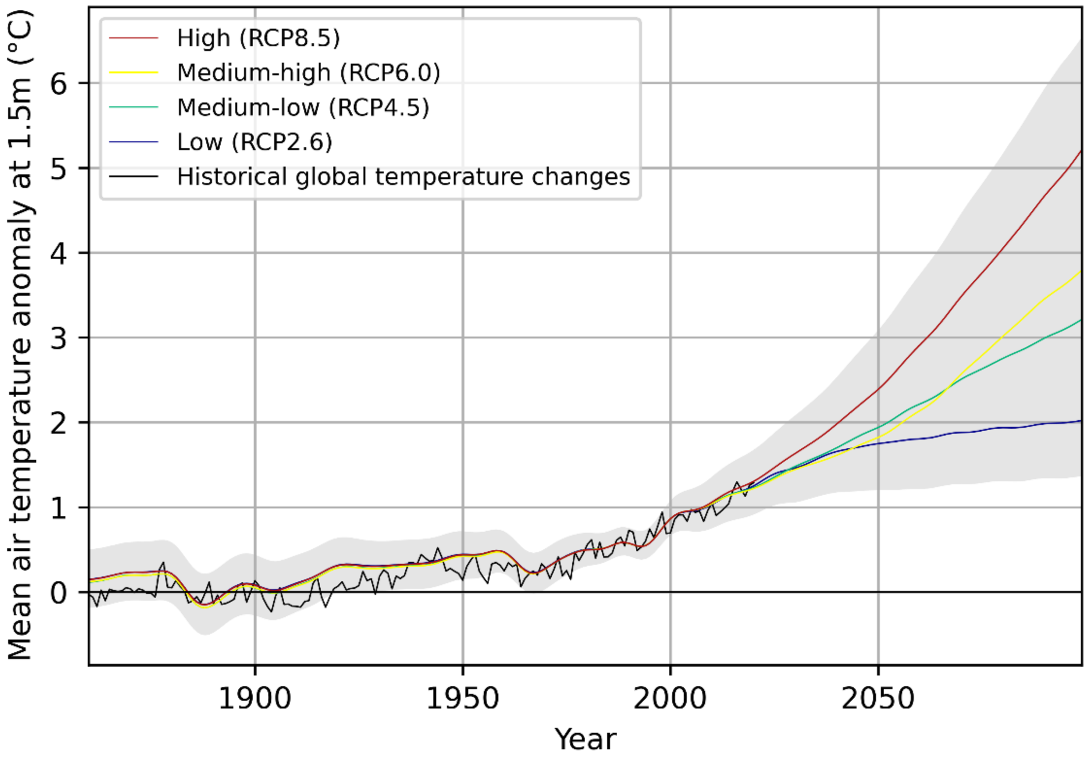


Global mean sea levels continue to rise (37), with rates estimated to be 3.4 ± 0.3mm·year^{-1} over the period from 1993 to 2022 and doubling since 1993 to 2002. The rate of sea-level rise varies across the globe, with the UK primarily affected by vertical land movement due post-glacial rebound. This means that sea-level rise rates are higher in the south, and lower in the north of the UK (38). As seen with global mean sea levels, the rate of sea-level rise in the UK has also increased; when excluding the vertical land movement, sea levels have risen around the UK by about 16.5cm (12 to 21cm, 5 to 95th percentiles) since the 1900s. The rate for the period 1993 to 2019 has increased to 3.6 ± 1.0mm·year^{-1} and some of the highest extreme water levels have been observed, where the 99th percentile water level (exceeded 1% of the time) at Newlyn, Cornwall in 2019 was the third highest in the series from 1916, behind years 2014 and 2018 (1).

5. Future climate change in the UK

One headline message in the latest UK Climate Projections is that "by the end of the 21st century, all areas of the UK are projected to be warmer, more so in summer than in winter", meaning that "hot summers are expected to become more common" (39). By the 2050s, the probabilistic projections indicate that global mean temperatures may reach 1.7°C above pre-industrial levels (median value), with an uncertainty range of 1.2°C to 2.3°C (10th to 90th percentiles) for the low emissions scenario (RCP2.6). Equivalent values for the high emissions scenario (RCP8.5) are 2.4°C with a range of 1.8°C to 3.1°C. By the end of the 21st century, global mean temperatures will depend on the scenario; if there is strong GHG mitigation (removing GHG from the atmosphere), then a low (RCP2.6) emissions scenario is projected to reach a median of around 2°C by 2100 relative to pre-industrial levels (Figure 13). Should a high emissions scenario (RCP8.5) pathway be followed, then global mean temperature may reach over 5°C by the end of the 21st century relative to pre-industrial levels (Figure 13).

Figure 13. Global mean temperatures relative to pre-industrial for different emissions scenarios based on UKCP18 probabilistic projections



The UK impacts of rising global mean temperatures are presented in tables 2a and 2b, showing that both summer maximum and winter minimum temperatures increase for all UK regions, but with Scotland warming less than other regions.

The probabilistic projections reported in (20) included a different set of emissions scenarios which were based on the 'Special Report on Emissions Scenarios (SRES)' (40). These included a high (A1FI), medium (SRESA1B) and a low (B2) emissions scenario, and climate variables were provided as 30-year mean changes compared to the period 1961 to 1990. For comparison, UKCP18 also included SRESA1B and there are some differences which can be attributed to the changes in method for developing the probabilistic projections including the use of different climate models. For example, for SRESA1B for the London region and mean summer temperatures compared to 1961 to 1990 are:

- UKCP18 projects: +2.4°C (1.1°C to 3.9°C) for 2040 to 2069 and
  +3.9°C (1.9°C to 6.0°C) for 2070 to 2099
- UKCP09 projects: +3.7°C (1.4°C to 6.5°C) for 2040 to 2069 and
  +5.2°C (2.2°C to 9.2°C) for 2070 to 2099

where the 10th and 90th percentile range are in parentheses. The individual values show some large differences, but of note here is that UKCP09 occupies a large range of UKCP18 values but the range of values tend to be higher.

Table 2. Changes in seasonal minimum and maximum temperatures at mid- (2040 to 2069) and end of the 21st century (2070 to 2099) for low (RCP 2.6) and high (RCP 8.5) emissions scenarios compared to the 1981 to 2010 average based on the probabilistic projections

Table 2a. For 2040 to 2069

Geographical area	Emissions scenario	Summer maximum temperature (°C): median	Summer maximum temperature (°C): 10th to 90th percentiles	Winter minimum temperature (°C): median	Winter minimum temperature (°C): 10th to 90th percentiles
UK	Low	1.5	0.4 to 2.6	0.9	0.0 to 2.0
	High	2.4	0.8 to 4.0	1.7	0.4 to 3.1
England	Low	1.7	0.5 to 2.8	1.0	0.0 to 2.1
	High	2.6	0.9 to 4.4	1.7	0.4 to 3.2
Northern Ireland	Low	1.2	0.3 to 2.2	0.7	-0.2 to 1.8
	High	1.9	0.5 to 3.4	1.5	0.3 to 2.8
Scotland	Low	1.0	0.1 to 2.0	0.6	-0.5 to 1.8
	High	1.6	0.2 to 3.0	1.4	0.1 to 2.8
Wales	Low	1.5	0.4 to 2.7	0.8	-0.1 to 1.9
	High	2.4	0.7 to 4.1	1.6	0.4 to 2.9

Table 2b. For 2070 to 2099

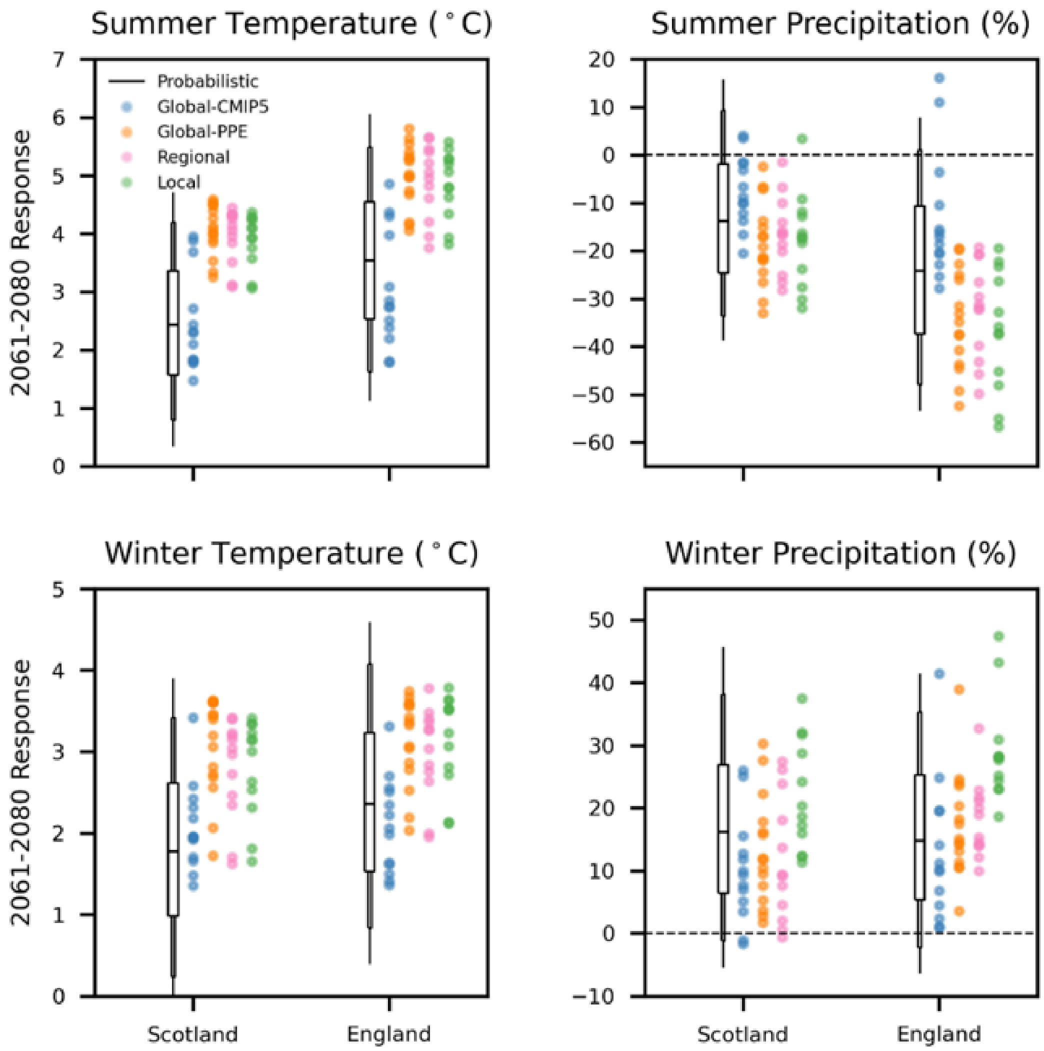
Geographical area	Emissions scenario	Summer maximum temperature (°C): median	Summer maximum temperature (°C): 10th to 90th percentiles	Winter minimum temperature (°C): median	Winter minimum temperature (°C): 10th to 90th percentiles
UK	Low High	1.8 4.8	0.6 to 3.1 2.1 to 7.6	1.0 3.1	0.0 to 2.3 1.0 to 5.5
England	Low High	1.9 5.3	0.6 to 3.4 2.3 to 8.3	1.0 3.2	0.0 to 2.3 1.0 to 5.6
Northern Ireland	Low High	1.5 4.3	0.4 to 2.6 1.7 to 6.9	1.0 2.8	0.0 to 2.1 0.8 to 5.0
Scotland	Low High	1.1 3.6	0.1 to 2.2 1.0 to 6.1	0.8 2.4	-0.4 to 2.0 0.3 to 4.7
Wales	Low High	1.9 5.1	0.7 to 3.1 2.1 to 8.2	1.0 3.0	-0.1 to 2.1 1.0 to 5.2

The probabilistic projections provide useful information on the uncertainty range, the monthly frequency and 25km spatial resolution. Depending on the analysis being carried out, this could be sufficient for assessing health impacts. Many studies using the UKCP09 or UKCP18 probabilistic projections take the monthly projected changes and apply these to daily or monthly observations to arrive at absolute future values: this is the ‘delta change method’ (for example, (41)) and is widely used. However, the future values produced by this method will have the same daily variability as in the observations and the changes are not spatially coherent – both of which could be important in an impacts analysis. Here, UKCP Global (60km), Regional (12km) and UKCP Local (2.2km) can provide spatially coherent time series that are often required for impacts modelling and analysis. Figure 14 shows how each of the products relate to each other in terms of the range of climate changes that they cover. All products show a consistent result, which that is that UK summers are projected to be hotter and drier, and UK winters will be warmer and wetter.

The probabilistic projections show the largest of the range of changes in 2061 to 2080 compared to the other products. The Met Office Hadley Centre climate models (UKCP Global-PPE, Regional and Local) cover the warmer range of summer temperatures and drier range in summer precipitation in England. UKCP Global also includes CMIP5 model results, and these cover the colder range of the temperature changes; they show less drying in the summer in England, with 2 models showing an increase in rainfall.

Figure 14. Comparison of seasonal mean changes across UKCP18 products: projected changes for 2061 to 2080 relative to 1981 to 2000 for Scotland and England in (top) summer (June, July, August) and (bottom) winter (December, January, February), under a high emissions scenario (RCP8.5)

Results are shown for surface air temperature (left, degrees Celsius) and precipitation (right, percentage). Box and whiskers denote the 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles of the UKCP probabilistic projections. Orange dots denote results from the Met Office Hadley Centre global climate model, HadGEM3 GC3.05 (Global-PPE) and blue dots are those of other international climate modelling centres (Global-CMIP5), which together comprise the UKCP Global (60km) projections. Pink dots show UKCP Regional (12km) and green dots those of UKCP Local (2.2km).



UKCP Local (2.2km) projects a warming of 3.8°C to 6.8°C for hot summer days by the 2070s under a high emissions scenario (RCP8.5). This is accompanied by an increase in the frequency of hot spells[4] but these are largely in the South East of the UK (42). This finding is also seen when translating temperature variables to heat warnings: previous research has used the UKCP product suite to investigate heatwaves as defined by the Met Office, heat-health alerts (amber alert) defined by UKHSA and occupational heat stress (43). They found that the number, duration and likelihood of heatwaves increase in the future, with an average annual likelihood increasing from around 40% in the current climate to more than 80% in southern England by the 2050s (43). Their occupational heat stress metric, which is dependent on not only daily maximum temperature but also daily mean relative humidity, similarly shows that in southern England, the likelihood of a discomforting day may double in 2010 to 2039 compared to 1981 to 2010; by the 2050s under the high emissions scenario (RCP8.5), the likelihood could be more than one year in 2 (43). However, as seen in Figure 13 and Table 2, the uncertainty is large.

For cold extremes, UKCP Local (2.2km) projects temperature increases of 5.4°C of cold winter days and a decrease in the frequency of cold spells[5] in northern UK (44). This is accompanied by decreases in falling and lying snow by the 2070s. A similar narrative has been previously reported, where even under a high emissions scenario (RCP8.5), there would be cold weather alerts although their frequency would decrease (43).

Rainfall patterns across the UK are not uniform; they vary on seasonal and regional scales and will continue to vary in the future (Figure 15). By 2070, under the high emission scenario (RCP8.5), the probabilistic projections project a change in precipitation of -45% to +5% in summer and -3% to +39% in winter for the 10th to 90th percentile range. As indicated in Figure 14, the magnitude of the changes depends on location and data product: there is a lot of overlap between all products but a stark difference in the summer over England where many of the CMIP5 models project reductions in precipitation, with a few projecting a small increase – 2 of these models are in the tail of the probabilistic projections distribution. UKCP Regional and UKCP Local are therefore samples of the dry end of future summer changes when compared to the probabilistic and CMIP5 projections.

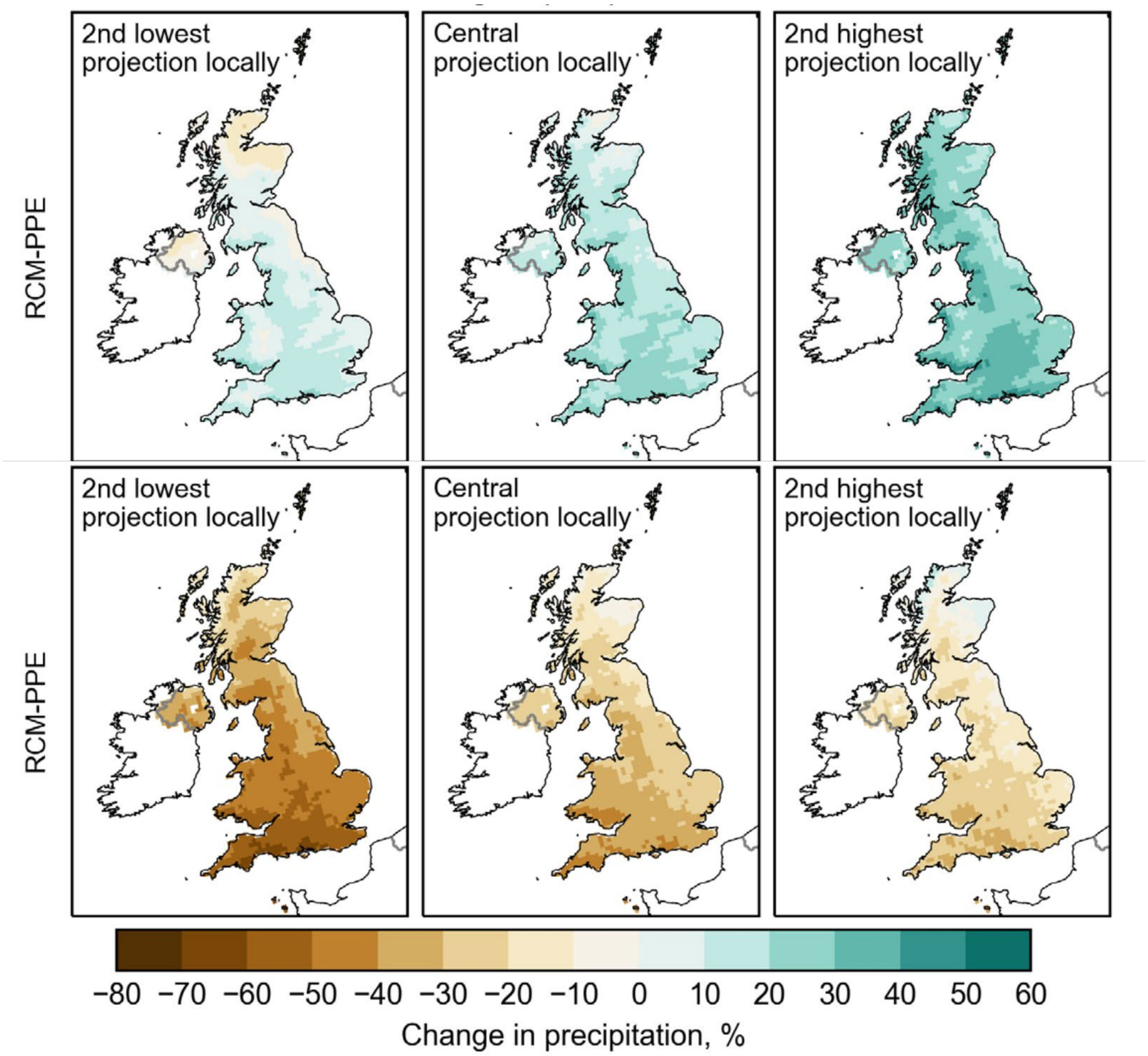
Despite overall summer drying trends in the future, UKCP Local projects future increases in the intensity of heavy summer rainfall events with significant increases in hourly precipitation extremes in the future (42). Future climate change is projected to bring about a change in the seasonality of extremes. UKCP Local projects an extension of the convective season (which can cause heavy rainfall events) from summer into autumn, with significant increases in heavy hourly rainfall intensity in the autumn. Alongside this, the frequency of drier summer-type weather regimes and a decrease in stormy winter types that emerge for the autumn as early as the 2020s (45). Chan and colleagues recently translated the UKCP Local precipitation projections for surface water drainage designers that indicate that the 30-year return level of 1-

[4] Defined as maximum daytime temperatures exceeding 30°C for 2 or more consecutive days.
[5] Less than -2°C for 2 or more days.

hour and 24-hour precipitation totals is projected to increase by 30% to 45% and 20% to 40%, respectively by 2070 under a high emissions scenario (RCP8.5) (46).
Mean wind speeds at the large scale show a small decreasing trend through the 21st century but this is relatively small when compared to the year-to-year variability. Instead, using weather patterns to understand the nature of wind and storminess shows that at the end of the 21st century, at the large scale, there is a tendency towards an increase in winter of weather patterns associated with cyclonic and westerly wind conditions at the expense of more anticyclonic, settled or blocked weather patterns (47). In summer, the results indicate a shift towards an increase in dry settled weather types, with a corresponding reduction in the wet and windy weather types (47). UKCP Local also provides information on extreme winds as well as lightning, and work is currently underway to evaluate the data and projected outcomes.

Figure 15. Spatial distribution and magnitude of projected range of changes in precipitation (%) across the UKCP Regional (12km) model ensemble for 2061 to 2080 relative to 1981 to 2000

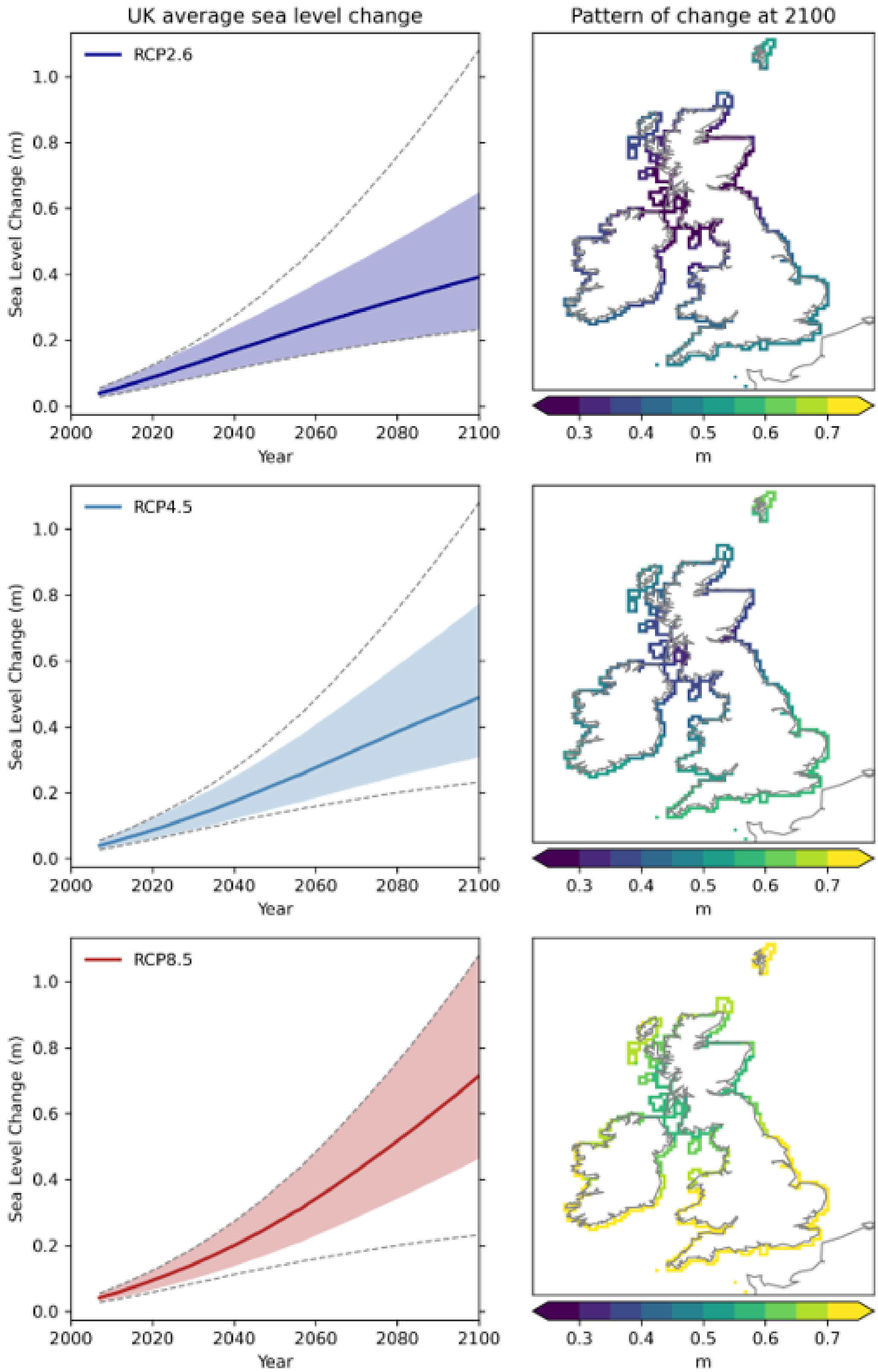
Columns show second lowest, central and second highest responses obtained by ranking the changes in the 12 members of UKCP Regional. Top row shows winter and bottom row summer changes (adapted from figures 4.8c and 4.8d in (23)).



Sea levels are projected to rise through the 21st century and beyond for all emissions scenarios. Strong reductions in GHG emissions will slow the rate of sea-level rise over coming centuries and avoid some of the largest eventual increases in sea levels experienced hundreds of years or more into the future. The amount of sea-level rise around the UK increases with higher emissions scenarios (Figure 16) diverging around the 2040s. The smallest projected increase is on the east and west coast of Scotland, which ranges from less than 0.3m and over 0.5m depending on RCP scenario (Figure 16). There is no evidence for significant changes in future storm surges, but larger changes cannot be ruled out. However, as sea levels are projected to rise, water levels during storm surges will also rise. It should be noted that there are also storm surge scenario data available that include small and large changes that enable sensitivity tests (48). Investigations into extreme sea levels show that they also increase driven mainly by increases in mean sea level (49).

Figure 16. Time series of time-mean sea level change based on the average of the UK ports (left) and the spatial pattern of change at 2100 associated with the central estimate of each RCP scenario (right)

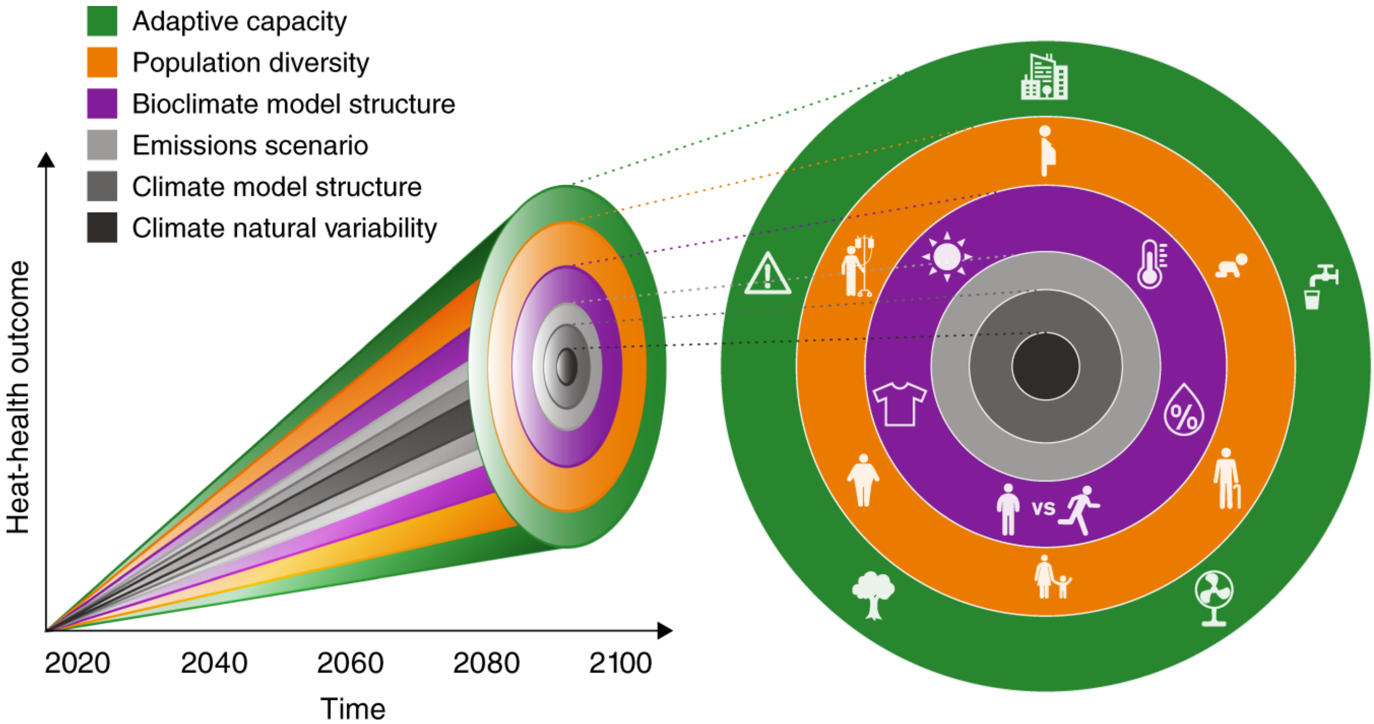
The solid line and shaded regions represent the central estimate and ranges for each RCP scenario as indicated in the legend. The dashed lines indicate the overall range across RCP scenarios. All projections are presented relative to a baseline period of 1981 to 2000 (49).



6. Using climate projections for health impacts

International climate model intercomparison projects (such as CMIP6 and EURO-CORDEX), as well as national efforts such as UKCP18, aim to capture the range of potential future outcomes by exploring uncertainty. Similarly, it is important to understand how uncertainties in the climate modelling cascade down to human health impacts modelling and risk assessments. Recent studies have used temperature-based metrics to infer heat-related health impacts (50 to 52), assessing the uncertainty range in the climate models. Vanos and colleagues propose going further, including 3 additional sources of uncertainty including population diversity, adaptative capacity and bioclimate models which can determine the vulnerability (see Figure 17) (53). These can interact to increase or decrease vulnerability which is one of the components of risk presented in Figure 1.

Figure 17. Uncertainties in projections of human health, well-being, and productivity due to extreme heat exposure in a warming climate (53)



Text version of Figure 17.

The left side of the figure shows that in addition to uncertainties regularly quantified in projecting environmental variables including climate variability, model structure, and emissions scenario, there are further uncertainties in projecting heat-health outcomes including bioclimate model structure, diversity and vulnerabilities in the population, and heat adaptations including warning systems, behaviour and urban planning). The right side provides graphics of these sources of uncertainty, with the concentric circle colours corresponding with the colours of uncertainty cones in the left side. These graphics represent inputs to bioclimate models, including solar radiation, temperature, humidity, clothing, and activity; considerations for population diversity, such as pregnancy, age, weight, and pre-existing illness; and various forms of adaptive capacity, such as building design, hydration, fans or air conditioning, green infrastructure, and the implementation of heat warnings systems.

End of text version of Figure 17.

While climate models are important tools to project future climate, they have traditionally been used primarily to understand the climate system and to provide physically argued evidence for the impact of anthropogenic GHG emissions and feedbacks. Consequently, there is often a gap between climate model output and the information required for impact models and risk assessments. In particular, the relevant spatial and temporal resolution, as well as appropriate metrics required for assessment, are often lacking. Impacts analyses can require extremes, high resolution, and different emissions scenarios (24, 54).

As stated in section 3.2, UKCP and other climate model ensembles only include a small number of emissions scenarios and metrics, and the higher the spatial resolution, the narrower the range of available data. These factors need to be assessed to understand their importance for the purpose of the impacts or risk analysis and the appropriate data sets selected. For example, UKCP Local provides more realistic high-resolution data on extreme rainfall and temperature, and its underpinning models are better able to capture the local effects of coastal areas and mountains. However, it is only available for the high emissions scenario (RCP8.5), downscaled using Met Office models and for 3 20-year time periods up to 2080. The probabilistic projections explore 5 emissions scenarios throughout the 21st century and provide a wider range of assessment of uncertainties. However, it is not spatially coherent and has monthly outputs. Therefore, choosing which data set to use in an analysis to exploit their advantages is an important decision. For example, Chan and colleagues aim to provide extreme rainfall projections to help inform the climate resilience of drainage systems and therefore use UKCP Local (46). Arnell and colleagues use the probabilistic projections to provide heat stress projections at the counties and district level to inform policy allowing the exploration across multiple emissions and global warming scenarios (50, 55).

Should a high-resolution climate data set be chosen, care should be taken to use the geographical locations directly; for example, using individual grid cells to inform a metric would be inappropriate. Instead, determining the statistical properties of a climate metric across groups of grid cells would be more appropriate. While high resolution is important for simulating atmospheric processes more realistically, it’s the impact of this model resolution on how it simulates future extremes which is of importance when understanding future climate risk. For example, several studies have calculated statistics across a larger region to determine the frequency of extreme events (44, 46).

The metrics used in heat mortality studies are often based on thresholds of a particular climate variable. As described in section 5, many studies use the ‘delta change’ method to carry out impact studies. However, in the previous iteration of the ‘HECC report’, many studies also relied on the UKCP09 Weather Generator and accompanying threshold detector (20). These are a set of tools that provided long synthetic series of daily climate variables and identified the frequency for which thresholds were exceeded. A weather generator was not provided in UKCP18. Instead, data was only provided from a physically based modelling system so that they could be evaluated against real world observations rather than the statistical approach of the weather generator (56).

A parallel technique using climate models would require adjusting the climate model data for systematic differences between model results and observations (such as bias-adjustment or bias-correcting (57)) the data and using the resulting time series for analysis. The appropriateness and method of bias adjustment is highly dependent on the application and to this end, a number of sectors have begun to do this including hydrological and water resources in CHESS-SCAPE (58) and eFLaG (59), flood drainage in FUTURE-DRAINAGE (60) as well as building design an ongoing project by the Chartered Institution of Building Services Engineers (CIBSE) to update their weather files (61).

7. Future of climate science for managing health impacts

There have been many advances in climate science over the last decade. In particular, observational data sets have been extended, both with new observations from recent years but also through data recovery exercises filling gaps in the historic record and extending it back further in time. This provides a tool for better understanding the range of possible observed events and their context. Event attribution has emerged as a technique that brings together observations and climate model simulations to provide an estimate of how the probability of extreme weather events in the observed record has altered due to long-term human-driven climate change, with a human driven signal evident in many but not all the most recent most damaging extreme weather events.

Models remain an abstraction of the real climate system, but they have progressed and are able to represent more complex processes, which bring the models closer to simulating the real climate, such as by routinely including many aspects of the way in which the land surface plays a role in weather and climate. Global climate models can explicitly represent finer spatial scales, instead of approximating the behaviour of these scales, adding further realism in the dynamic evolution of the atmosphere and ocean. However, typically global models still stop short of simulating atmospheric convection and realistic interaction of the atmosphere and ocean with fine-scale topographic features. Regional climate models can improve the simulation of many of these processes over particular regions, reaching down to scales of a few kilometres previously seen only in short term weather forecasts. This has greatly improved the simulation of extreme weather in future climate. At the same time many more estimates of climate impacts have become available and some even include some effects of adaptation.

Alongside the improvements of physical climate science there has been a drive to bring together physical and social science and engineering disciplines to better understand how climate change affects human systems and to explore potential solutions to the climate challenge. This includes better linking climate model simulations of the future to mitigation and adaptation decision-making. Recent advances in constructing internally consistent socio-economic scenarios for the UK that are traceable to larger-scale regional and global trends were provided by UK specific shared socio-economic pathways (62). It will be important to build on this with updates as new global scenarios are provided.

What can be expected from the next decade of scientific development? First, models with higher spatial resolution and greater process complexity can be expected, which will provide more realistic simulations of the climate system with potentially lower biases. Uncertainty still needs to be represented, most likely through ensembles of model simulations, but more focus will be placed on constrained, weighted and filtered ensembles to provide a better representation of the distribution of uncertainty in climate simulations.

There will likely be more availability and use of skilful near-term initialised climate forecasts. With the skill from seasonal forecasts increasing and the time horizon being extended to routinely include time horizons out to 5 years into the future. Together with the longer-term climate projections, these will form seamless packages of advice for future periods.

Some model components, or entire models will be replaced in some circumstances by machine-learning alternatives, which tend to run much faster. For instance, many downscaling or impact simulation tasks may use this form of model. However, there will still be a role for more traditional physically-based models in looking for surprising emergent outcomes and providing tuning data sets. Because of the large data volumes produced by climate and impact models, much more processing of model output will be done remotely using cloud computing near to the storage location of the data, rather than transporting copies of the raw data across the internet. Data science tools and methods are also likely to increase the speed of analysing new climate data sets, for instance by revealing patterns in the data automatically. They will additionally make it easier to bring together climate and other relevant data, such as age demographics or information on other drivers of health outcomes. A key development will be the inclusion of response methods, for instance adaptations and including early warning, into model simulations to assess the effectiveness of different approaches.

Simulations may eventually take the form of digital twins: in the context of climate change, these are systems models that bring together hazard, vulnerability and exposure as well as taking advantage of big data sets from real-time monitoring. Digital twins have a stronger coupling to and from the real world. One potential example of this could be the linking of weather digital twins to health, building and transport digital twins. Linking the digital twins could provide an automated system to optimise responses to, for example, high temperature events. This might involve a connection from the twin via the internet of things to close windows and turn on air purification during poor air quality or activate active cooling during high temperature events.

Against this backdrop of evolving climate sciences, the UK Met Office will continue to support and update UKCP18, which will likely form a major input to the next UK climate change risk assessment (CCRA4). As part of this update, more information will be provided at particular global warming levels including 2°C and 4°C above pre-industrial values. This will make it easier to relate the climate projections to the framing used in CCRA3. Additionally, a major consultation of users and potential users of UK climate information will begin in 2023. This will provide the evidence base for longer-term updates of UK climate information for decision-making, including climate projections, which will draw on the new developments in climate science.

In summary, a growth in understanding of how weather and climate impact on health is expected. There will also be greater understanding of how the impacts interact with other determinants of health, such as poverty or with threats such as infectious disease. Most usefully, methodologies should be developed to better assess how interventions can deal with both the impacts of weather and climate change and other drivers of health impacts, using virtual environments to tailor and optimise interactions whilst keeping in mind the wider cobenefits and trade-offs. Some interventions will become automated, with forecast models linked directly to the internet of things and enabling early warning to become early action. The increased inter and transdisciplinary ways of working, and the increasingly sophisticated modelling approaches may require enhanced training of professionals working at the interface of health and climate sciences.

Acronyms and abbreviations

Abbreviation	Meaning
CCRA	Climate Change Risk Assessment
CMIP5	Climate Model Intercomparison Project
GHG	greenhouse gas
HECC	Health Effects of Climate Change in the UK report
IAMs	integrated assessment models
IPCC	Intergovernmental Panel on Climate Change
NDCs	Nationally Determined Contributions
RCP	representative concentration pathways
SRES	Special Report on Emissions Scenarios
UKCP	UK Climate Projections
UKHSA	UK Health Security Agency

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