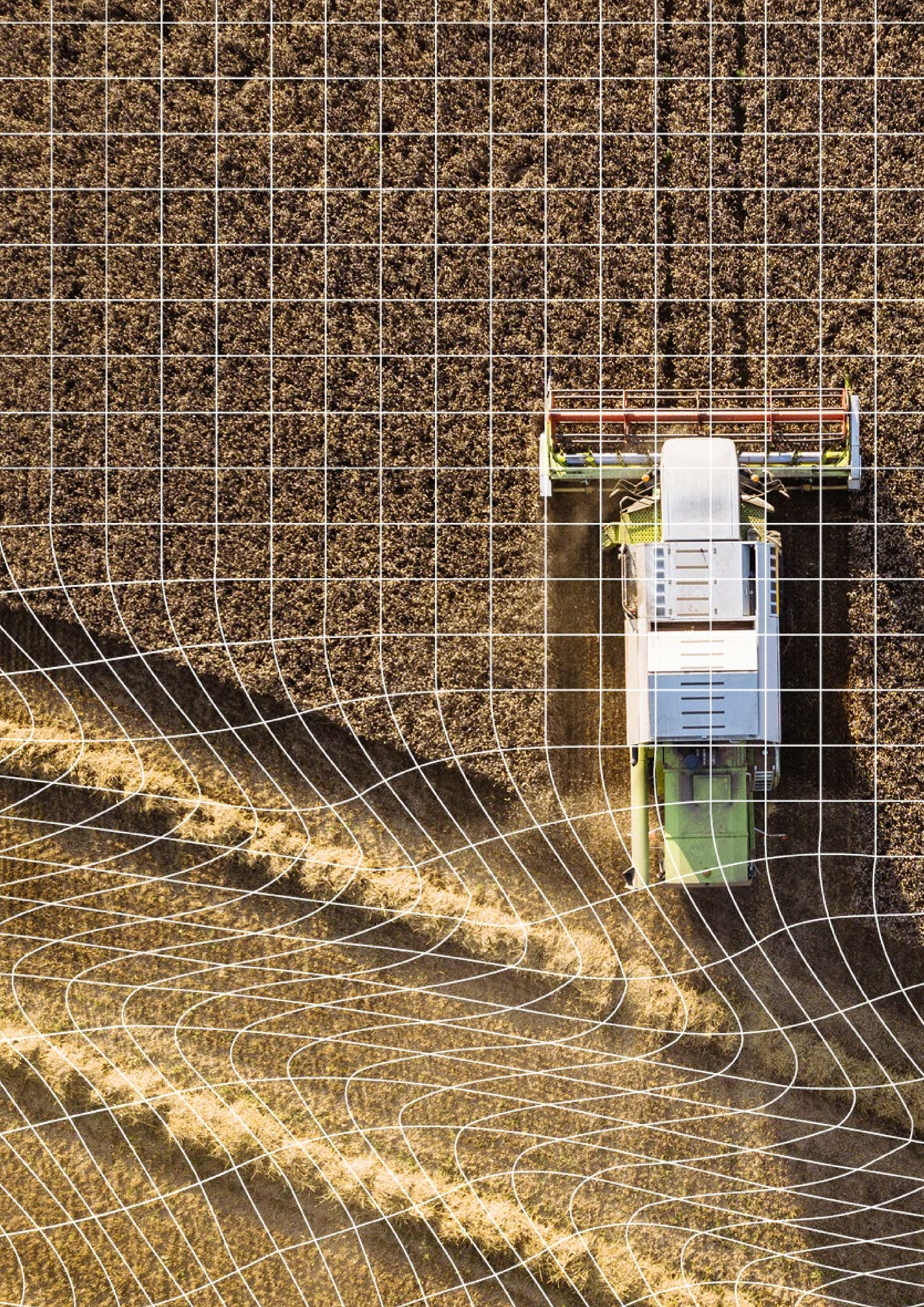
Chapter 1

The UK's changing climate



Introduction and key messages

This chapter summarises observed and possible future changes in the UK's weather and climate.

This Chapter gives an overview of how the UK's climate has changed and may continue to change in the future. It summarises the aspects of climate change that will drive the direct climate risks to the UK considered in this report. It builds on the analysis in Chapter 1 of the CCRA Technical Report.[1] Our conclusions are:

- **The UK's climate has already changed over recent decades.** Over recent decades the UK's annual average temperature has warmed at nearly 0.3°C per decade. Heatwaves are now more common and intense across the country and cold extremes significantly less likely. Sea levels are over 5 cm higher than in 1990 and continue to rise. A signal of climate change is also being detected in some extreme heavy rainfall events.

- **Further changes in the UK's climate is expected by mid-century.** Changes in UK climate by 2050 are largely insensitive to the trajectory of global emissions over the next few decades. The UK is more likely to experience warmer and wetter winters in future together with hotter and drier summers. Rainfall and temperature extremes will become more intense and frequent. Sea levels will continue to rise around the UK.

- **A wide range of future UK climates remains possible in the second half of the century.** UK climate after 2050 depends on global efforts to reduce global greenhouse gas emissions. If the world successfully reduces emissions to limit global warming to the temperature goal of the Paris Agreement, only limited changes would occur in many aspects of UK climate beyond those expected by 2050 (however, sea levels would continue to rise). If global emissions remain high, summers will continue to become even hotter and drier, and winters warmer and wetter. Considering a range of global warming levels (e.g. 2ºC to 4ºC above preindustrial levels by 2100) can help to assess risks over the long-term.

- **The UK's weather and climate will continue to be highly variable.** In the future, summers will still occur that are cooler and wetter than typical over the recent past (as well as winters that are cooler and drier) despite trends in the opposite direction expected on average. The future variability of the UK climate needs to be considered in risk assessments to be fully resilient to the full range of weather and climate conditions expected.

- **Low-likelihood, high-impact climate changes outside the envelope considered in current projections could still be possible.** These changes include global warming higher than 4°C by 2100, and potential instabilities such as collapse of the Atlantic Ocean currents. These changes could have a large impact on UK climate. At present there are no monitoring systems to consider whether many of these changes are imminent. Storyline approaches or the use of 'what if' scenarios could be useful to help consider these low-likelihood impacts in risk assessments.

We set out our analysis in three sections:

1. Observed climate changes

2. Projected future changes in UK climate

3. Climate variability, extremes, and low-probability outcomes

Changes in the global and UK climate have been observed over recent decades. These changes demonstrate the emerging signal of climate change that is now clear in many aspects of weather and climate. There is no 'safe' level of warming in which climate change impacts in can be avoided entirely. Future warming will bring additional increases in the climate-related risks already present as well as the emergence of new ones.

Observed global climate change since the mid-19th century

Global temperatures continue to rise rapidly – with human influence the driver.

The earth is warming, with clear evidence linking this warming to human activities:

- The last six years have been the six warmest on record globally (Figure 1.1).
- Estimated human-induced global warming has now reached around 1.2ºC above 1850 - 1900 (which has been regularly used as an approximation for preindustrial levels) when disentangled from the effects of natural climate variability.[2] Human-induced warming is estimated to explain 100% (+/- 20% uncertainty) of the observed warming since 1850-1900.[3]
- Human-induced warming is increasing at around 0.25ºC per decade, leading to further increases in global and UK climate hazards into the future.[*]

Rising global temperatures have much wider effects on climate around the world – impacting people and ecosystems today.

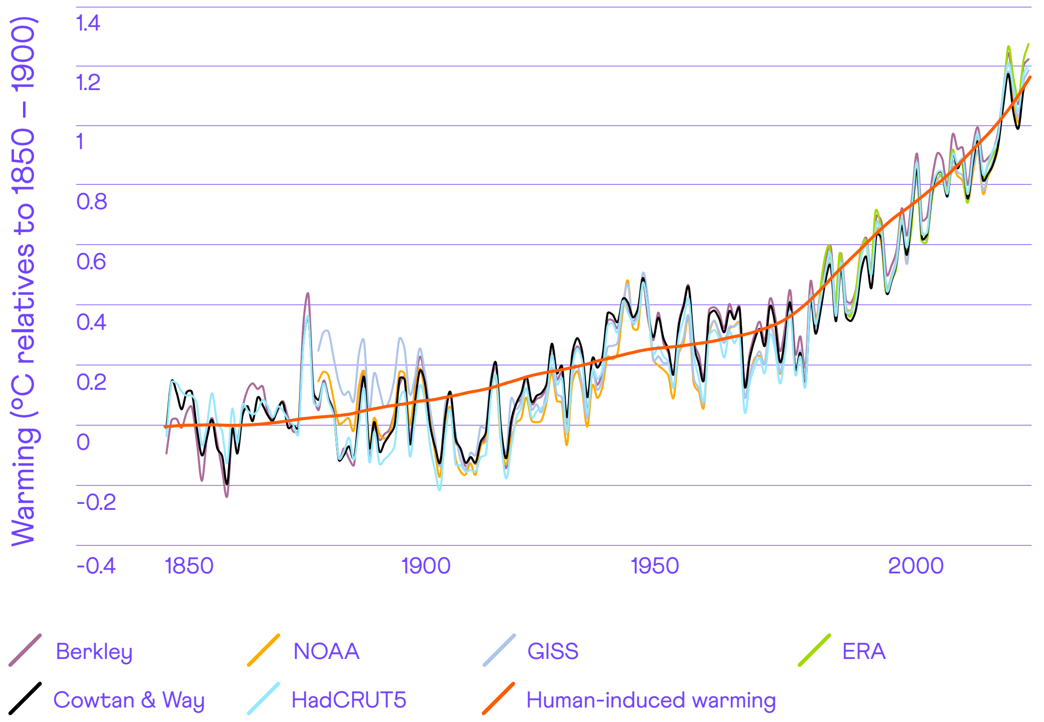
This observed increase in global average temperature is also driving wider changes in the climate around the world:

- Global sea-level has risen by about 20 cm since the start of the 20th century and the oceans are becoming more acidic. These ocean conditions are unprecedented in at least the last 65 million years.[4]
- The heat stored in the planet's oceans continues to rise. Temperatures are rising in the deep ocean (below 2 km depth) with more than 90% of the extra energy trapped by greenhouse gases ending up in the oceans.
- Around the globe, more frequent heatwaves are occurring in most land regions, global-scale extreme precipitation has intensified, and climate change has increased heat-related mortality.[5]
- Patterns of water availability are changing due to melting land-ice and shifting rainfall in some parts of the world. Glaciers have been melting across the world due to climate change, affecting runoff and downstream glacier-fed water availability.[6]

Impacts from these changes in global climate are becoming clearer and their consequences for people and ecosystems more apparent. This is particularly so in the tropics where the climate is less variable and climate change more rapidly leads to unprecedented weather conditions.[7]

[*] Based on the linear trend in human-induced warming over the last decade (2011-2020) and rounded to nearest 0.05ºC per decade.

Figure 1.1 Global average surface air temperature change



Source: CCC analysis
Notes: Each thin line represents a different global temperature dataset. The NOAA, GISS and ERA datasets are expressed relative to 1850 - 1900 using the anomaly over the 1961-1990 period from the HadCRUT5 dataset. Human-induced warming is taken from globalwarmingindex.org.

Observed climate change in the UK over recent decades

Changes in aspects of the UK's weather and climate are already being seen.

Observations document several clear recent trends in different aspects of the UK's weather and climate (Figure 1.2):

- **Warmer average temperature.** The UK's annual average temperature has risen by around 0.6°C above the average of the 1981-2000 period, consistent with a trend of around nearly 0.3°C per decade since the 1980s. The signal of human-induced warming above 1850 -1900 in the UK is estimated to be similar to the global average.[8]

- **Higher average sea levels.** The level of the seas around the UK has risen by around 6.5 cm since 1981-2000. They are currently estimated to be rising at around 2.5 cm per decade.*

Temperature extremes in the UK have changed. Heatwaves and warm summers are now significantly more likely than a few decades ago.

- **Changed temperature extremes.** The average duration of heatwaves (periods in which there are more than three days in excess of 25°C) has increased over time.[9] For the UK as a whole, summers as hot as in 2018 (the joint warmest summer on record) are currently expected to occur in up to

* Based on a linear trend over the past 20 years.

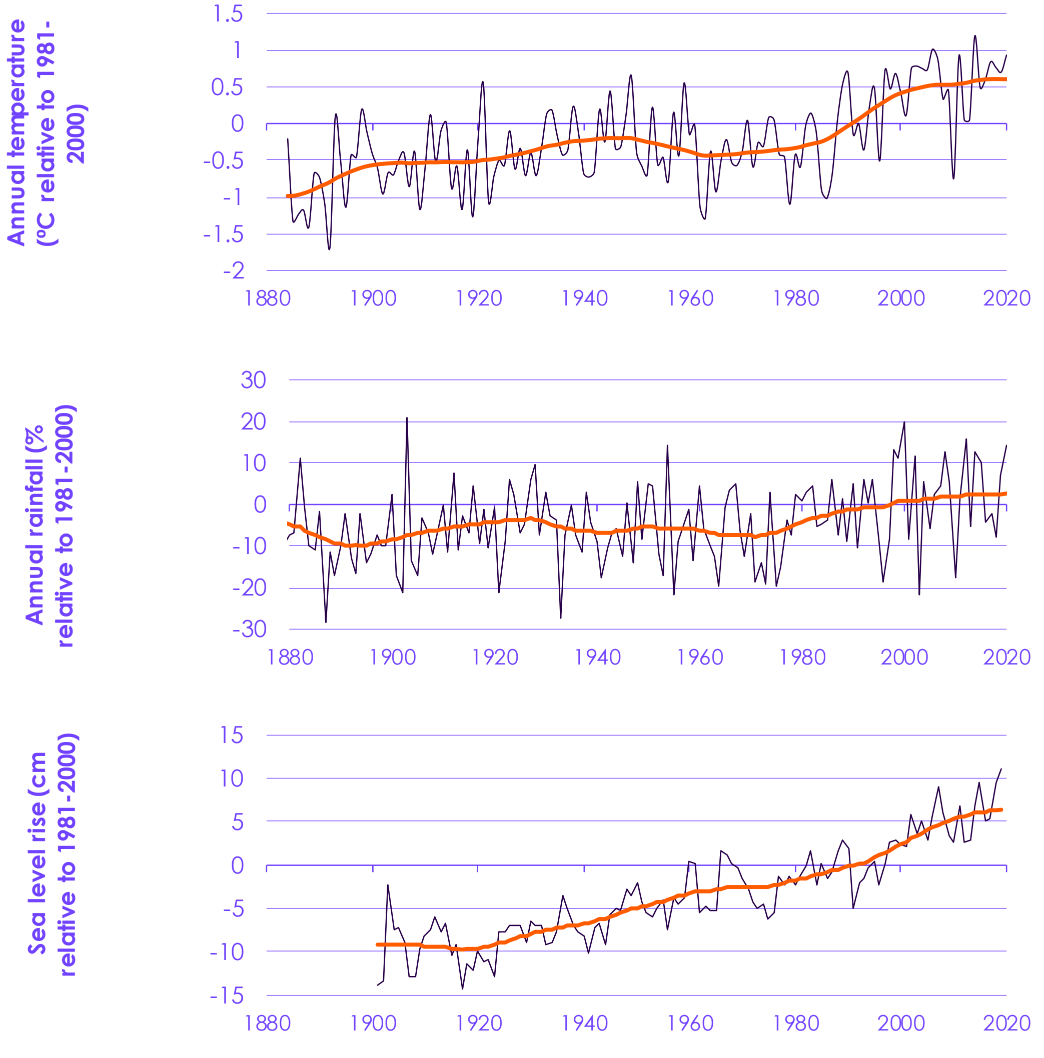
25% of years, whereas they would be expected in less than 10% of years only a few decades ago.[10] Cold extremes have also decreased in frequency and intensity.

- **Changed precipitation extremes:** Metrics for heavy rainfall generally show an increase in very wet days across the UK. However the expected signal associated with human-induced climate change remains hard to distinguish from the large interannual variability in the observational record at a UK-wide scale.[11] Extreme event attribution studies indicate that human-induced climate change has increased the likelihood of some observed UK precipitation extremes linked to significant flooding impacts.[12]

Further changes in the UK's climate linked with global climate change will emerge over coming years.

Evidence of the effects of global climate change in these and other aspects of the UK's weather and climate is expected to grow over the coming years as human-induced warming continues to increase and as observational records get longer.

Figure 1.2 Observed changes in aspects of UK climate



Source: CCC analysis; HadUK-Grid dataset, Kendon, M. et al. (2020) State of UK Climate 2019. *International Journal of Climatology*, 40 (S1), 1-69.
Notes: Annual data is shown in all panels. The orange line is a moving 29-year triangular averaging window (reflecting at ends of timeseries) in all panels.

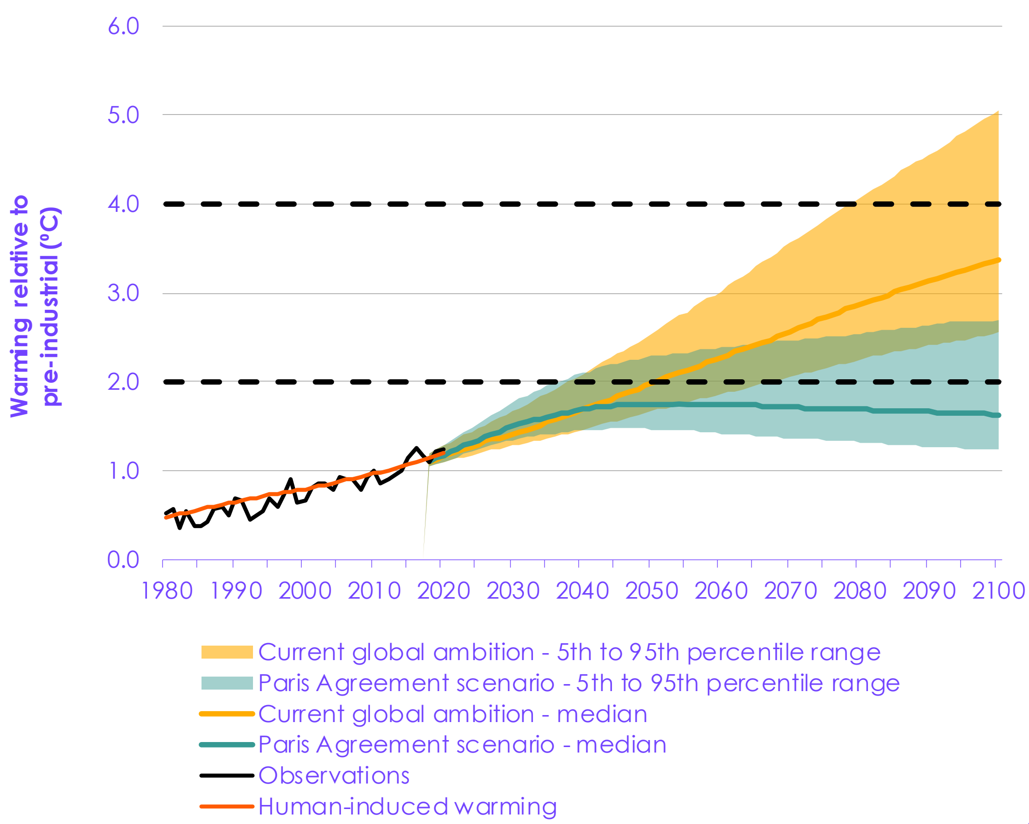
Further change in aspects of the UK's climate is inevitable – no matter how global greenhouse gas emissions change in future.

Future changes in UK weather and climate depend on both the amount of future global greenhouse gas (GHG) emissions and on how the climate responds to these emissions. Although the latest evidence indicates that there is expected to be no significant future global warming 'locked-in' from past emissions, further changes in the global and UK's climate by 2050 is inevitable as the world will take several decades, at the very least, to reach Net Zero emissions.[13] Longer-term (post-2050), changes in the UK's climate will largely depend on how rapidly global emissions are reduced and then brought toward Net Zero.

Changes in global temperature over the next few decades do not significantly differ across the range of possible global emissions pathways. Countries around the world are currently strengthening their commitments to reduce emissions ahead of the next UN climate change conference, COP26, scheduled for November 2021. A similar range of possible levels of global warming over the next several decades is expected, irrespective of whether global decarbonisation ambition continues at current levels or is successfully strengthened to align with global emissions pathways expected to achieve the Paris Agreement (Figure 1.3).

There is little difference between different pathways for global emissions for the range of global temperature changes expected in the near-term.

Figure 1.3 Global temperature projections under a range of global emissions reduction ambition



Source: CCC (2020) The Sixth Carbon Budget: The UK's path to Net Zero.
Notes: This 'current global ambition' scenario is one in which current global commitments for emission reductions in 2030 are achieved with a similar decarbonisation effort maintained over the rest of the century. Pledged Net Zero targets are not assumed to be met in this scenario. The Paris Agreement scenario sees global emissions fall rapidly from 2020 with Net Zero CO2 emissions reached around 2060 and is estimated to be consistent with keeping (central estimate) warming 'well-below' 2°C above preindustrial levels. The range of climate outcomes shown here are based on the recent World Climate Research Programme estimate and include a median estimate of additional climate feedbacks not typically included in current climate models (e.g. permafrost thawing).

Changes in the UK's climate by mid-century

Expected changes in the UK's climate by 2050 are also (largely) independent of the pathway of global emissions.

Expected changes in the UK's climate by 2050 are also (largely) independent of the pathway of global emissions. Across a range of possible future pathways for global emissions a consistent picture of expected changes in UK weather and climate emerges:*

- **Warmer and wetter winters:** By 2050 the UK's average winter could be around 1ºC warmer (0.5ºC cooler – 2.5ºC warmer uncertainty range) than it was on average over 1981-2000 and around 5% wetter (10% drier – 20% wetter uncertainty range). An increase in both the intensity of winter rainfall and the number of wet days is expected.

- **Hotter and drier summers:** By 2050 the UK's average summer could be around 1.5ºC warmer (0ºC – 3ºC uncertainty range) than it was on average over 1981-2000 and around 10% drier (30% drier – 5% wetter uncertainty range). A summer as hot as in 2018 (the joint hottest summer on record) for the UK as whole could be normal summer conditions by 2050. The temperature of the hottest days each year are expected to increase more than the average summer temperature increase. The intensity of summer rainfall (when it occurs) is expected to increase.

- **Continued sea-level rise:** The seas around the UK will continue to rise over the next three decades to 2050. By 2050 sea levels could be around 10 – 30 cm higher than over 1981-2000, depending on the specific location in the UK.†

These changes in aspects of the UK's weather and climate over the next three decades will create additional weather and climate risks. For example, wetter winters will drive up the risk of flooding whilst drier summers increase the risks of water shortages, hotter summers come with more intense heatwaves that can affect farming and human health, and higher sea levels increase the risk of coastal erosion and coastal flooding from high tides and storm surges. The risks these climate changes create are summarised in Chapter 2.

* Quantitative changes are taken across the RCP2.6, RCP4.5 and RCP6.0 scenarios from UKCP18 results, with uncertainty ranges based on the 5th – 95th percentiles given there. Changes are rounded.

† Range (in 50th percentile) outcomes across UK capital cities is given here. Climate uncertainties means that changes could range from 30 – 40 cm above 1981 – 2000 levels across capital cities under a high climate response (95th percentile).

Possible changes in the UK's climate after 2050

In the second half of the century the level of global warming is strongly dependent on the success of global efforts to reduce emissions, with a wide range of global warming levels possible.

Levels of global warming of 2ºC and 4ºC above preindustrial levels by 2100 are used as indicative of the range of possible long-term changes that could occur for this risk assessment. Beyond 2050, changes in global and UK climate strongly depend on the future trajectory of global GHG emissions (Figure 1.3). If large reductions in global emissions have been achieved by 2050 (on the pathway to Net Zero soon after) only relatively minimal changes in global temperature would occur above the level reached by 2050.[*] If however global emissions remain significantly above Net Zero after 2050 then continued increases in global temperature would occur. This leads to a wide range of possible levels of global warming by 2100.

The 2ºC to 4ºC range is a useful indicator of the spread of possible 2100 climate outcomes that can inform adaptation strategies for the second half of the century (whilst acknowledging that they do not represent the full range of possible changes).[†]

Reaching a global warming level of 4ºC by 2100 would bring significant additional climate changes in the UK.

Global warming reaching 4°C above preindustrial levels by 2100 would see significant further changes to the UK's climate beyond the changes by 2050:[‡]

- **Much warmer and wetter winters:** the UK's average winter could be around 1 - 3ºC warmer (depending on the location across the UK) than it was on average over 1981- 2000 and around 10 - 30% wetter. Wetter winters are expected due to both an increase in the number of wet days and the intensity of rainfall when it is raining.

- **Much drier and hotter summers with frequent and intense heatwaves:** the UK's average summer could be around 3 – 5ºC warmer (depending on the part of the UK considered) than it was on average over 1981- 2000 and around 20 - 40% drier. A summer as hot as in 2018 (the joint hottest summer on record) for the UK as whole would now be significantly cooler than the average summer. Over 50% of days could have 'very high' fire risk in the peak months of the summer.[14]

- **Much higher sea levels:** UK sea levels could continue to rise reaching around 55 – 80 cm above their levels in 1981-2000 (depending on the location across the UK).[§]

These changes would see an increase in the rate of climate change compared to the recent decades. The faster rates of climate change can also create additional risks in of themselves, particularly on ecosystems.

[*] In the most ambitious global emission pathways global net negative CO_2 emissions are achieved after 2050, reducing the level of global warming in 2100 below that in 2050. However, the plausibility of the very large levels of net negative emissions needed to achieve this is uncertain.

[†] Global average warming can be kept below 2ºC above 1850 - 1900 levels if global emissions can be cut sufficiently rapidly on a path to reaching global net-zero CO_2 emissions around 2050. Similarly, the worst cases of high climate and Earth System feedbacks under continued high global emissions could see warming exceed 4ºC above 1850-1900 levels by 2100. The falling costs of low-carbon technologies, and increasing global commitment to addressing climate change, is making these high-warming outcomes less likely over time but they remain possible and relevant for consideration in climate risks assessments.

[‡] Quantitative changes are taken from Gohar, L. et al. (2018) *UKCP18 Derived Projections of Future Climate over the UK*.

[§] Sea level rise could be significantly higher (>1 metre in the south of the UK) at the high end of climate response.

Changes in UK climate beyond 2050 would be much less if global warming is kept to below 2°C above preindustrial levels by 2100.

A 2°C rise in global temperature above preindustrial levels by 2100 would see relatively small additional changes in many (but not all) aspects of UK climate beyond those already expected by 2050. Further changes in summer and winter temperature and precipitation would be relatively limited (Table 1.1) – however UK sea levels would continue to rise through to 2100 (and beyond) even under a stabilisation of global warming at 2°C above preindustrial levels or below.

Table 1.1
Observed and projected changes in UK hazards due to climate change

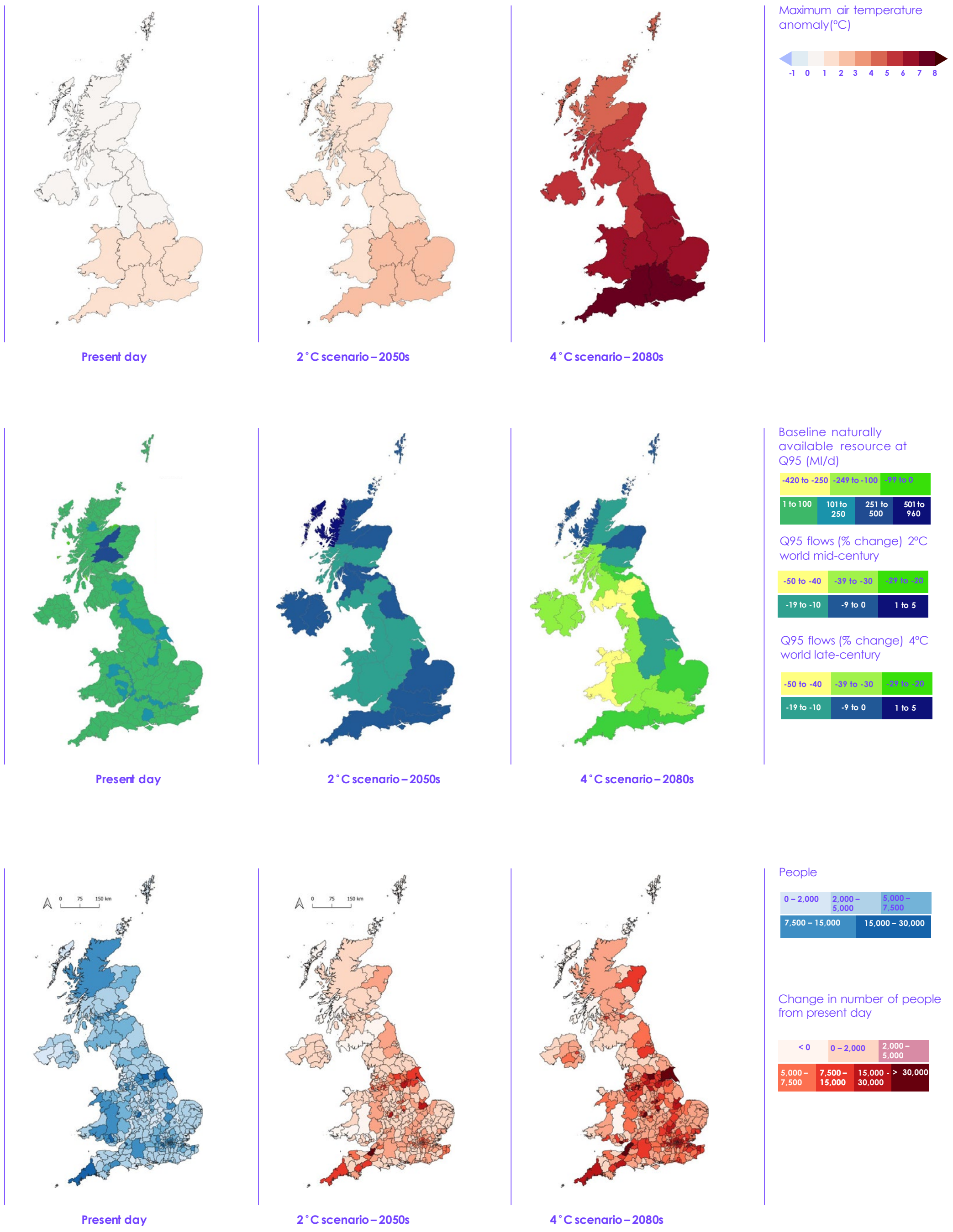
Observed change	Expected change by mid-century	Global warming of 2°C above preindustrial levels by 2100	Global warming of 4°C above preindustrial levels by 2100
0.6°C from 1981 – 2000	**~1.3°C** from 1981 – 2000	**~1.5°C** from 1981 – 2000	**~3°C** from 1981 – 2000
10 – 25% chance of a '2018 summer', up from <10% a few decades ago	**~50%** chance each year	**~50%** chance each year	**>>50%** chance each year
0 no significant long term trend	**~10%** drier than over 1981 – 2000	**~15%** drier than over 1981 – 2000	**~30%** drier than over 1981- 2000
0 no significant long term trend	**~5%** wetter than over 1981 – 2000	**~5%** wetter than over 1981 – 2000	**~20%** wetter than over 1981 – 2000
0 Some increase, but no significant long-term trend	**~10%** increase	**~20%** increase	**~50%** increase
~6.5cm above 1981-2000	**10 – 30cm** above 1981-2000	**25 – 45cm** above 1981-2000	**55 – 80 cm** above 1981-2000

- Average annual UK temperatures
- 'Hot summer' occurrence
- Average summer rainfall
- Average winter rainfall
- Heavy rainfall
- Sea level rise

Notes:
* Changes to mid-century are taken from across RCP2.6, 4.5 and 6.0 scenarios for UKCP18 probabilistic projections (50th percentiles).
** Changes are taken from the 50th percentile of the RCP2.6 probabilistic projections from UKCP18 averaged over 2081 – 2100 (approximately consistent with a global warming level of 2°C above preindustrial levels.
*** Estimated from the UKCP18 Derived Projections for a global warming level of 4°C above preindustrial levels using the median model realisation. Values given are indicative of the middle of the range of local changes expected across most of the UK.
Heavy rainfall is here defined as the mean of the wettest 5% in the distribution of hourly rainfall over winter. Future projections taken from Sayers et al. (2015) Projections of future flood risk for the UK.
Future sea level changes are given as a range across UK capital cities (50th percentile of projections). Future projections are taken from the UKCP18 Marine Projections for the RCP2.6 and RCP8.5 scenarios which correspond to global warming levels of 2°C and 4°C by 2100 respectively (50th percentiles). Change to 2050 are the range of 50th percentile change across UK capital cities and the RCP2.6 – RCP8.5 scenarios.
Throughout this table values are rounded. Climate response uncertainty means that a broader range of changes are possible around the central estimates presented in this table.

These changes in aspects of the UK's weather and climate are the fundamental drivers of the direct climate risks that the UK will face in future. Throughout this independent assessment, the framing of global warming levels of 2°C and 4°C above preindustrial levels by 2100 has been used to turn these projected changes in aspects of weather and climate (e.g. reduced summer average rainfall) into the climate hazards (e.g. low river flows) that create risks to people and ecosystems (Figure 1.4).

Figure 1.4 Projections of UK climate hazards



Source: a) Maximum summer temperature - UKCP18 user interface, b) Low flows - HR Wallingford et al. (2020), c) Flooding (all source) provided by Sayers et al. (2020)

Notes: a) Probabilistic projections for the 1-year average change in summer maximum air temperature from 1981-2000 baseline for 2021, 2050 (RCP2.6 50th percentile) and 2080 (RCP6.0 90th percentile) b) maps of changes in low flows (Q95 indicator) for the present day, and then % change in the 2050s (2C scenario) and 2080s (4C scenario). Note that a larger area around Northern Ireland has been included in the future projections as the analysis has used the UKCP18 river basin areas for the future projections but not for the baseline. c) Present day number of people exposed to significant flood risk (river, coastal and surface water flooding combined), and then the absolute change in number of people from the present day for 2050 (2C scenario) and 2080 (4C scenario).

Implications for adaptation policy

Several principles relevant to adaptation policy can be identified from our current understanding regarding possible future UK climate.

Several conclusions relevant to climate adaptation can be drawn from the current understanding of how the UK's weather and climate may change over the coming decades:

- **Continued change in the UK's climate should be expected.** In all scenarios for global emissions the UK's climate continues to change over the coming decades. Only under the very lowest possible values for climate sensitivity is there close to no future change in UK climate. Assuming a static UK climate at today's levels does not provide a good basis for decision making.

- **Changes in the UK's climate out to 2050 are largely insensitive to the trajectory of global greenhouse gas emissions.** Changes in the UK's climate to 2050 are not strongly sensitive to how successful the world is in cutting emissions. This means that there is significantly more certainty in the range of UK climates that could occur by 2050 than over longer time horizons (e.g. by 2100). This can help focus decision making for policy, assets and infrastructure that have a lifetime of only a few decades on a more constrained set of expected UK climates than for the assets and infrastructure that will also need to be robust to weather and climate significantly beyond 2050.

- **Very long-lasting policy and investment decisions being made today need to consider a wide range of changes in climate for the second half of the century.** Some investments being made today (e.g. housing new build) is expected to still be around in 2100. Future pathways of global emissions have a strong effect on the range of possible climates after 2050. Using a range of outcomes spanning at least 2ºC to 4ºC above preindustrial levels by 2100 (as in this Independent Assessment) can help to assess adaptation needs over these time horizons. Building-in flexibility mechanisms to enable the targeted long-term level of global warming resilience to be adjusted over time as more is learnt about plausible futures of global emissions and climate response can support effective decision making for these longer time horizons.

These principles can help guide effective decision making over different timescales despite the uncertainty regarding the magnitude of changes that will be experienced in the UK's future weather and climate.

Considering climate variability, changes in weather extremes and low-probability climate outcomes are important for risk assessments.

The previous section described the expected changes in the average climate conditions of the UK under different possible futures for global emissions and different time horizons. This section considers three additional aspects, climate variability, climate extremes, and low-probability outcomes that are also important for assessing future UK weather and climate risks.

Climate variability and climate extremes

Variability in weather from year-to-year will continue to be very important for future weather and climate risks.

The UK's weather and climate are naturally variable today and will continue to be in the future. Individual years and seasons can be significantly warmer or colder than the average climate conditions as well as significantly wetter or drier. Cycles of average conditions of the Jet Stream over the North Atlantic can also drive large variations in the UK's climate over multi-year periods. Adequately preparing for future climate and weather hazards means building resilience to the expected year-to-year fluctuations in the UK's weather and climate as well as to the range of possible average conditions.

Maintaining resilience to individual years that could be very different from the expected future average is important for climate adaptation.

Incorporating climate variability and climate extremes into adaptation planning is important for multiple reasons:

- **Individual years could still see conditions opposing the long-term average trend.** Climate variability in the UK means that, for example, total rainfall in an individual future UK summer could still be significantly greater than typical over the recent past despite drier summers expected on average (Figure 1.5). Whilst preparing for more hotter and drier summers on average, it is therefore important that resilience to individual summers that are significantly wetter and cooler than the recent average is maintained.*

- **The frequency of damaging UK weather patterns may shift due to global climate change.** Evidence from new modelling produced for the latest UK climate projections indicates future UK winter weather may be dominated more often by weather patterns associated with wetter, wilder and windier winter weather, particularly over western parts of the UK. This would bring increases in flooding risks as well as strong winds and waves.† Possible shifts in the frequency of different patterns of UK weather should be factored into effective adaptation planning as this evidence base becomes more robust.

- **Changes in climate extremes may look different to changes in the average climate conditions.** Many climate risks are driven by changes in weather extremes (e.g. flash flooding is driven by the intensity of rainfall over the period of a few hours). At the UK-wide scale the chance of a summer as hot as in 2018 (the joint warmest UK summer) rises to around one in every two years by 2050 from up to one in every four today.

* This also applies to other aspects of the UK's weather and climate, such as winter temperature and precipitation, where individual winters in future could still be colder and drier than over the recent past despite a shift to wetter and warmer winters on average.

† Detail is provided in Chapter 1 of the CCRA3 Technical Report. Slingo, J. (2021) Latest Scientific Evidence for Observed and Projected Climate Change. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.

The temperature of hot summer days is also expected to warm more than the summer average temperature. Although summers are expected to be drier on average, the intensity of rainfall when it does rain is expected to increase significantly in summer, with the possibility of intense localised rainfall extending into the autumn – raising the risks of flash flooding and extending the duration of the year in which it could occur.

Insights from high-resolution modelling suggest that increases in climate extremes might be larger than in coarser resolution models.

It is necessary to go beyond average changes to fully understand the extent of the hazards and the range of outcomes that resilience needs to be built for. Important new insights on the extent of this variability is now available from new high-resolution projections for the UK that suggest that some aspects changes in UK extremes may be larger than expected from coarser-resolution modelling (Box 1.1).

Box 1.1
Insights from high-resolution modelling for future UK climate

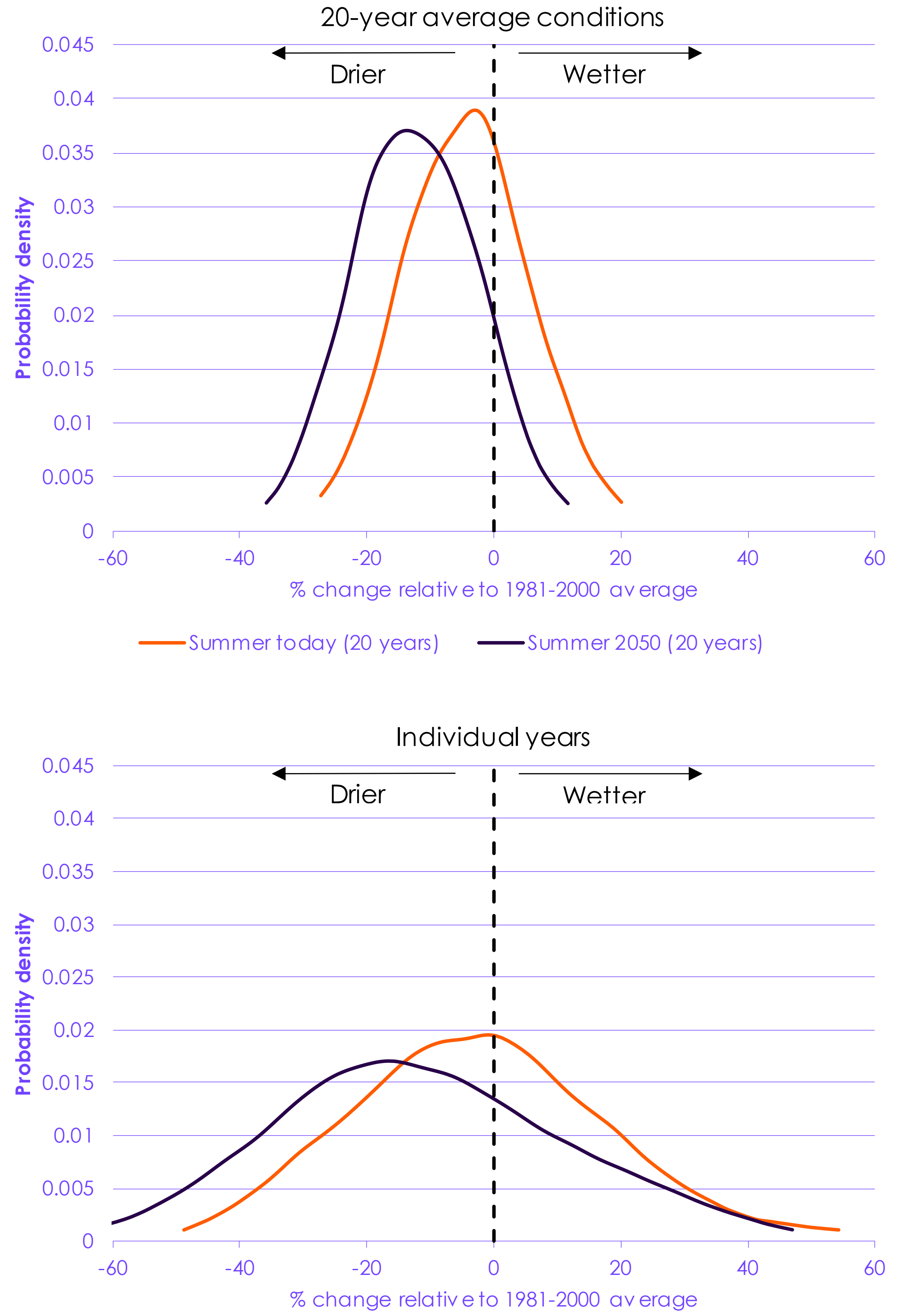
The latest UK climate projections (UKCP18) include, for the first time, a new set of high-resolution projections produced using a climate model with a resolution of 2.2 km over the UK. This resolution is the same used in weather forecast models and allows convection (the vertical movement of air) processes relevant to the formation of clouds to be resolved within the model. These processes are particularly important for representing intense rainfall events that occur over just a few hours and can lead to flash-flooding. These simulations improve the ability to represent how rainfall varies day-to-day and hour-by-hour across the UK as well as the representation of the UK's average climate today. This high-resolution modelling has been used to explore possible changes in the UK's climate under a very high global emissions future. There are a number of relevant differences to lower-resolution models:

- **Increases in winter rainfall are significantly larger than in lower resolution models:** Changes in winter total rainfall in convective-permitting models can nearly twice as large as in modelling with a resolution of around 10 km. This occurs due to a larger increase in the number of days with rainfall than in the lower resolution models, and possibly due to better representation of convective rainfall moving inland.
- **Larger increases in intense summer rainfall:** Both convection-permitting and coarser resolution models project summers to be drier overall in future, but project heavier rainfall when summer rainfall does occur (wet days are projected to become less frequent overall). The increase in the intensity of summer rainfall is more pronounced in the convection-permitting models – with potentially increased risks of summer flash-flooding.
- **More intense temperature extremes:** The higher-resolution projections from the convection-permitting model show that it is more likely to exceed high temperature thresholds in summer (e.g. 40ºC) than in lower-resolution projections. This is due to the improved representation of urban heat island effects within the higher resolution models. More frequent exceedance of these high-temperature thresholds can increase the risks of heat-related mortality.

These new high-resolution projections are an important new resource for understanding future UK weather and climate risks. The differences outlined above provide a compelling case that higher resolution projections may offer a more accurate estimate of how UK climate extremes may change in the future, with larger changes than in more conventional resolution climate models. These projections do however need to be set within the context of other strands of UKCP18 which consider a broader range of uncertainties, for example a range of global simulations providing boundary conditions to the UK model covering a wide range of climate sensitivities.

Source: Kendon E. et al. (2019) UKCP Convection-permitting model projections: Science report; Slingo, J. (2021) Latest Scientific Evidence for Observed and Projected Climate Change. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London.

Figure 1.5 Probability density functions for future and current UK summer total precipitation for 20-year averages (top) and individual years (bottom)



Source: UKCP18

Notes: Future conditions (for 2050) are shown under the RCP4.5 scenario. A similar qualitative picture is expected for other possible futures for global greenhouse gas emissions and for other climate variables (e.g. temperature) and seasons.

Low-likelihood, high-impact outcomes

Low-probability climate changes outside of the main envelope of climate projections could still occur and may have a large impact in the UK.

'Low-likelihood high-impact' outcomes are weather and climate changes that, whilst possible, are thought to be sufficiently unlikely that they don't feature within the standard range of projections for the UK's future weather and climate, but nonetheless can have large impacts if they were to occur. For examples, an abrupt collapse in the Atlantic Ocean currents this century is thought unlikely but would have a large impact on the climate of Western Europe including the UK. The CCRA Technical Report has considered the low-likelihood, high-impact events that may occur over the course of the rest of the century and the climate risks they could create in the UK.*

Low-likelihood, high-impact outcomes can be classified into three groups:

- Changes that have a direct effect on the UK's local weather and climate – for example: collapse in the Atlantic Overturning Circulation, or large shifts in the position of the North Atlantic Jetstream.
- Changes involving melting of land ice, affecting sea level rise impacts in the UK and worldwide – for example collapse of the Greenland or West Antarctic ice sheets.
- Changes that provide a large feedback on carbon or other biogeochemical cycles that would act to significantly amplify global warming – for example significant and rapid greenhouse gas release from thawing permafrost.

Considering possible low-probability outcomes through 'what-if' scenarios can help understand the risks they pose to the UK and what actions could be taken to reduce risks.

If these low-likelihood high-impact outcomes were to occur, there would be significant implications for the climate and weather risks that the UK would face (Table 1.2). For many of these low-likelihood high-impact events further research is required to better understand the mechanisms underlying these changes, their plausibility, and the effects they would have if they were to occur. 'Storyline' or 'what-if' scenarios (which consider the implications of a particular event occurring without trying to assess how likely this would be) can be useful ways to help understand the risks that low-likelihood high-impact events would pose to the UK. Monitoring systems that may be able to identify early signals of these events occurring could be a useful part of understanding and addressing these risks.

* These low-likelihood high-impact outcomes (also known as earth-system tipping points, and sometimes as climate tipping elements) are described in Chapter 1 of the Technical Report and where evidence is available, summarised in relation to each risk and opportunity in Chapters 3 – 7. A special report on 'Effects of Potential Climate Tipping Points on UK Impacts' has also been produced for CCRA3 Technical report.

Table 1.2
Risks arising from low likelihood, high impact events

	Types of climate change that could occur	Resulting risks
Extreme changes to regional and UK climate	• Abrupt collapse of the Atlantic Meridional Overturning Circulation (AMOC), leading to reduced European warming, reduced summer rainfall, increased winter storminess over and above projected trends in Europe • Changes to the Jet Stream due to Arctic warming, leading to persistent and amplified 'waviness', leading to changes to UK weather patterns	• Widespread and large reductions in arable farming output • Severe depletion of groundwater reserves and severe summer drought
Land ice melt-accelerated sea level rise	• Accelerated loss of Antarctic and Greenland Ice Sheets, leading to sea level rise of over 1 m and up to 2 m by 2100 (and much more beyond)	• Extreme coastal flooding and widespread loss of viable coastal communities
Carbon and biogeochemical feedback cycles – accelerated global warming	• Large and rapid release of carbon from permafrost thawing significantly amplifying the level of global warming so that it reaches above 4°C from preindustrial levels by 2100 • Large reduction in the carbon uptake by the biosphere (oceans, Amazon, northern boreal forests), leading to abrupt ecosystem collapse and accelerated warming	• Major increases in heat-related deaths and losses to well-being and productivity • Major increases in cooling demand

High-impact events can also occur within the standard range of climate outcomes.

The CCRA3 Technical Report also highlights potential extreme events that could 'tip' particular systems into severe impacts. These outcomes could be possible even within the standard range of UK climate changes outlined in the Technical Report. Some examples of these changes are:

- Consecutive seasons with stable atmospheric circulation patterns driving a very dry summer followed by a dry winter; this could lead to severe drought and soil moisture deficits, drought orders, major impacts on biodiversity, agriculture and forestry, with consequent disruptions and economic losses to agriculture, water supply and the natural environment.

- A warm autumn followed by a wet spring, leading to severe drops in agricultural harvests (as was seen in France in 2016). The East of England is at particular risk from such events.

- Changes in atmospheric circulation patterns leading to increased UK storminess with severe impacts on the coast, such as experienced in winter 2013/14 leading to extreme flooding and erosion.

- Successive storms (e.g. Storm Ciara and Dennis in 2020) where the second storm hampers recovery from the first and leads to even greater human health, environmental and economic impacts.

- The risk of novel vector-borne diseases reaching the UK and spreading rapidly even in the current climate with related human health costs and productivity impacts.

These examples highlight the potential for instances of climate variability within the current and expected envelope of possible UK climate changes, to drive potentially very high impact events on specific systems.

Endnotes

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[3] IPCC (2018) Special Report on Global Warming of 1.5°C - Chapter 1: Framing and context.

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