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Contents

Tables

Figures

1. Introduction

1.1 Climate background

The UK climate is changing, with warmer wetter winters and hotter drier summers expected in the future. Our current best estimates put the localised rate of warming at approximately 0.25°C per decade [1], a pace of change which challenges our ability to quantify risks in the current climate based on observed historical patterns. Looking forward multiple decades into the future, the potential exists for even more dramatic shifts due to a range of critical thresholds or “tipping points” being exceeded, leading to abrupt changes that may be irreversible.

Climate models are an essential tool in understanding what changes the future may bring and have been tentatively used to make probabilistic projections of future weather patterns. However, this approach to defining probabilities of future events remains controversial. The current generation of global models face difficulties in accurate representation of some large-scale atmospheric processes, including those associated with tipping point mechanisms, such as the Atlantic Meridional Overturning Circulation (AMOC). They are also typically run at spatial resolutions which struggle to capture, or do not capture at all, the interplay between large-scale processes and smaller-scale weather events that produce extreme conditions.

For the UK, the uncertainty in the projections of future extremes is accentuated by the important role played by the North Atlantic Jet Stream, which has been particularly challenging to capture in global models. In addition, long-term natural variability in the positioning and strength of the Jet Stream tends to mask the underlying climate change trends, reducing our ability to confirm the extent to which changes have already taken place. Despite this deep uncertainty, and indeed because of it, consideration of high-end scenarios for future climate extremes is essential in making good planning decisions for critical national infrastructure.

1.2 Guidance for dutyholders in the nuclear industry

Nuclear licensed sites are designed to withstand meteorological and hydrological hazards with a one in ten thousand chance of being exceeded each year. In characterising these events, ONR expects dutyholders to include the “reasonably foreseeable” effects of climate change. In practice, this tends to assume a future climate which is broadly similar to our existing one, but in which some elements – such as frequency and duration of heatwaves – have become elevated. However, there is also an expectation to consider the impact of more extreme scenarios, which are deemed to be plausible but for which a reliable probability cannot be estimated.

In its Overarching National Policy Statement for Energy (EN-1) [2], the UK government sets out the following expectation:

“The Secretary of State should be satisfied that there are not features of the design of new energy infrastructure critical to its operation which may be seriously affected by more radical changes to the climate beyond that projected in the latest set of UK climate projections, taking account of the latest credible scientific evidence…”

Such scenarios, referred to as “credible maximums” in ONR’s guidance, may not be reasonable to design for at the outset. Instead, a managed adaptive approach can be used, in which it is demonstrated that practical options are available should it become clear that the scenario is becoming more likely, and that these options could be implemented in a timely manner.

Expectations for assessment of credible maximums are set out in ONR’s Safety Assessment Principles [3], the External Hazards Technical Assessment Guide (TAG 13 [4]) and joint regulatory guidance – Use of UK Climate Projections 2018 Position Statement and the Principles for Flood and Coastal Erosion Risk Management [5].

The guidance defines credible maximum scenarios as *“peer-reviewed, high-end, plausible scenarios of climate change”*. Their purpose is to carry out “sensitivity testing” and is separate from analysis of design basis events. Sensitivity testing in this context is intended to satisfy the following expectations:

1. Dutyholders[1] should demonstrate that it is *possible to maintain safety* for credible maximum scenarios.
2. Dutyholders should identify *the potential effects* of the credible maximum scenarios, for example, to not foreclose modifications needed to enhance resilience in the future. They may take a *managed adaptive approach*, as it is recognised there is *large uncertainty* with future credible maximum scenarios.
3. Dutyholders are expected to use *the most up to date* credible maximum scenarios in any new analysis of climate change.

ONR's guidance is intended to be non-prescriptive, placing the onus on dutyholders to justify their choices in meeting these requirements. A widely recognised set of credible maximum scenarios for the UK have been developed under the umbrella term "the H++ scenarios". These scenarios form part of the official UK Climate Projections (UKCP18) guidance on assessment of plausible upper bounds to future extreme events.

Further details on the process used to develop H++ scenarios themselves is given in the following section, along with other important sources of information on future climates.

2. Exploring plausible future extremes

2.1 The Coupled Model Intercomparison Project

As we progress through the current century, it is expected that we will increasingly see climatic excursions that fall outside of the range of human experience. Two of the main approaches that can inform our understanding of how plausible upper bounds for a range of hazards may change under these conditions are:

- Palaeoclimatology, in which we seek evidence from the distant past, which can shed light on what might be possible in future through comparison with periods when the Earth's climate was substantially different – for example, we can understand the upper limits of sea level rise based on physical evidence from periods where the poles were ice free.

- Climate projections, in which we seek to simulate how our climate will behave in future using computer models, which aim to provide, as far as possible, a realistic mathematical representation of the global climate system. These models are then perturbed, principally by imposing a range of carbon emissions scenarios, to explore how the climate system will respond.

Coordination of international efforts in continuous improvement of global climate projections is carried out under the Coupled Model Intercomparison Project (CMIP). To date, outputs from CMIP have been delivered in five distinct phases (see Figure 1) with CMIP6 being the latest released in March 2023 and a further phase (CMIP7) underway. The main purpose of each phase has been to support the periodic IPCC (Intergovernmental Panel on Climate Change) Assessment Reports, though the project is gradually evolving to deliver a more continuous output.

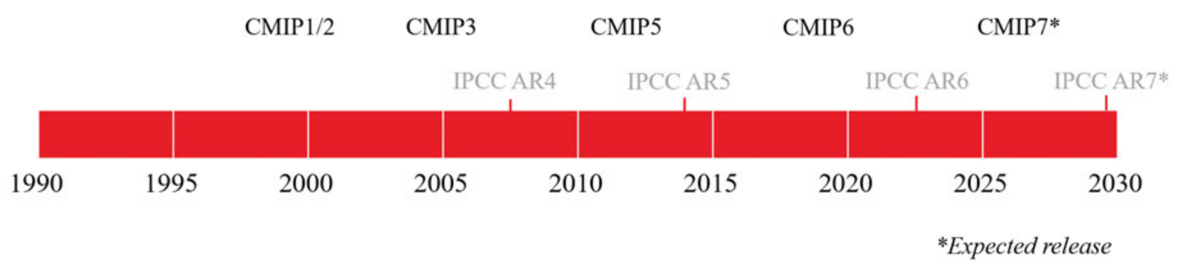

Figure 1: Timeline for publication of CMIP model data.

[1] The term 'dutyholder' refers to nuclear site licensees, potential licensees, current and potential environmental permit holders for radioactive waste disposal, applicants for planning consents and Requesting Parties undergoing the Generic Design Assessment process.

IPCC Assessment Report 7 (AR7) is expected to feature an increased focus on targeted exploration of climate tipping points. It is scheduled for release in late 2029 and will include a chapter on high-end scenarios: “Chapter 8: Abrupt changes, low-likelihood high impact events and critical thresholds, including tipping points, in the Earth system” [6]. Release of CMIP7 models is expected before the AR7 synthesis report date in 2029.

2.2 UK Climate Projections

As part of the Hadley Centre Climate Programme, the UK Met Office produces a range of datasets and tools to help decision makers assess their exposure to climate change risk. UK planning policy states that [2]:

“The Secretary of State should be satisfied that applicants for new energy infrastructure have taken into account the potential impacts of climate change using the latest UK Climate Projections.”

In the last 20 years, two generations of official UK Climate Projections have been produced, with no confirmed plans currently in place to produce a third. Both generations are named according to the year of publication, with the first being UKCP09 (2009) and the second UKCP18 (2018).

The projections are produced from a selected subset of global CMIP models, which are then mapped onto a higher resolution grid using a process known as dynamical downscaling, whereby the results of a large model with a coarse spatial resolution are used to enforce conditions along the boundary of a smaller, higher resolution model. This allows smaller scale physical process to be resolved but carries through any errors or biases that are present in the larger model. Care has therefore been taken to select the global models that provide the best representation of the UK climate.

UKCP18 has largely been produced through downscaling of CMIP5 data, along with data from HadGEM3-GC3.05, which is closely related to the model the Met Office contributed to CMIP6. An initial set of twelve models were selected based on their ability to represent key features important for the UK climate, such as circulation patterns and temperature, as well as a diversity in future changes, especially during summer. Four new models have now been added as of December 2024.

There are similarities with UKCP09, which is based on CMIP3 model data, such as the use of probabilistic projections at 25km resolution. However, the modelling of potential extreme scenarios has improved with UKCP18 through the use of higher spatial resolution (12km & 2.2km) downscaling models and provision of sub-daily (hourly and 3-hourly) time series, which can better describe the peak intensity of short duration weather events.

The 2.2km local projections are downscaled using what is known as a “convection-permitting” model, meaning smaller scale, thermally driven weather features are simulated directly. This allows climate effects over the UK which were not as well addressed in UKCP09 or other climate datasets to be captured, such as the influence of mountains, urban heat islands and coastal cooling.

UKCP18 also offers exploratory sea level rise data up to 2300, rather than the more typical 2100 for UKCP09 sea level rise projections and other climate variables within UKCP18. This allows exploration of credible maximum scenarios further into the future, aligning to expected asset lifetimes in the nuclear industry.

2.3 UK Climate Change Risk Assessments

UK Climate Change Risk Assessments are mandated every five years by the Climate Change Act (2008) and are used to inform national adaptation policies. The H++ scenarios were originally developed to inform the second such assessment, which was published in 2017. At the time of writing, the draft technical report for CCRA4 [1] has just been released for public comment, in advance of the official publication date in 2027.

CCRA3 did not provide an update of the H++ scenarios but was informed by early analysis of then newly published data from the CMIP6 models. The CCRA3 technical report [7] observed that, even for the latest generation of climate models, accurate simulation of the North Atlantic Jet Stream remains a challenge, impacting our ability to confidently project trends for a wide range of hazards, particularly those associated with persistent high pressure systems during summer.

Another important observation was the increased likelihood of earlier than expected slowdown or collapse of the Atlantic Meridional Overturning Circulation (AMOC) ocean circulation system, which would lead to a sharp decrease in temperatures in the UK. System collapse by the middle of the current century may now be considered plausible (CCRA3 section 1.8.1 [7]).

As part of their recommendations, the authors discuss the need for an "event-based storylines" approach to help explore the risk due to credible maximum scenarios. The authors note the following regarding this approach [7]:

"The conventional approach to representing uncertainty is through probabilistic approaches, based on ensembles of climate model simulations. One consequence of this is that the low-likelihood, high impact events that may pose the greatest risks are difficult to isolate and factor into a risk assessment. An alternative approach is emerging called event-based storylines. Event-based storylines are physically self-consistent unfoldings of past events, or of plausible future events, with an emphasis on plausibility rather than probability…they are particularly applicable to extreme or unprecedented events whose probability cannot be quantified, but whose impacts could be profound."

Along with an updated assessment of projected future extremes and potential impact of climate tipping points, the draft CCRA4 technical report lists further development of the storylines approach as a key advance since CCRA3 and makes explicit use of it in its discussion on compound, multi-hazard risks. Compound events were only loosely considered in developing the H++ scenarios but are of potential high importance for nuclear facilities.

Further discussion of the storylines approach is given in section 2.5.

2.4 The H++ Scenarios

With the exception of sea level rise, coastal flooding and peak river flows, the primary scientific basis for the H++ scenarios was developed by researchers at the UK Meteorological Office (UKMO) and University of Reading, in support of the second UK Climate Change Risk Assessment (CCRA2). The conclusions of this work are laid out in a 2015 report (henceforth "the H++ report" [8]), which forms the main technical reference for the philosophical underpinning, methodology and outputs of the work.

The scenarios were produced using an informal expert elicitation process, in which a structured approach was used to synthesise different types of evidence, with the outcome being determined based on a mixture of quantitative arguments and expert judgment. Evidence types considered included (but were not restricted to):

- Historical observations;
- Global and regional climate projections;
- Limiting physical arguments;
- Palaeoclimatological evidence of past extremes.

Evidence was gathered and assessed on a hazard-by-hazard basis, with each scenario being expressed in different forms, depending on the constraints of the evidence upon which it is based.

The most recent national projections at the time the work was carried out were those from UKCP09, which were based on global climate projections from Phase 3 of the Coupled Model Intercomparison Project (CMIP3). The authors were also able to draw on the then recently published IPCC AR5 scientific findings and accompanying CMIP5 global models, as well as the first Met Office climate change simulations at a very high resolution of 1.5km (the CONVEX project [9]). The resulting scenarios were adopted as part of UKCP18 guidance on credible maximums.

The main hazards covered by the H++ report are:

- Heatwaves;
- Low rainfall;
- Low (river) flows;
- High rainfall;
- High (river) flows;
- Wind storms;

- Cold Snaps;
- Sea Level Rise.

Taken together, these hazards encompass a range of systemic effects related to potential changes in large scale climatic drivers, including tipping point mechanisms which may lead to regional cooling (e.g. AMOC collapse). A discussion on each hazard is provided in Section 3.

2.5 Climate Storylines

2.5.1 Overview

Climate storylines is a concept which is rapidly gaining prominence as an alternative to the traditional use of probabilistic climate change projections for exploration of credible maximum scenarios. It has much in common with the more general term "scenario analysis", which is employed in many domains to identify vulnerabilities in complex systems under extreme but realistic conditions. For example, the bi-annual Bank Capital Stress Test carried out by the Bank of England to assess banking sector vulnerability to a large-scale financial crisis or earthquake scenarios used for seismic risk management. However, in the domain of climate science, "scenario" is also used in relation to emissions pathways and the term "storyline" is preferred to avoid confusion.

The core ideas behind the concept are set out in seminal papers by Hazeleger et al. [10] and Shepherd et al. [11], which define a storyline as:

- A physically consistent unfolding of events, which can take place over short durations (e.g. a storm) or long ones (e.g. ice sheet destabilisation).
- Plausible/credible, associated with a low probability but not necessarily linked to a time frame or associated with a specific probability of occurrence.

There is also an intention that the end user of the scenario will influence its design. This allows expert knowledge about the vulnerabilities of a given system to inform the specification of the events that will be used to test its resilience.

The current Bank of England "System Wide Exploratory Scenario" is designed to address concerns resulting from specific historical events – the "dash for cash" at the onset of the Covid-19 pandemic and the 2022 UK pensions crisis. Its design is therefore informed by these events but with elevated characteristics to assess the impact of a market shock, which is faster, wider ranging and more persistent.

Climate storylines can also be informed by historical events. In 2012, major flooding occurred in northern parts of England and Wales when a slow-moving depression was intensified after interacting with a weather feature referred to as a "potential vorticity anomaly", in which a mass of air intrudes down from higher up in the atmosphere. Questions were raised after the fact as to how much worse this event could have been, which were addressed in a 2017 study [12].

Starting from a point leading up to the event, a numerical weather model was run many times, with slightly adjusted initial conditions. This process produces many "synthetic" realisations of how the event could have developed but for some minor differences in the conditions that produced it. By screening the set of synthetic events, a plausible worst-case scenario can be established. This differs from the traditional, statistical approach to defining extremes, where the output is restricted to a single parameter, such as a peak rainfall intensity, and lacks a coherent description of how the associated event developed over space and time.

2.5.2 UK and International Examples

As discussed in the preceding section, storylines have become a prominent aspect of the UK's five-yearly Climate Change Risk Assessments. A storyline approach is also used in:

- New guidance on development of high-end scenarios for sea level rise in the UK by Weeks et al [13]. This provides a framework to assess multiple high-end pathways, as opposed to the deterministic upper bound value provided with H++.
- Development of the HILL (high-impact low-likelihood) scenarios [14], which were commissioned by the Met Office as part of the UK Climate Resilience Programme.

The HILL framework defines two sets of scenarios for the UK, which, in the words of the authors *"are designed to supplement and contextualise the UKCP18 climate projections, and to meet requirements of users for plausible high-end or worst-case climate scenarios."*

The first set are the **transient scenarios** (shown in Table 1) which consider long-term climate change to 2100. The scenarios are designed to explore how the UK climate may be affected by climate system forcings and/or climate system responses which lie outside of conventional ranges represented within the current generation of climate models. They include the UK relevant tipping points identified in the Met Office seminal report [15] and in the ONR Technical Report for ONR-RRR-115 [16], for example a step change in North Atlantic Ocean circulation (e.g. AMOC) and rapid ice sheet destabilisation.

Name	Scenario	Storyline
HILL-1	Enhanced global warming	The rate and magnitude of climate change is greater than assumed, resulting in global warming in excess of 4°C above pre-industrial levels by 2100.
HILL-2	Rapid aerosol reductions	Air quality concerns result in large, rapid reduction to anthropogenic aerosol emissions, which accelerate greenhouse gas driven warming for a few decades.
HILL-3	Volcanic eruption	A major volcanic eruption ejects large quantities of aerosol into the stratosphere, cooling the earth for several years.
HILL-4	Stronger Arctic Amplification	More extreme Arctic Amplification and/or a more extreme response to it, leading to changes in the position of the jet stream and therefore UK weather and climate.
HILL-5	Ocean circulation change	A step change in ocean circulation in the North Atlantic leads to cooling across western Europe. Includes two scenarios, one which is full shut-down and one is partial.
HILL-6	Enhanced sea level rise	Accelerated ice loss from Antarctica and Greenland will substantially enhance sea-level rise.

Table 1: Storylines for each HILL Transient Scenario in Arnell et al. (2025) [14]

Other prominent international examples include:

- Various on-going international projects employ storylines to understand possible future climate and are described in the Centre of International Climate Research (CICERO) workshop (2019) [17] and American Meteorological Society (AMS) meeting summary (2022) [18]. These projects are not directly comparable with H++ and cover purposes from understanding a high-end event to stakeholder engagement in impacts.
- Storylines are used by the Royal Netherlands Meteorological Institute (KNMI) to capture the spread of future projected precipitation change with a dry trending storyline and wet trending storyline [19].
- The US Department of Energy are using storylines to engage stakeholders in research for number of high impact climate events through the HyperFACETS[2] framework [20]. The events considered include worst-case hurricane tracks, wildfires in western US, and winter windstorms.
- At a broader scale, the RECEIPT[3] project in Europe uses storylines to explore the impacts of climate change elsewhere in the world on Europe, for example the impacts on supply chains [21].

2.5.3 The UNSEEN method

Ensemble boosting is a method used to generate large samples of data from climate models, to supplement the timeline of historically observed events with synthetic ones – the flooding storyline discussed at the end of section 2.5.1 is an example of this. The UK Met Office have used a similar approach, referred to as UNSEEN (Unprecedented Simulated Extremes using Ensembles), to explore plausible bounds for a range of meteorological phenomena. The method was first explored for precipitation in the UK in 2017 [22], with further research on temperatures in 2025 [23].

The UNSEEN method has primarily been deployed based on hindcasts produced from the Met Office Decadal Prediction System, which is in turn based on the 60km HadGEM3-GC2 global coupled model. However, the method is not linked to a specific climate model and higher resolution models, such as the

[2] A Framework for Improving Analysis and Modeling of Earth System and Intersectoral Dynamics at Regional Scales
[3] REmote Climate Effects and their Impact on European sustainability, Policy and Trade

2.2km UKCP-Local, convection permitting model have been used, though still rely on larger scale, lower resolution models to provide boundary conditions (forcing).

2.5.4 The 2021 Pacific Northwest Heatwave

Much of the literature on climate storylines can be philosophical in nature, leaving the reader asking how it can be used in practice. Some examples have been briefly mentioned above but a particularly informative case study can be found in the 2021 Pacific Northwest Heatwave, which shattered previous record temperatures across a wide area up to 5°C. The affected region is also strongly impacted by the behaviour of the Jet Stream. Lessons learnt from this event therefore have direct implications for the UK.

The 2021 heatwave can be regarded as a climatic "black swan", in that prior to the event it would have been considered as effectively impossible based on statistical analysis of historical temperatures. However, after the event, our understanding of what caused the event and our appreciation of the risk of something of this magnitude or greater happening again has been updated.

A 2023 study by researchers at ETH Zurich and Cornell University [24] addressed the question of whether this event could have been anticipated in advance, given the historical record suggested the risk was insignificant. They first screened a set of global climate simulations to identify heatwave events which had similar lead-in characteristics to the actual 2021 heatwave but were ultimately less intense. They then used an ensemble boosting approach to generate further synthetic realisations of these events and test if any could be found that matched or exceeded the real event (illustrated in Figure 2).

Their work confirmed that the event could have been anticipated in advance using the current generation of global climate models. However, it requires purposeful identification of the conditions that produce extremes, followed by an extensive exploration of how they might develop in order to estimate plausible upper bounds.

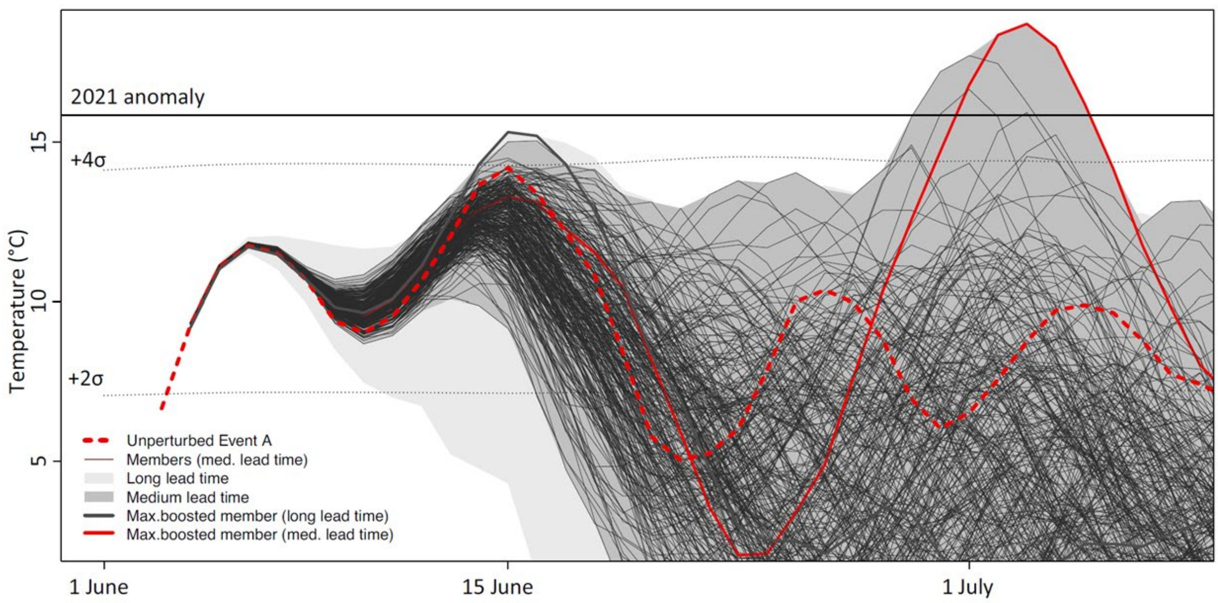

Figure 2: Illustration of the ensemble booting approach used by Fischer et al. in their study of the 2021 heatwave, reproduced from Fig. 3 of their 2023 paper [24]. The dashed line shows a "near miss" heat wave extracted from a multi-decadal simulation using a global climate model. The other lines show alternative realisations of this event, some of which can be seen to exceed the peak of the actual 2021 event. The variable plotted is the 5-day mean of the daily maximum temperature, relative to the long-term mean.

3. Re-examining the H++ scenarios

3.1.1 Overview

This section provides a hazard focussed review of the current information which could be used to inform development of credible maximum scenarios. It is not an exhaustive review of the available scientific literature in each area, which even for a single hazard is extensive and fast moving. It is instead aimed at establishing how far our scientific understanding has moved on since the publication of the H++ scenarios in 2015, and whether they still serve as a suitable reference point.

3.1.2 High Temperatures and Heatwaves

There is no single definition for an extreme heat scenario; some events may be short lived but reach higher peaks, while others may be sustained over long periods but involve lower peaks. The worst-case scenario should be defined based on the system being impacted and its specific vulnerabilities – to avoid repetition, this statement can also be taken as applying to other hazards.

H++ scenario

- Annual averages of summer maximum temperatures exceeding 30°C over much of the UK, with central and southern England seeing annual averages over 34°C.
- Summer maximum daily temperatures over individual years exceeding 40°C across the UK and exceeding 48°C in London.

Urban heat island effects are excluded in both cases. The basis for the scenarios was a combination of historical record temperatures, combined with climate change uplifts taken from the UKCP09 projections.

Recent Evidence

Given the information we have today, a straightforward conclusion can be made that the authors would have reached a different outcome, since:

- Record peak temperatures across most of mainland UK have increased by nearly 2°C due to the July 2022 heatwave.
- The uplift based on UKCP18 projections would have been 0.7°C higher than the UKCP09 equivalent (8.8°C vs. 8.1°C by 2080, under the high emissions scenario).

However, the process adopted to synthesise the available evidence would likely have also been influenced by heightened awareness of a potential underestimation of risk in the current climate.

Since the record-breaking July 2022 heatwave, the UNSEEN method has been used to gain a better understanding of plausible limits for heatwaves in the current climate [23]. The study suggests a plausible risk of:

- Peak temperatures of 46.6°C;
- Five days above 40°C within the same month;
- Twenty days over 35°C;
- Heatwaves (above 28°C) lasting over a month.

The example of the 2021 Pacific Northwest heatwave suggests that these figures should be given significant weight.

3.1.3 Cold Snaps

Increases in global mean temperatures will in general tend to reduce risk due to extreme cold. This trend is seen in both the UKCP09 and UKCP18 projections. However, there are mechanisms which may lead to increased risk which are not represented in these datasets, with a collapse in the Atlantic Meridional Ocean Circulation (AMOC) being the most impactful.

H++ scenario

The H++ scenario for cold snaps (referred to as the L-- scenario) is for average temperatures across the UK[4] of 0.3°C over the winter period and −7°C for a single day. This is based on the historically cold winter of 1962/63, combined with adjustments for:

- AMOC collapse late in the current century.
- A prolonged reduction in solar output, with correlated changes to North Atlantic circulation patterns.

Recent Evidence

A collapse in the AMOC system is the dominant of the two mechanisms considered in the H++ scenario, with an associated reduction of 4.7°C on mean temperatures. The likelihood of an AMOC collapse was considered low within the current century but nonetheless plausible. Recent analysis of CMIP6 data has suggested that the likelihood is higher than had previously been understood, with a collapse in the middle of the current century now a plausible scenario. However, as the L-- scenario is not linked to a specific timeframe, this would not necessarily have affected the authors' conclusions.

The impact of an AMOC collapse is considered in the recently published HILL scenarios [14], which provides both magnitude and timeframe for the associated adjustments, with guidance on how they can be used in combination with UKCP18 projections. The peak adjustment applied to mean temperatures is 5°C, similar to the 4.7°C adjustment applied for the L-- scenario.

3.1.4 Low Rainfall / Low Flows

Low rainfall refers to periods where rainfall is reduced in comparison with a long-term average, otherwise known as meteorological droughts. Rainfall deficits for periods ranging from 6 months to 60 months are the technical indicator for a meteorological drought. Six months is indicative of a short meteorological drought, which most water resource systems should be resilient to, whereas longer, multi-season, multi-annual low rainfall anomalies pose more of a challenge to systems.

Low flows refers to periods in which rivers or other water channels see reduced throughput and may dry out. The indicator for low flows is the percentage change in Q95, which is the flow exceeded 95% of the time. Occurrence of low flows are closely linked to rainfall deficits, however, catchment characteristics, e.g. size, soil type, geology and snow fall and melt patterns are significant controls regulating the hydrological response to low rainfall. In addition, river flows are influenced by human activities, such as abstractions and discharges, which are regulated and may be subject to management plans in response drought conditions.

As a result, low flow scenarios are substantially harder to characterise in a general sense than low rainfall scenarios and further context may be needed on a case-by-case basis to ensure a suitable scenario has been defined.

H++ Scenario

The H++ scenarios for low rainfall are:

- A credible maximum 6-month rainfall deficit of 50% in the current climate (based on historical data spanning 1900–1999), increasing to a 60% deficit by late in the current century.
- Credible maximum rainfall deficits of up to 20% lasting 3 to 5 years, similar to the most severe long droughts on record. No climate change adjustments were made.

The scenarios were developed using a seven-model subset of the CMIP5 models, which were selected based on a statistical comparison against observed patterns of rainfall deficit in the HadUK-P dataset for the 1900–1999 period.

The H++ scenarios for low flows are:

- Summer low flows (Q95) are reduced by between 40–70% in England and Wales and 30–60% percent for Scotland and Northern Ireland.

[4] Temperatures are a spatial average across the whole UK, local temperatures may therefore be lower.

- For multi-season (2–3 seasons) droughts across consecutive summers there is a 20–60% reduction in flows in England and Wales and 20–50% reduction in Scotland and Northern Ireland.
- For longer droughts (2 years or more) the H++ scenario is for 50% reductions in flow for England and Wales and 45% in Scotland and Northern Ireland.

The assessment of changes in low flows builds on the analysis of rainfall deficits using the same subset of CMIP5 models. Response surfaces representing the sensitivity of a river flow to meteorological drought (rainfall deficit and duration) were generated as part of a separate project [25].

Recent Evidence

Despite the availability of a new generation of global climate models in CMIP6, the draft CCRA4 [1] conclusion is that, while there is an expectation that drought frequency will increase, "*hydrological trends remain hard to detect due to large variability and the impacts of water management*" and "*further research is needed to ensure hydrological models accurately capture key drought processes*."

Historical observations remain the key source of evidence of plausible upper bounds to rainfall deficits over a range of timescales. Palaeoclimatological analysis of tree ring data is noted in the H++ report as suggesting that long term variability is greater than that seen over the period for which we possess reliable measurements (approximately 120 years). Specifically, prolonged deficits of between 15–50% were seen over a period of up to 50 years around 500 AD.

However, over the last 10 years there have been several research projects, carried out under the UK Droughts & Water Scarcity research programme[5], focussing on understanding drought dynamics and improving drought prediction. The eFLaG dataset is a national dataset of hydrological projections, based on UKCP18 regional projections using four different hydrological models. Drought durations, intensities and severities are all projected to increase in most catchments [26]; drought intensity is predicted to increase by >50% for more than half the catchments modelled. The results for the Q90 flows suggest that changes of >60% are predicted by some models towards the end of the century; however, the results vary significantly between regions and between models.

3.1.5 High Rainfall / High Flows

A flood is defined as 'any case where land not normally covered by water becomes covered by water' [27]. There are different sources of flooding, e.g. surface water (pluvial), fluvial, groundwater, coastal, sewers etc. These sometimes overlap, or compound, meaning that sometimes floods result from a combination of sources, and can be exacerbated due to issues such as channel restrictions, e.g. bridges and culverts, and blockages.

Climate change impacts on coastal flooding are overwhelmingly governed by projected changes in sea level rise, which are discussed in Section 3.1.7. Other contributing factors, namely storm surge and wave climate, are strongly associated with windstorms (discussed in Section 3.1.6). Fluvial flooding is typically caused by high flows in a river channel in response to high rainfall, resulting in the capacity of the channel being exceeded and overland flow occurring. Changes in peak flows are not directly proportional to changes in rainfall due to catchment dynamics influences on runoff rates.

H++ Scenario

The H++ scenario for high rainfall is presented as an increase of 70–100% on average winter rainfall (from 1961–1990 baseline) by 2080s. For heavy daily and sub-daily rainfall over the same period, a 60% to 80% increase in rainfall depth for summer or winter events is suggested. This scenario is significantly higher than the upper bound of the UKCP09 projections and was informed by expert judgement and theoretical considerations based on Clausius-Clapeyron equation.

The scenario for high flows provides uplifts in comparison to a 1961–2001 reference period for:

- Lower bound uplifts at catchment level over the course of the current century, ranging from 15–30% in the 2020s to 55–125% in the 2080s.

[5] https://aboutdrought.info/about-us/projects/

- An upper bound uplift of 290% over all catchments for the 2080s.

The uplifts were based on the UKCP09 Sampled Data for UK river basin regions, combined with a national scale hydrological model[6].

Recent Evidence

SEPA and the Environment Agency have both updated their climate change peak flow allowances since publication of the H++ scenarios to incorporate data from UKCP18. These are based on the study by Kay et al. [28] using the UKCP18 probabilistic projections high emissions scenario (RCP8.5) and are based on a 50-year return period event.

In 2021 the Environment Agency (England) updated their fluvial peak flow climate change allowances for 92 river management catchments[7]. These included three scenarios based on RCP8.5: Central (50th percentile), Higher Central (70th percentile) and Upper End (95th percentile). The current Environment Agency guidance for a credible maximum scenario is to use the Upper End scenario for peak flows. The median uplift across catchments for the Upper End scenario by 2080 is 68% (lower than the median of the 23 lower end regional estimates of H++) and the 95th percentile is 103% with a maximum of 127% (Test and Itchen catchment, South-East England).

In Scotland, peak river flow uplifts are based on the 67th percentile for the 50-year return period and provided for 10 geographical regions. They range from 34% in North-East Scotland to 59% in Argyll and the Tweed.

In Wales, suggested peak flow uplifts are still based on UKCP09. The upper end estimates (90th percentile) for 2080 range from 45% for the Dee catchment to 70 and 75% for the Severn and West Wales regions respectively.

In all cases the more recent guidance has suggested a reduction in credible maximum uplifts in comparison with the H++ scenarios. However, this is primarily based on evidence from climate model projections, which was only one of a number of sources of evidence considered by the H++ authors, expert judgment and theoretical arguments also playing an important role.

3.1.6 Windstorms & Coastal Flooding

Extreme winds in the UK are primarily related to the actions of extra-tropical cyclones, which track from West to East and are strongly influenced by the position and dynamic behaviour of the North Atlantic Jet Stream. Engineering design standards for the UK (e.g. BS EN 1991-1-4) are calibrated against wind speeds generated by these storms, with limited consideration given to other storm mechanisms. Extreme ocean waves and storm surges are generated by these storms and are therefore closely linked with respect to future trends.

An important associated climate driver is the North Atlantic Oscillation (NAO), which is loosely defined based on relative positions of the semi-permanent pressure systems known as the Azores High and the Icelandic Low. Multi-decadal swings in the typical position of these systems leads to natural variability in the European wind climate, which has potential to mask long terms trends due to climate change. Significant wind effects can also result from convective storms, such as tornados and thunderstorm downbursts, which are currently of secondary importance in terms of risk to people and assets but may not remain so under future climate scenarios. This is also true for tropical cyclones, which may plausibly track as far as the UK under extreme departures from current northern hemisphere circulation patterns.

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[6] Note that hydrological model structure is a form of uncertainty in the estimation method. Estimates of change may vary if different hydrological models are used.

[7] The values presented for each scenario and epoch is the areal mean of the change across the management catchment. The results are based on a 1km gridded hydrological model (Grid-to-Grid, G2G) of Great Britain; however, results are only available for cells with upstream contributing catchment areas >100km^2 due to concerns regarding representatives of the results for more fast responding catchments [28].

H++ Scenario
The H++ scenario for windstorms is based on analysis of a subset of 13 CMIP5 models, which have been selected based on their "reasonable representation" of the North Atlantic storm track over the historical reference period [29]. Within these models a maximum increase of 50–80% was found for the number of windstorms over the UK by 2070–2100 in comparison to a 1975–2005 baseline. No guidance is offered on how this scenario is to be used by practitioners and it is not obvious how it would be translated into the short duration gust speeds that are relevant for structural design.

Recent Evidence
The most significant developments since H++ have been the improvements in winter storm track position present within the CMIP6 model ensemble and the availability of hourly mean wind speed time series via UKCP18. Access to surface level, hourly mean wind speeds is an important step forward in that it enables assessment of extreme wind speeds.

However, UKCP18 projections may not be appropriate for use in defining credible maximum wind speeds. Figure 3 shows a comparison of 50-year return period, hourly mean wind speeds for an illustrative location in Oxfordshire. Along with lower-than-expected extreme wind speeds for the baseline period, a reduction in extreme speeds is generally seen over the course of the century. Increases in wind speeds may result from long-term natural variability and abrupt changes in large scale systems, such as AMOC collapse. Neither of which is captured within the UKCP18 dataset.

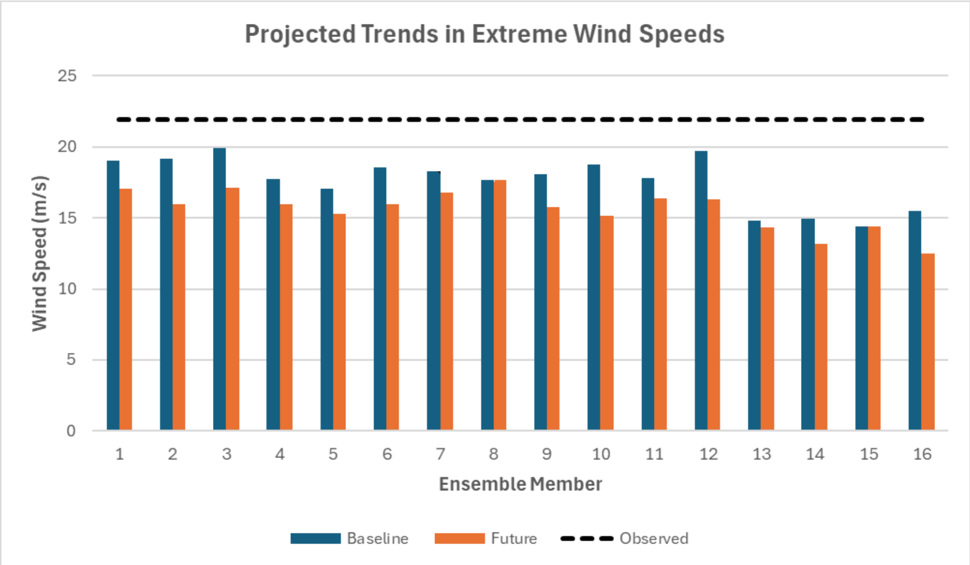

Figure 3: Illustrative comparison of 50-year return period wind speed based on historical observations (1975-2024) vs. UKCP18 local projections for baseline (1981-2000) and future (1961-2080) periods.

As for other hazards, confident estimates of future trends in storminess are challenged by difficulties in representation of Jet Stream behaviour by climate models and multi-decadal variability related to climate drivers such as the NAO. The draft CCRA4 technical report [1] concludes that an increase in surface wind speeds is expected, but states that this cannot be confidently attributed to climate change and may be the result of natural variability. The draft report concludes that models of the large-scale, North Atlantic circulation are still not sufficiently robust and higher resolution models are needed to improve predictions of Jet Stream dynamics and storm generation.

Model limitations also inform consideration of future trends in extreme ocean waves and storm surge, which are an important contributor to coastal flood risk The UKCP Marine Report high-end projection has an additional contribution from climate change to storm-surge of 2–3mm/year due to potential changes in atmospheric storminess and 10–20% in extreme wave height [30].

Limiting physical arguments can be straightforwardly applied to credible maximum wave heights, since beyond a certain limit the wave will break. However, other characteristics of an extreme wave condition may be more onerous, depending on the system under study. For example, Storm Babet (2023) exposed the east coast of Scotland to waves which were not just large but which also persisted for an unusually long period, resulting in extensive erosion damage in some areas due to progressive loading. Understanding how the risk of such events may change in future is subject to all the caveats already discussed in relation to modelling of North Atlantic circulation patterns.

3.1.7 Sea Level Rise

Extreme sea levels cause coastal flooding, erosion and saltwater intrusion, which are likely to increase with sea level rise. Global mean sea level has risen faster in the 20th century than in any prior century over the last three millennia, increasing by 20cm between 1901 and 2018 [31]. The average rate of sea level rise has more than doubled since the start of satellite records, from 2.1mm per year (1993–2002) to 4.7mm per year (2015 to 2024) [32]. Sea level rise around the UK is around 19.5cm since 1901. It is accelerating and may now be rising faster than the global average [33]. The IPCC states it is certain that sea levels will rise until at least 2100, and by 2100 the Arctic will become practically ice-free in September.

Total sea level rise experienced at a particular location involved contributions from multiple factors. The largest contributor to extreme scenarios for future sea level rise in the UK is rapid Antarctic ice loss, particularly the rate of melting of the West Antarctic Ice Sheet. Changes in regional ocean circulation such as AMOC collapse would also impact regional UK sea levels.

Sea level rise projections are most often based on one of two methods:

- The “process-based” method models each component before summing them to give the total sea-level change.
- The “semi-empirical” method relies on statistical relationships between total sea-level observations with global mean temperature or radiative forcing.

H++ Scenario

The upper bound of the H++ scenario was based on a semi-empirical approach, informed by expert judgement, using historic rates of sea level rise from the last interglacial period (~125,000 years ago), when the global mean surface temperature and ice-sheet configuration were similar to present day [34]. This gave a varying amount of sea level rise, from 0.93m–1.9m around the UK coast for 2100 compared to 1990 [34].

Recent Evidence

When UKCP18 was released, the H++ sea level rise value, which was based on UKCP09 data, was re-considered. This value of 1.9m sea level rise by 2100 (compared to 1990 baseline) was concluded to still be a reasonable plausible high-end scenario [35], with the caveat that it may be updated.

The future contribution of Antarctic ice sheet melt is a key area of uncertainty for UK sea levels. When the H++ scenario was derived, limited evidence based on modelling studies of ice sheet dynamics was available. Modelling of ice-sheet processes has improved in CMIP6, with higher confidence in models simulating climate processes, and good comparisons between modelled values and observations. However, deep uncertainty remains, such as the possible initiation of rapid melting due to positive feedback, there has been a shift in the literature towards a storyline approach.

AR6 was the first IPCC study to present a low-likelihood, high-impact storylines for future global mean sea level rise with rapid and runaway Antarctic ice sheet melt. The IPCC AR6 SSP5-8.5 extreme scenario projects a spread of global sea level rise trajectories, representing model uncertainties. For the 95th percentile, the estimate is for 2.3m by 2100 (relative to a baseline of 1995–2014). As credible maximum scenarios are not based on any defined probability level, the choice of percentile is subjective.

Work has been ongoing in the last few years to develop updated sea level rise scenarios for the UK, combining the AR6 scenario and research by van de Wal et al [36] with UKCP modelling to extend to projections to 2300. Analysis by Weeks et al. [34] in 2023 compared extreme sea level rise estimates presented in AR6 and the H++ scenario. Their choice of storyline based on the high-end AR6 scenario is lower in 2100 than the H++ value of 1.9m but accelerates post-2100 and by 2150 is more than double H++, see Figure 4.

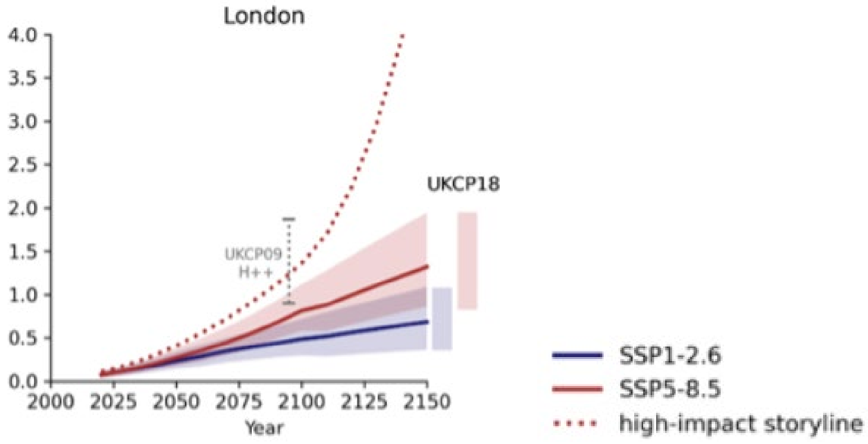

Figure 4: High-impact storyline based on AR6 for mean sea level rise in London to 2150 compared to UKCP09 H++, and to mean sea level rise scenarios without ice-sheet melt. For sea level rise without ice-sheet melt, the trajectories show the likely range from AR6 for SSP1-2.6 and SSP5-8.5 (adjusted for London location) and bars show the 5th–95th percentile range for UKCP18 at 2150 for RCP2.6 and RCP8.5 scenarios. Reproduced from Weeks et al [34].

Work by Palmer et al [37] in 2024 defines two extreme sea level rise storylines for the UK:

- Storyline H1 based on van de Wal et al. (2022)
- Storyline H2 based on the IPCC AR6 (83rd percentile).

The storylines give substantially different future sea level rise by 2300 for UK coastal capital cities: between 8.2m (Belfast) and 9.2m (London) for H1, and between 16.3m to 17m for H2 for the same cities.

Recent work by Weeks et al [13] published in 2025 presents a framework to carry out flexible exploration of the latest high-end scenarios for the UK. The design of the framework was influenced by requirements set out by the Environment Agency, who played the role of "super user" in co-producing the scenarios. A key point of difference is the recognition is that a deterministic projection is not sufficient to meet the needs of downstream users. Instead, a dynamic framework offers a more robust methodology to adapt to developments in climate science and allow screening to identify potential trigger points, under which adaptive strategies would become necessary.

A separate set of high-end storylines for the UK for sea level rise to 2100 are given in the HILL scenarios [14]. The HILL-6 scenario is based on the AR6 report high-end storyline (95th percentile) with regional sea level rise by 2100 of 2.11m in the South and East, and 1.91m in the North and West. Under HILL-6 it is noted that between 2100 and 2150 there could be a further 3.4m sea level rise, so regional sea level rise by 2150 would be 5.5m–5.8m.

Ice sheet dynamics is also an area of rapidly improvements in scientific understanding, modelling methods and datasets, uncertainty may therefore reduce significantly over some asset lifetimes. Current best estimates vary by large margins post 2100, however estimates up to this point have remained relatively stable, with some showing a small decrease (~15%) compared to the H++ scenario and some a small increase (~10%). Although the science has continued to develop, much of the variability across scenarios can be attributed to subjective choices, such as use of 83rd vs 95th model percentile values from the IPCC AR6 scenario.

3.1.8 Other Hazards

A range of other external hazards are likely to be affected by climate change:

- **Wildfires** are expected to increase in frequency along with increased prevalence of hot dry summers. However, a credible maximum wildfire scenario is largely based on non-climatic factors, including available biomass for fuel, which are sensitive to human activity.

- **Lightning** was only considered qualitatively in the UKCP09 projections, whereas UKCP18 offers quantitative projections on total lightning flashes at the local UKCP18 spatial scale [38]. The latest UKCP18 projections at the upper end of the RCP8.5 climate projections allow quantitative analysis of lightning through a flash rate variable. In the UK context, studies have determined a 1 in 10,000-year lightning strike intensity of 300kA [39].

- A simple physical upper bound can be established for **humidity** based on the saturation vapour pressure at a given air temperature. UKCP18 projections provide humidity projections for RCP8.5 and a 4°C Global Warming Level (GWL), with the latter showing annual decreases in relative humidity, up to 6% lower than present day in the South-East of England [40]. Sustained high levels of humidity would impact the viability of wet cooling systems and could form the basis of cooling system stress tests for some sites.
- UKCP18 projections show decreases in both falling and lying **snow** [41]. However, climate scenarios such as the Met Office tipping point reports suggest increases in snowfall magnitude and duration are possible with AMOC collapse [15]. High-end scenarios for snow are not quantified in the HILL report with the storyline related to AMOC collapse. In the absence of high-end scenarios for the UK, snow loads from Eurocodes of other countries with colder climates could be considered, for example Norway which experiences colder, more snowy winters.
- Changes in **sea surface temperatures** (SST) are explored in the HILL storylines, primarily in relation to its impacts on other hazards such as temperature. The HILL scenario related to changes in ocean circulation and links to AMOC could lower SST, which itself causes lower temperatures [14]. Another scenario references high pressure over Scandinavia causing higher SST around the UK. The extreme anomalies scenarios of persistent cyclonic and persistent anticyclonic conditions also affect SST and exacerbate these extreme conditions further. Whilst these are discussed in HILL storylines, they are not quantified.

  Recent marine heatwaves (July 2025) in the south of the UK have shown SST uplifts of up to 3°C compared to a 1982–2012 average. As explored in the HILL storylines, SST increases can be due to a range of reasons, including anticyclonic conditions, weaker winds and increased solar irradiance [42]. Increased SST can cause a range of climate phenomena including increased land temperatures, reduced sea breezes and extreme rainfall events.

  Global projections from CMIP6 for the SSP5-8.5 scenario at the 95th percentile show SST increases of 5.8°C around Northern Europe at the end of the century, compared to a 1981–2010 baseline.

3.1.9 Compound Events

Combined or compound events are comprised of multiple events, which occur simultaneously or concurrently. These events can produce system failures which would not result from exposure to each component on an individual basis, i.e. the failure may be produced from combinations of below design basis events. The system response can be sensitive to the sequence and timing of the events as well as their magnitude, making these scenarios hard to define without reference to a specific system vulnerability that the scenario is designed to test.

The H++ report provided some discussion of combined events, such as storms associated with heavy rain and wind, but did not offer quantitative guidance. The HILL framework can be used to combine transient scenarios (for instance enhanced global warming and ocean circulation change) and gives detail on how these may simultaneously affect climate hazards. As with the general concept of storylines, the joint probabilities of high-end events occurring are not available through this approach.

More recently, the draft CCRA4 report outlines two high impact, compound event scenarios – “wet and windy” and “hot and dry”, where a series of extreme meteorological events occur within a period of weeks.

Compound events do not need to be limited to meteorological factors and can include factors such as human activity, or other natural hazards such as earthquakes. Storylines are an effective method to combine multiple hazards and are widely used in global disaster risk management with multi-risk scenarios, which could inform dutyholders consideration of high-end, combined events [43].

The storylines approach is particularly well suited to development of scenarios involving compound events. This can involve identification of particularly impactful historical events, which can be used as a basis for scenario design. It may also use a known or anticipated vulnerability in the system to be tested, which is used to inform the design of scenarios which provide a suitable stress test.

4. Conclusions & Recommendations

Conclusion 1: The H++ scenarios in their current form no longer reflect current understanding of credible maxima for some hazards.

The H++ scenarios were informed by projections based on a mixture of the CMIP3 and CMIP5 generation of global climate models. They were largely retained for UKCP18 and remain a key reference for dutyholders with respect to definition of credible maximum scenarios – not just for the scenarios they produced but for the methods used in developing them.

Since their publication, data from a new generation of global climate models (CMIP6) has been published and data from a further generation (CMIP7) will emerge in the near future (see Figure 5). Events such as the July 2022 UK heatwave have also heightened awareness that important features of the large-scale climate processes that govern the UK's weather may be changing in ways that are not well captured by climate models. Use of ensemble boosting methods – such as the UNSEEN method – have potential to reduce our exposure to "black swan" type events but remain subject to the limitations of the underlying climate models.

It is likely that the authors of the H++ scenarios would have reached different conclusions in at least some respects should they have had access to the information we now hold. An argument can therefore be made that they should be updated. However, the pace at which new scientific evidence emerges will if anything increase, particularly as the CMIP project moves towards more continuous releases of new data, making it hard for such authoritative updates to stay aligned with the scientific state-of-the-art.

Notwithstanding this point, a systematic update to the H++ scenarios, timed to allow access to early results from CMIP7, would be beneficial to assist dutyholders in meeting ONR's expectations.

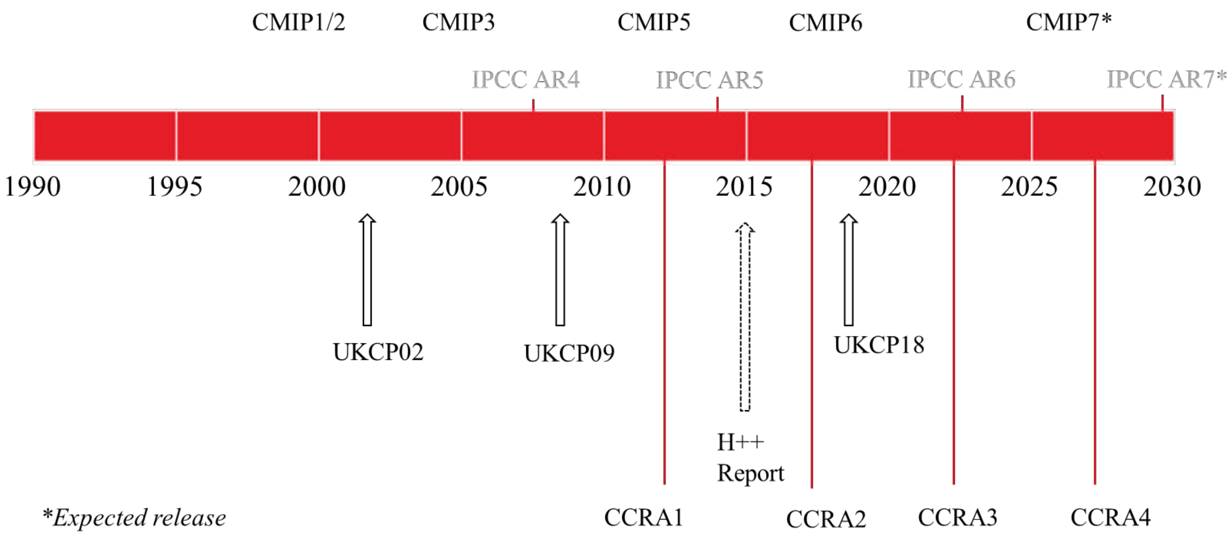

Figure 5: Timeline for updates in key sources of scientific evidence and/or guidance.

Conclusion 2: More recent guidance is available to dutyholders but may not be sufficient to meet ONR's expectations.

Newly published research, such as the HILL scenarios [14] or work by Weeks at al. [13] on extreme sea level rise scenarios, provide updated frameworks for dutyholders to explore the potential range of future climatic pathways. However, they do not always translate through to information which is directly useable in engineering models that are often needed for detailed impact assessments. They also leave important questions open as to where and how to draw the line on credible upper bounds for specific types of extreme events and their knock-on impacts.

As such, while dutyholders have greater access to toolkits that can be used to explore the impact of a range of high-end, plausible scenarios, these do not offer an off the shelf solution to demonstrate they have met ONR's expectations.

Conclusion 3: Climate storylines have potential to provide a structured process for dutyholders to demonstrate they have met ONR's expectations based on current state-of-the-art scientific evidence.

The storylines concept would allow dutyholders to co-produce scenarios that are designed with their needs in mind, with active involvement from dutyholders alongside expertise from climate scientists, meteorologists and engineers. This is attractive for a number of reasons:

- It ensures deep understanding of the system being tested is built into the design of the scenarios at the outset.
- It encourages cross disciplinary conversations that may help to identify vulnerabilities that would not be properly tested by a generic set of scenarios.
- It provides a mechanism to transparently document subjective decision making that would otherwise be obscured.
- It ensures the scenarios are framed in a way that they can be straightforwardly used as an input to standard engineering workflows to assess impacts.

The storylines concept is becoming widely used across a range of other fields, which suggests the skills to facilitate the process are likely to be accessible to dutyholders and there is benefit for ONR consider this further. Use of storylines was identified in CCRA3 as a key focus area for CCRA4. While the full outputs from CCRA4 are yet to be published, the draft technical report contains many references to storylines, makes use of the concept in defining two compound hazard scenarios for the UK and lists use of storylines as a key advance since CCRA3.

While there are many useful actions that could be taken to clarify the current state of scientific understanding of high-end climate scenarios, this is a time-consuming activity and would likely soon be superseded by ongoing developments. Perhaps of greater value to dutyholders, would be an industry led effort to develop methods which can be used alongside relevant specialists to co-produce a curated set of scenarios; thus allowing dutyholders to tailor the scenarios with their specific needs in mind and keep up with the rapid pace of scientific developments.

Conclusion 4: Long term climate variability requires an ongoing focus alongside anthropogenic climate change.

Our understanding of long-term fluctuations in the large-scale mechanisms that govern the UK climate is still evolving and should form an important part of dutyholders' considerations regarding credible maxima. In some cases, the influence of natural cycles that take place over multiple decades may leader to greater uncertainties than those associated with climate change.

5. Abbreviations

AMOC	Atlantic Meridional Overturning Circulation
AMS	American Meteorological Society
CCRA	UK Climate Change Risk Assessment
CICERO	Centre for International Climate and Environmental Research
CMIP2	Coupled Model Intercomparison Project 2
CMIP3	Coupled Model Intercomparison Project 3
CMIP5	Coupled Model Intercomparison Project 5
CMIP6	Coupled Model Intercomparison Project 6
CMIP7	Coupled Model Intercomparison Project 7
CONVEX	CONVective Extremes
GWL	Global Warming Level
HILL	High Impact Low Likelihood
IPCC	Inter-Governmental Panel on Climate Change
KNMI	Koninklijk Nederlands Meteorologisch Instituut/Royal Netherlands Meteorological Institute
NAO	North-Atlantic Oscillation
ONR	Office for Nuclear Regulation
RCP	Representative Concentration Pathways
RRR	Regulatory Research Report
RECEIPT	REmote Climate Effects and their Impact on European sustainability, Policy and Trade
SEPA	Scottish Environment Protection Agency
SSP	Shared Socioeconomic Pathways
SST	Sea-Surface Temperature
TAG	Technical Assessment Guides
UKCP09	UK Climate Projections 2009
UKCP18	UK Climate Projections 2018
UKMO	UK Meteorological Office
UNSEEN	Unprecedented Simulated Extremes using Ensembles

6. Glossary

Term/ Acronym	Definition
Atlantic Meridional Overturning Circulation (AMOC)	A major ocean current influencing UK climate that transports warm water northwards from the tropics northwards.
Coupled Model Intercomparison Project (CMIP)	A framework for comparing climate models (e.g., CMIP3, CMIP5, CMIP6).
Climate Storyline	A physically plausible sequence of climate events used to explore impacts without assigning probabilities.
Credible Maximum Scenario	High-end scenario used for sensitivity testing in safety assessments and stress testing vulnerabilities.
Downscaling	Translating global climate model outputs to regional/local scales.
Fluvial Flooding	Flooding from rivers exceeding their capacity.
Global Warming Level (GWL)	Indicating the level of global temperature increase from greenhouse gas emissions.
High-End Climate Scenario	A physically consistent, low-probability but plausible climate event used for stress testing. An example is the 2015 H++ scenarios for the UK.
Hydrological Drought	Periods of reduced river flow due to prolonged dry conditions.
HyperFACETS	A Framework for Improving Analysis and Modelling of Earth System and Intersectoral Dynamics at Regional Scales. HyperFACETS is a research project funded by the U.S Department of Energy
Intergovernmental Panel on Climate Change (IPCC)	A global body assessing climate science.
Jet Stream	Fast-flowing air current influencing storm tracks and weather patterns.
Managed Adaptive Approach	Strategy allowing for incremental adaptation based on evolving risks.
North Atlantic Oscillation (NAO)	A climate pattern affecting weather variability in Europe. The NAO is defined by the difference in atmospheric pressure between the Azores High and the Icelandic Low.
Pluvial Flooding	Flooding caused by heavy rainfall overwhelming drainage systems.
RECEIPT	REmote Climate Effects and their Impact on European sustainability, Policy and Trade. RECIEPT was a EU-funded research project that ran from 2019 to 2023.
Representative Concentration Pathways (RCP)	Emission scenarios used in climate modelling which represents a radiative forcing value.
Shared Socioeconomic Pathways (SSP)	Scenarios combining socioeconomic trends with climate projections such as increased greenhouse gas emissions.
Scenario Analysis	Method for exploring system vulnerabilities under extreme but plausible conditions.
Sea Level Rise (SLR)	Increase in ocean levels due to climate change.

Storm Surge	Rise in sea level due to atmospheric pressure and wind during storms.
TAG 13	ONR's Technical Assessment Guide for external hazards.
Tipping Point	Tipping points are sudden, dramatic, and potentially irreversible changes to the climate system. They represent thresholds beyond which a small change in conditions can lead to a disproportionately large impact, often with cascading effects across environmental and human systems.
UK Climate Projections (UKCP)	Climate projections produced by the UK Met Office e.g. UKCP09 and UKCP18.
Unprecedented Simulated Extremes using Ensembles (UNSEEN)	A method developed by the UK Met Office to simulate plausible but unobserved extreme events to generate synthetic data.

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