

And the weather forecast for the coming decades is...

Dr Stephen Blenkinsop



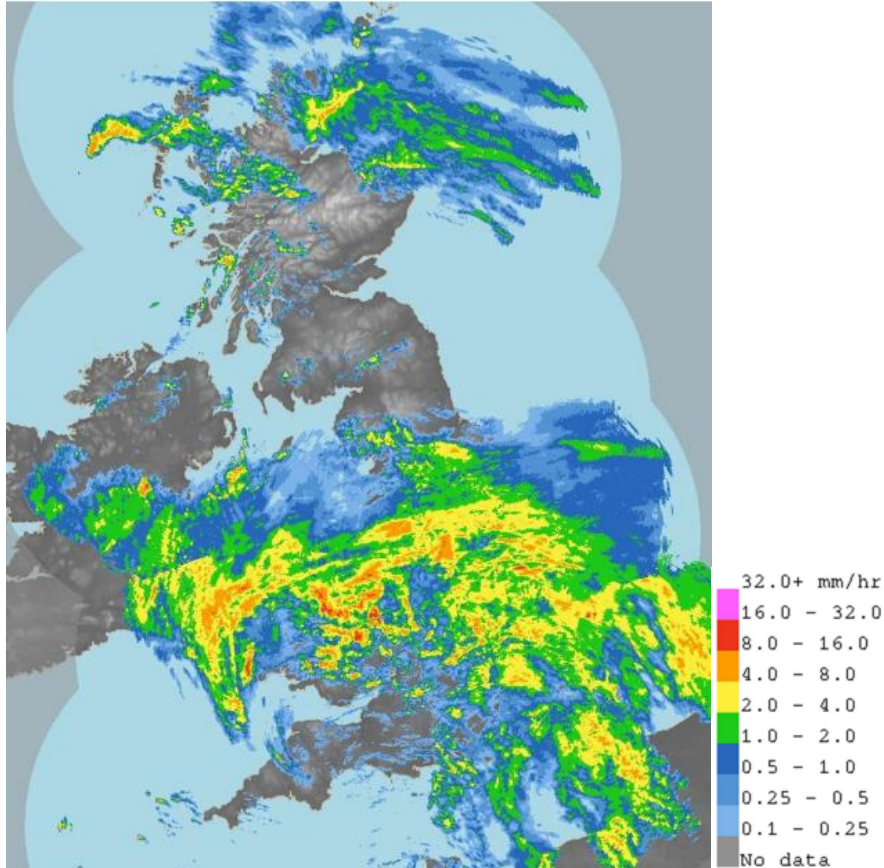
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[@Climate_Stephen](https://twitter.com/Climate_Stephen)

From Newcastle. **For the world.**

Storm Henk, 2 January 2024



Source: [UK Met Office](#)



Source: [Drew de F Fawkes](#) 

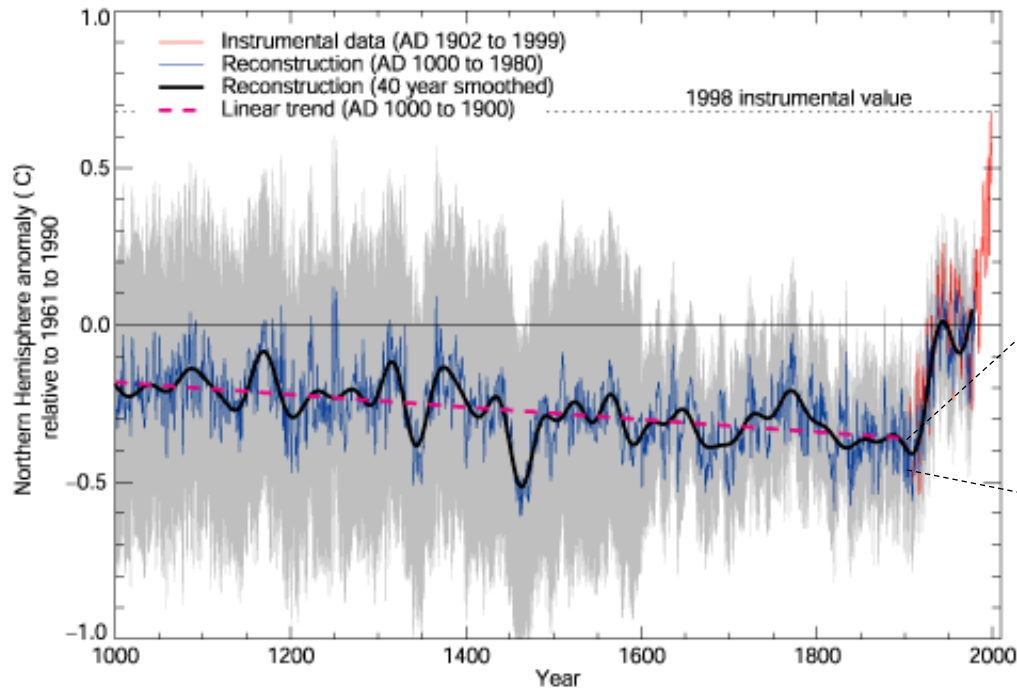
Almost 300 flood warnings were in place in England, others in Wales and Scotland. Hundreds of properties near the Severn in the West Midlands were flooded, flooding in York as the River Ouse burst its banks,

1. Introduction

Climate change: evidence and attribution

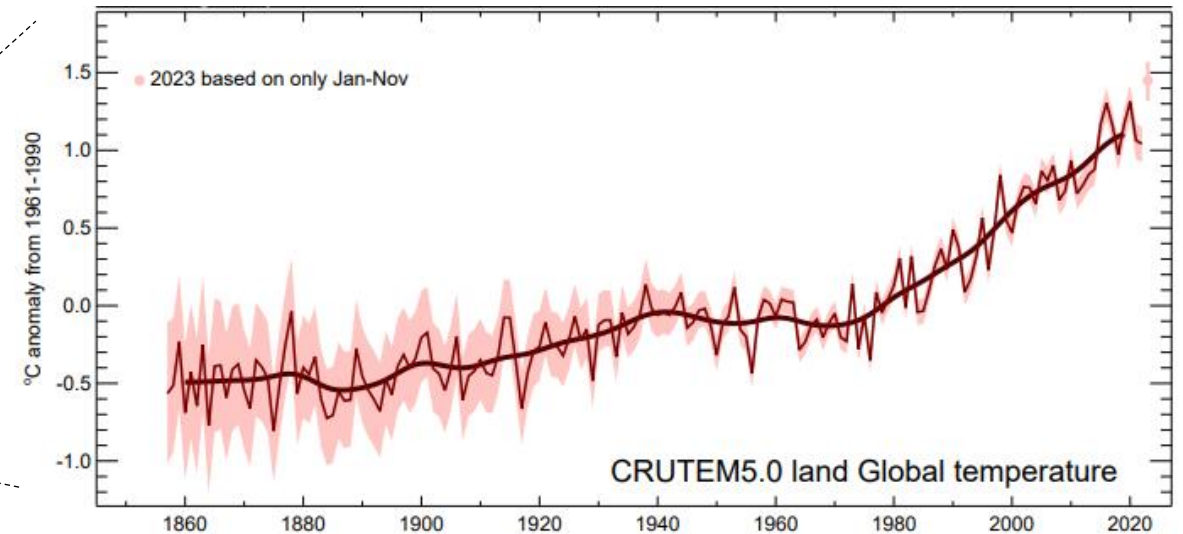
Primary evidence – the global temperature record

The hockey stick graph



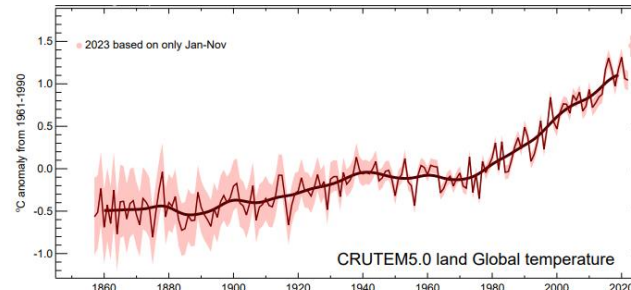
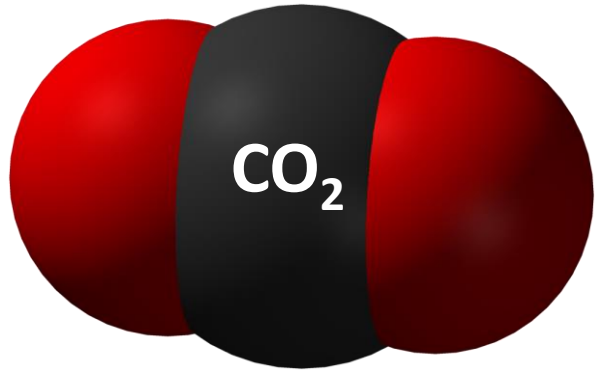
Millennial Northern Hemisphere temperature reconstruction (blue) and instrumental data (red) from AD 1000 to 1999, adapted from Mann et al. (1999). Smoother version of Northern Hemisphere series (black), linear trend from AD 1000 to 1850 (purple dashed) and two standard error limits (grey shaded) are shown.

The CRUTEM5 land surface temperature record

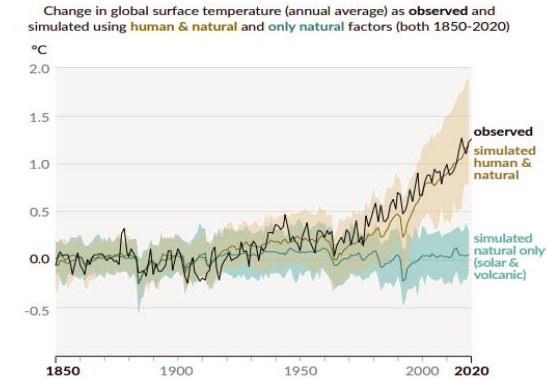


Source: <https://crudata.uea.ac.uk/cru/data/temperature/>

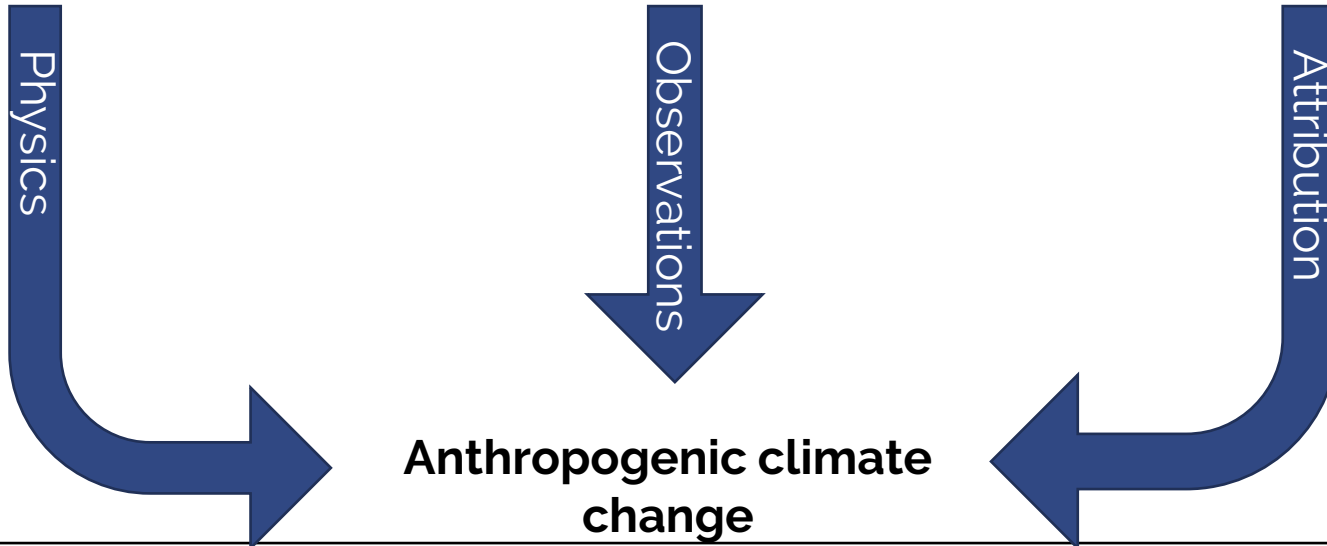
Three lines of evidence point to a changing climate



Source: [CRU](#)



Source: IPCC



What is the physical basis for changes in rainfall?

Key headlines: intensified water cycle

'The frequency and intensity of heavy precipitation events have increased since the 1950s over most land area for which observational data are sufficient for trend analysis (high confidence), and human-induced climate change is likely the main driver.'

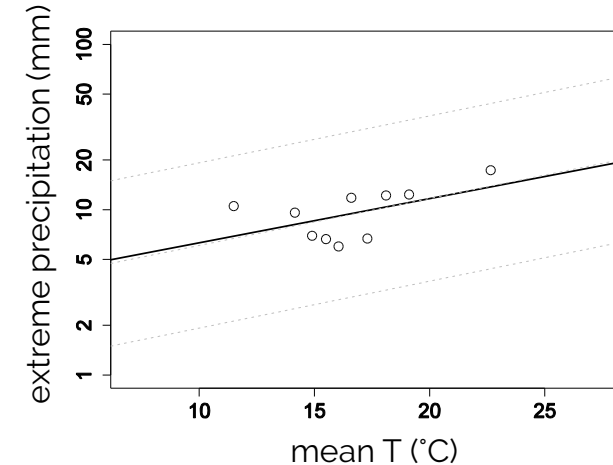
'A warmer climate will intensify very wet and very dry weather and climate events and seasons, with implications for flooding or drought (high confidence).'

[IPCC 6th Assessment Report, Summary for Policymakers](#)

Drivers:

- Higher temperatures -> greater evaporation
- As the air warms its water-holding capacity increases.

According to the Clausius-Clapeyron relationship, the air can generally hold around 7% more moisture for every 1°C of temperature rise.

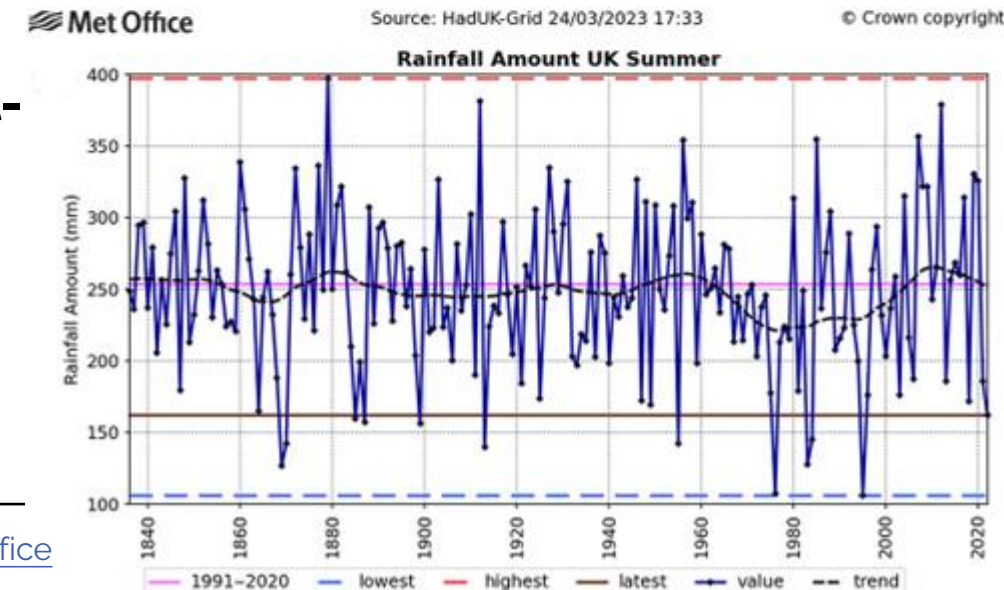
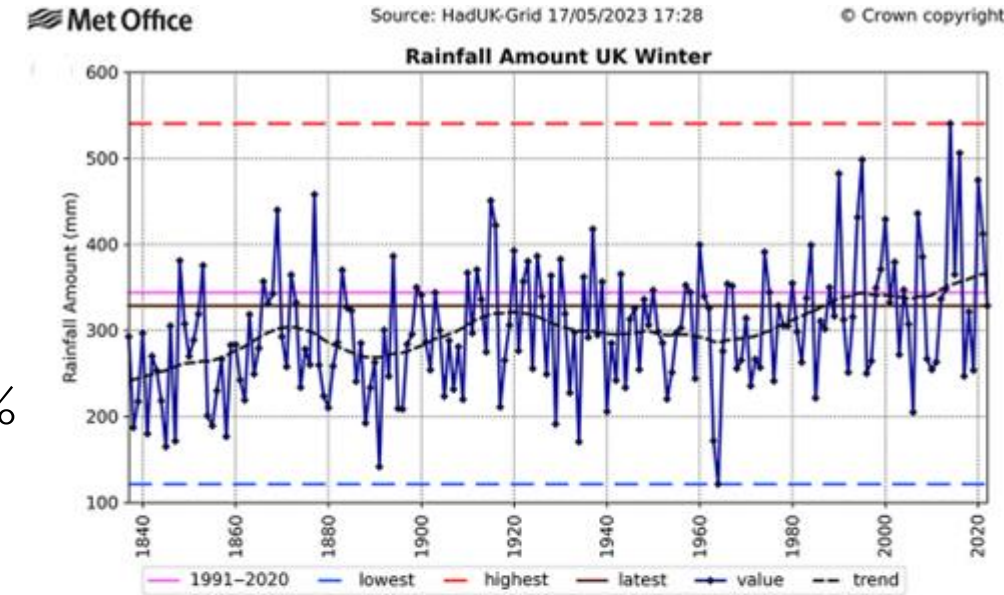


Source: [Blenkinsop et al. \(2015\)](#)

Shifting weather patterns, storm tracks etc. and other factors.

What changes have we observed?

- **UK's climate is getting wetter**
 - Five of the 10 wettest years in the UK series from 1836 have occurred in the 21st century
- **The most recent decade (2013–2022):**
 - UK winters have been 10% wetter than 1991–2020, 25% wetter than 1961–1990
 - UK summers have been 3% drier than 1991–2020 and 6% wetter than 1961–1990
- **Since 2000, nine seasons have been in the top 10 wettest in UK seasonal series** (winter 2014, 2016, 2020, 2007, spring 2006, summer 2012, 2007, autumn 2000, 2022)
- **Caution** on interpreting trends

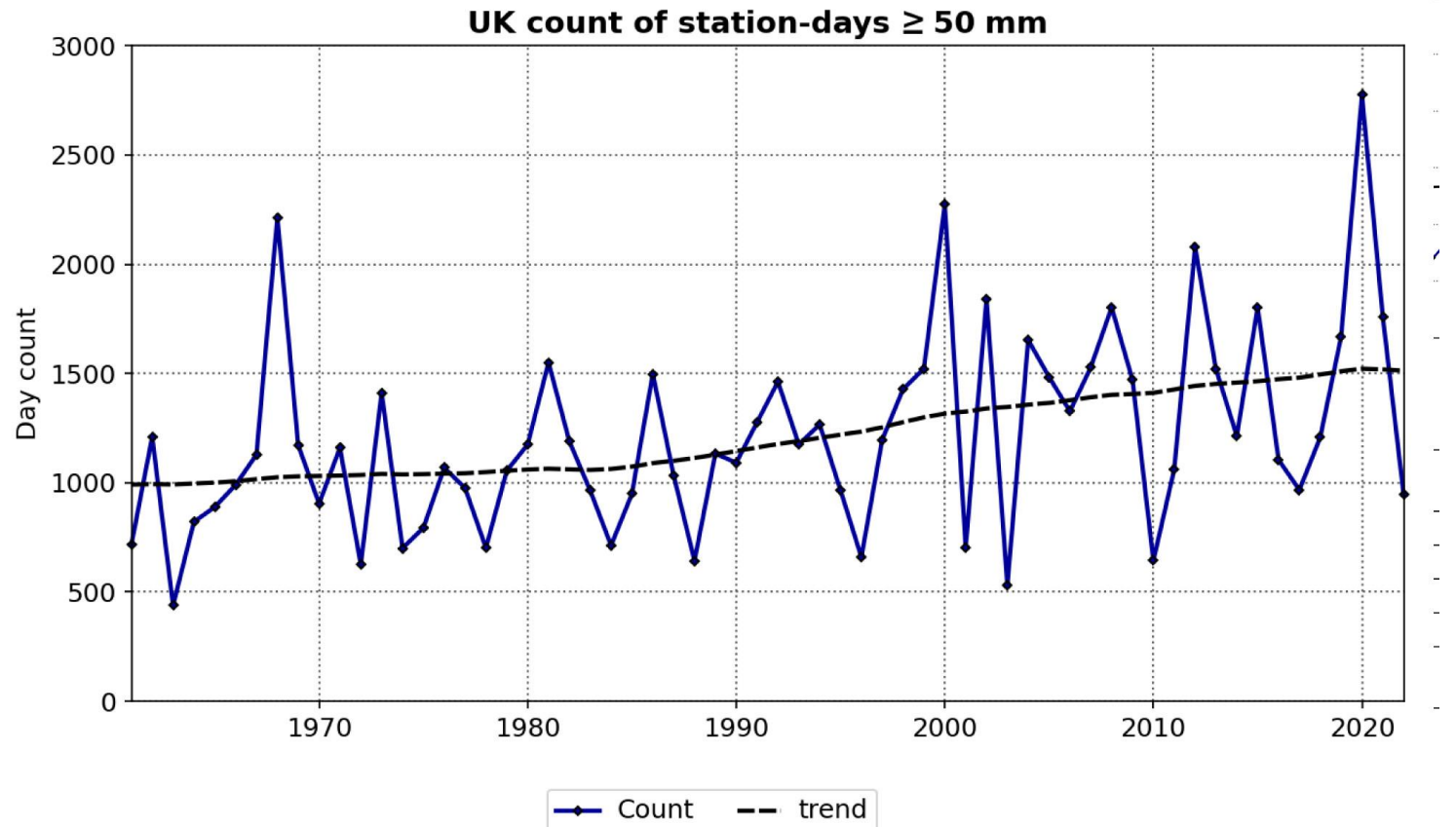


- **Increased intensity of rainfall extremes** in the latest decade but annual variability is high for the most extreme events

More heavy rain events have been recorded in the most recent decade than in earlier decades in the series

 Met Office

Source: Met Office station data archive 17/05/2023 © Crown copyright it



Source: [State of the UK Climate - Met Office](#)

We can also use climate models to examine the contribution of climate change to extreme weather events, and the extent to which they are 'loading the dice'.



Lancaster the morning after Storm Desmond hit,
[Christopher Cable](#) 

On December 5, 2015, Storm Desmond led to heavy rainfall and devastating flooding in the UK.

Climate models run
without human
influence



compared with

Climate models run
with human influence



Such a level of extreme rainfall is at present roughly 60% more likely due to human-caused climate change.

2. How do we tell what the future might look like?

The climate system is complex and not fully understood so we use models:

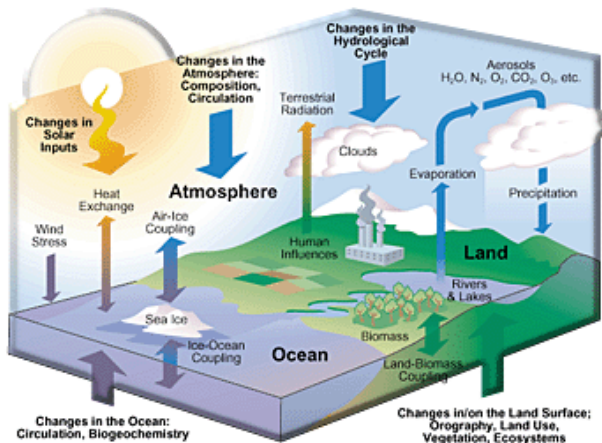
- i) to improve **understanding** of how the climate system works
- ii) as a **predictive** tool to see how the future might change

They represent the complex climate system...

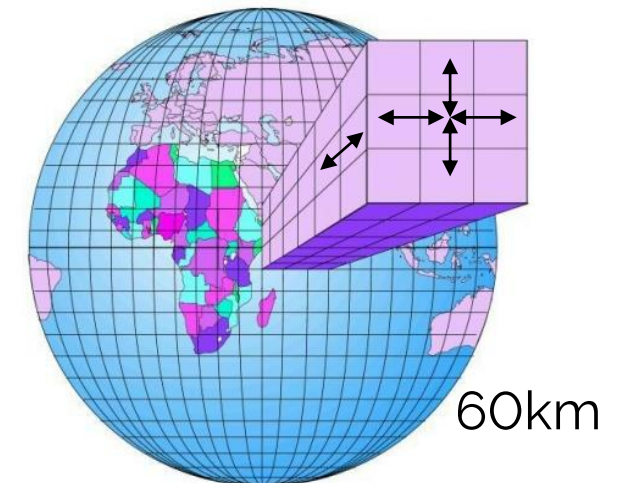
...by simulating physics using mathematical representations of complex processes in computer code...

...simplifying the spatial representation of the world in to grid cells.

Global Climate System Components



```
1 /* ***** IDENT NDEEP4V */ Update to UGAMP GCM versi
2 C
3 ZQSATC=C2ES*EXP(C3LES*(ZTC(JL,JK)-TMELT)* (1./(ZTC(JL,JK)-C4LES)))/APP1(JL,JK)
4 ZCOR=1./MAX(ZEPCOR,(1.-VIMP1)*ZQSATC)
5 ZQSATC=ZQSATC*ZCOR
6 ZQCD=(ZQC(JL,JK)-ZQSATC)/(1.+C5LES*ZCONS2*ZQSATC*ZCOR* (1./(ZTC(JL,JK)-C4LES))**2)
7 ZTC(JL,JK)=ZTC(JL,JK)+ZCONS2*ZQCD
8 ZQC(JL,JK)=ZQC(JL,JK)-ZQCD
9 ENDIF
10 C
11 C PARCEL TEMPERATURE FOR BUOYANCY.
12 C *ZGAMMA* IS A MIXING FRACTION FROM CLOUD-TOP C ENTRAINMENT.
13 C
14 ZZQ=MAX(ZEPCO,ZQP1(JL,JK))
15 ZP1=ZZQ*APP1(JL,JK)/(ZC6+ZC7*ZZQ)
16 ZTSF=ZC2+ZC3/(ZC4*ALOG(ZTP1(JL,JK))-ALOG(ZP1)-ZC5)
17 ZSFP=APP1(JL,JK)*XLG((ZTSF/ZTP1(JL,JK)),ZC1)
18 ZRATDP=APP1(JL,NLEV)-ZSFP/(APP1(JL,NLEV)-APP1(JL,JK))
19 ZAPP1=APP1(JL,IBASE(JL))
20 ZTCLD=ZTC(JL,JK)*(1.0-ZGAMMA*ZRATDP)+ZGAMMA*(ZTP1(JL,JK)+
21 * ZTCB(JL)*XLG((APP1(JL,JK)/ZAPP1),ZCONS1)* (ZRATDP-1.0))
22 C
23 C
24 C BUOYANCY CONSIDERATION - SET FLAGS. C *LOVS* ACCOUNTS FOR MARGINAL STABILITY.
25 C *ILAB* = 2 DRY: UNSTABLE OR MARGINALLY STABLE.
26 C *ILAB* = 3 MOIST: UNSTABLE, OR MARGINALLY STABLE
27 C NEAR CLOUD-BASE.
28 C
29 LOVS=(ZTP1(JL,JK)-ZTCLD).GT.ZTCRIT
30 LOIS=(ZTP1(JL,JK)-ZTCLD).LT.0.
31 LOC(ZL)=WGED(ZL).NE.0
32 LOC(ZL)=WGED(ZL).NE.0
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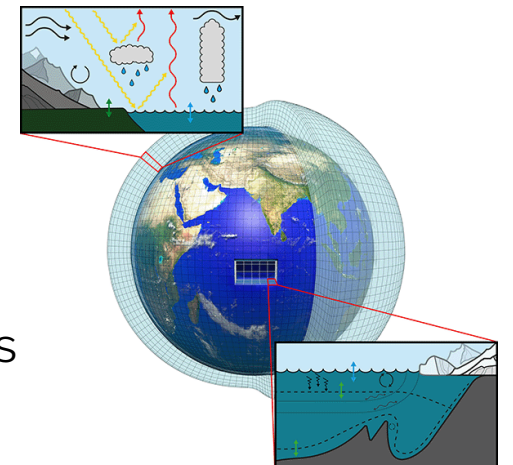
General Circulation Models (GCMs)

Vilhelm Bjerknes developed equations uniting thermodynamics and hydrodynamics, known as Bjerknes's General Theorem of Circulation. **Realised equations together describe the dynamics and physics of the atmosphere:**

- Clapeyron's ideal gas law
- Newton's laws of motion
- First law of thermodynamics
- Second law of thermodynamics
- Conservation of mass

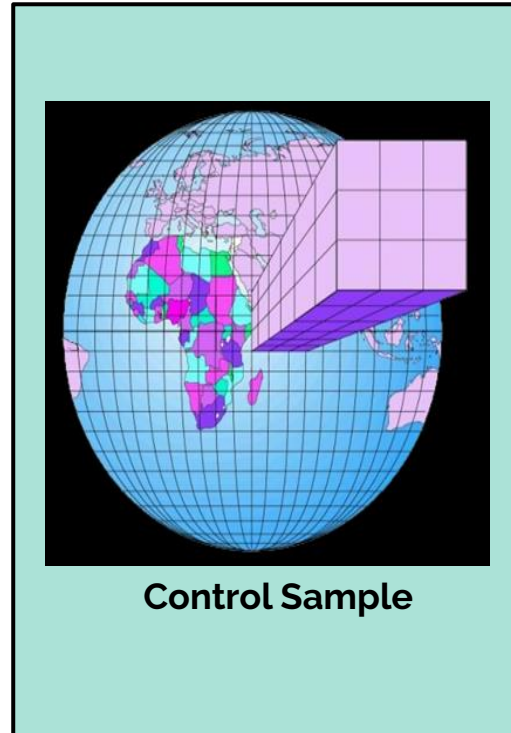


But, some processes are not represented by these equations – these are represented by simple equations or parameters e.g. convection

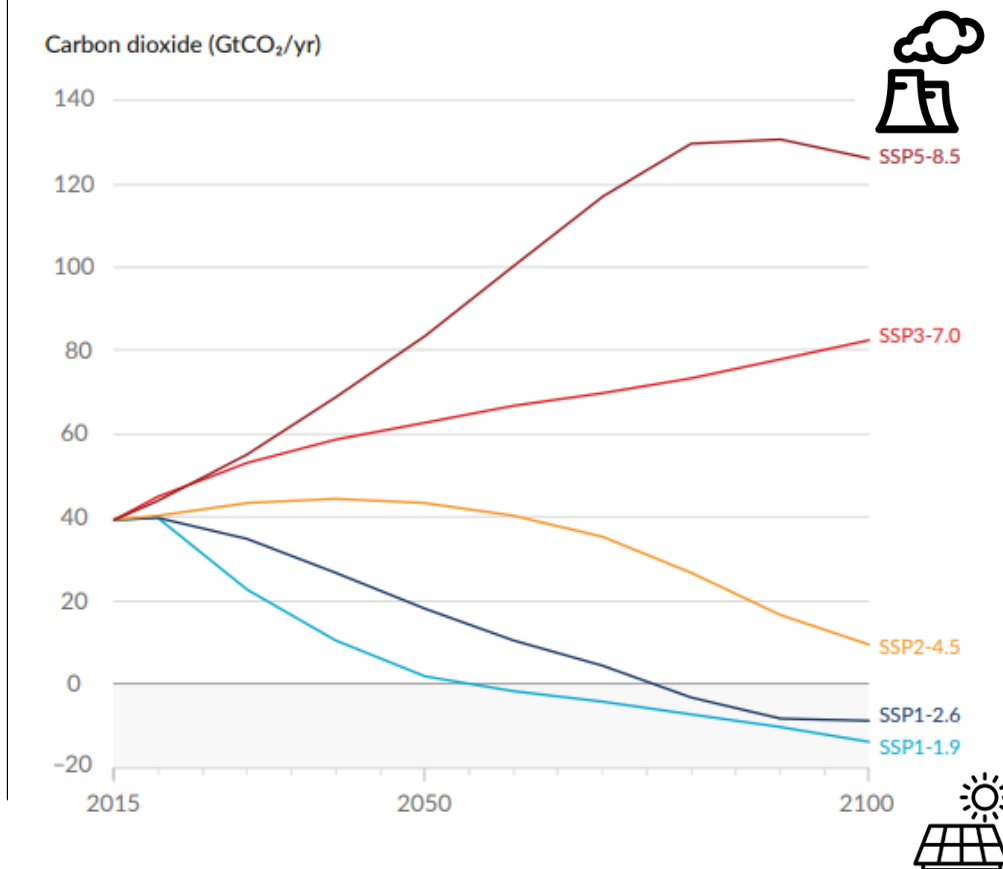


A climate change experiment

The climate modellers' experiment: **Future emissions cause future additional warming, with total warming dominated by past and future CO₂ emissions**



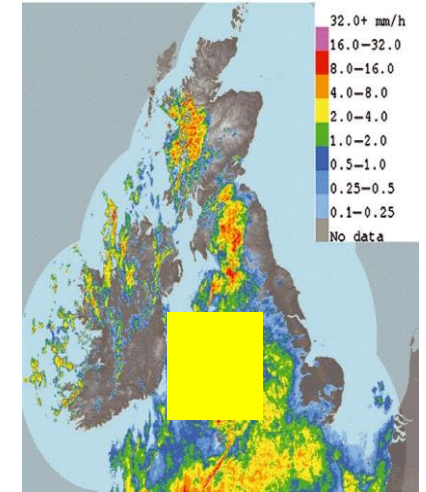
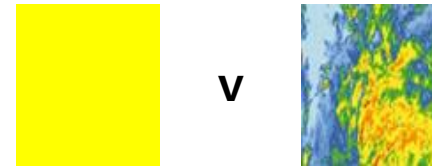
(a) Future annual emissions of CO₂ (left) and of a subset of key non-CO₂ drivers (right), across five illustrative scenarios



Source: IPCC AR6, [Summary for Policymakers](#)

Imagine you want to understand the impact of climate change on flooding in cities. You need to know how the intensity of rainfall will change in the future.

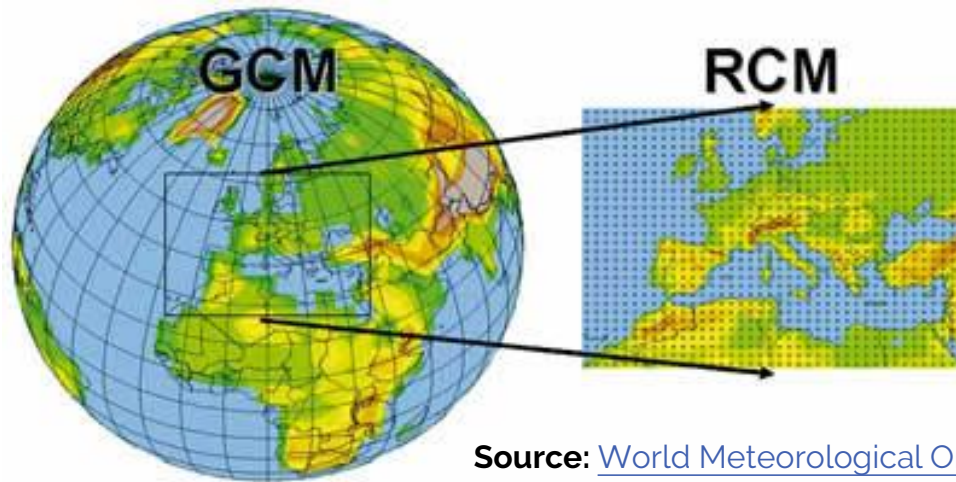
There is a gap between climate model resolution and that needed by users of climate information.



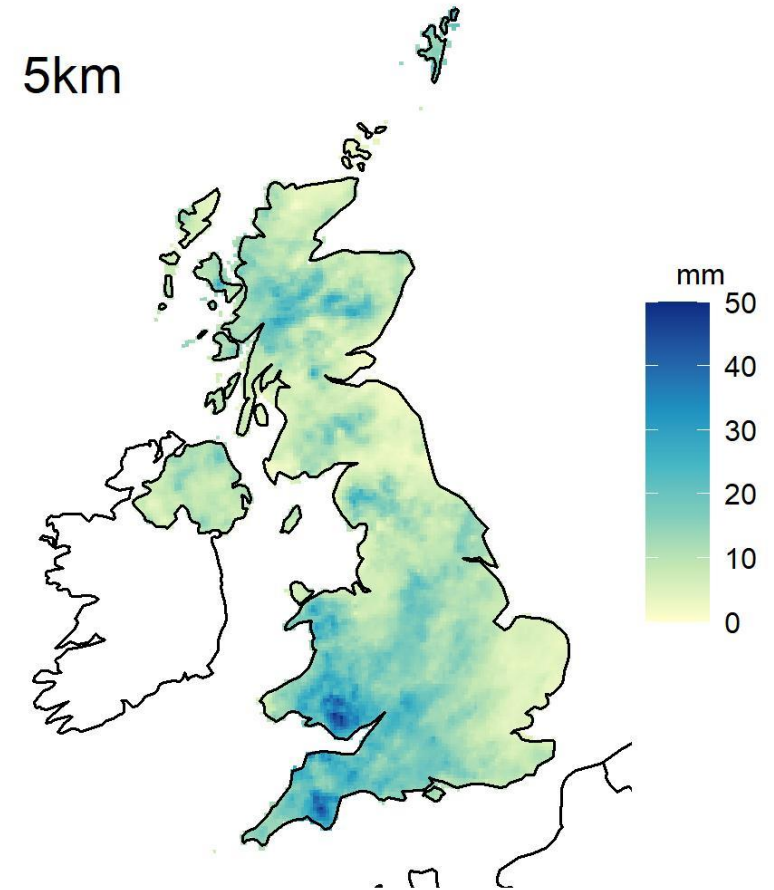
Thus, there is a need for local projections to assess the climate change impacts.

Downscaling refers to a range of techniques that aim to bridge this gap.

So, just as a higher resolution image provided more detail, so **dynamical downscaling** using **Regional Climate Models (RCMs)** can do the same.

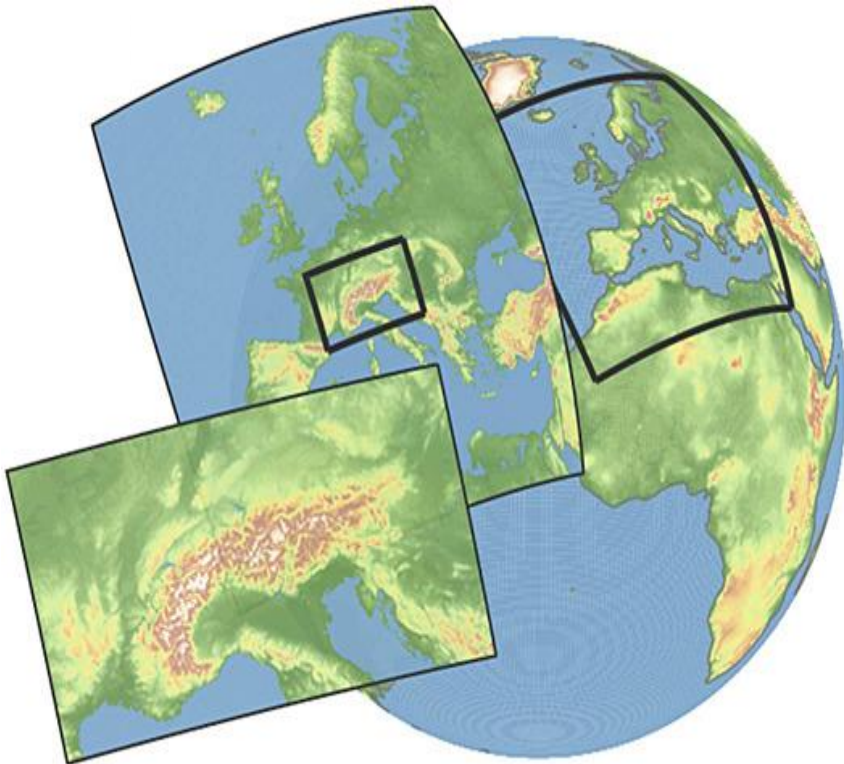


Source: [World Meteorological Organisation](http://www.wmo.int)



Very-high resolution models/convection-permitting models

Horizontal grid spacing $< 4\text{km}$, hourly simulations



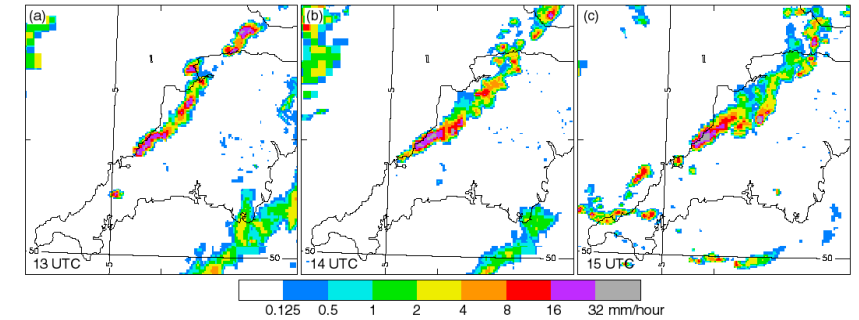
Source: Prein et al., 2015, Reviews of Geophysics



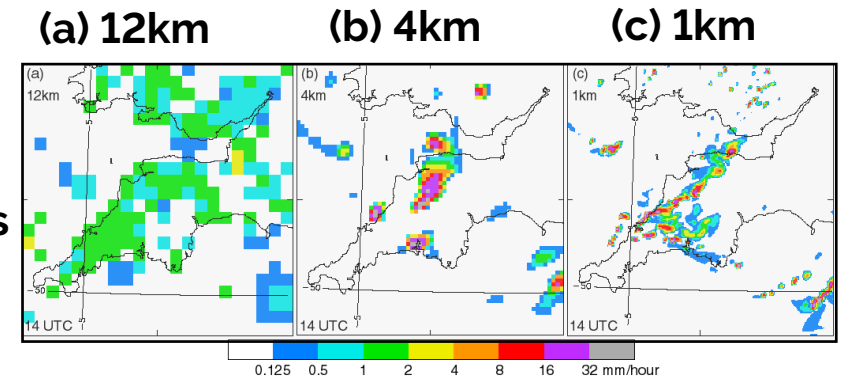
Source: UK Met Office



Hourly
rainfall
rates from
radar



Model
simulations



Case study: Boscastle, 16th Aug 2004; Courtesy: Nigel Roberts, UK Met Office

3. How might UK rainfall change in the future?

The [UK Climate Projections \(UKCP\)](#) provides the most up-to-date assessment of how the climate of the UK may change over the 21st century. The latest iteration (**UKCP18**) were released in 2018.

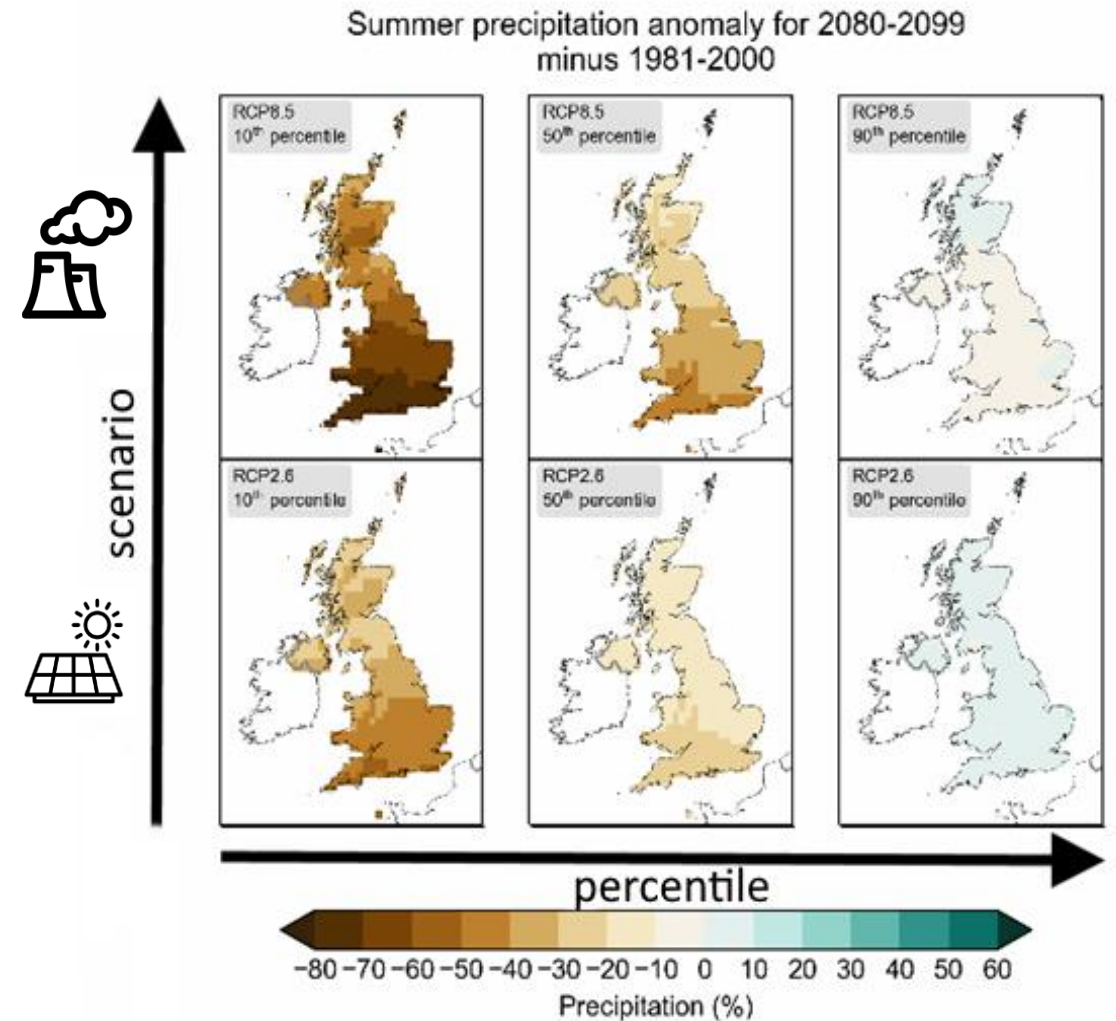
UKCP18 uses **state-of-the-art climate science** to provide updated **observations** and **climate change projections** from a range of models out to 2100 for the UK and globally.

Marine projections of sea-level rise and storm surge have also been updated.



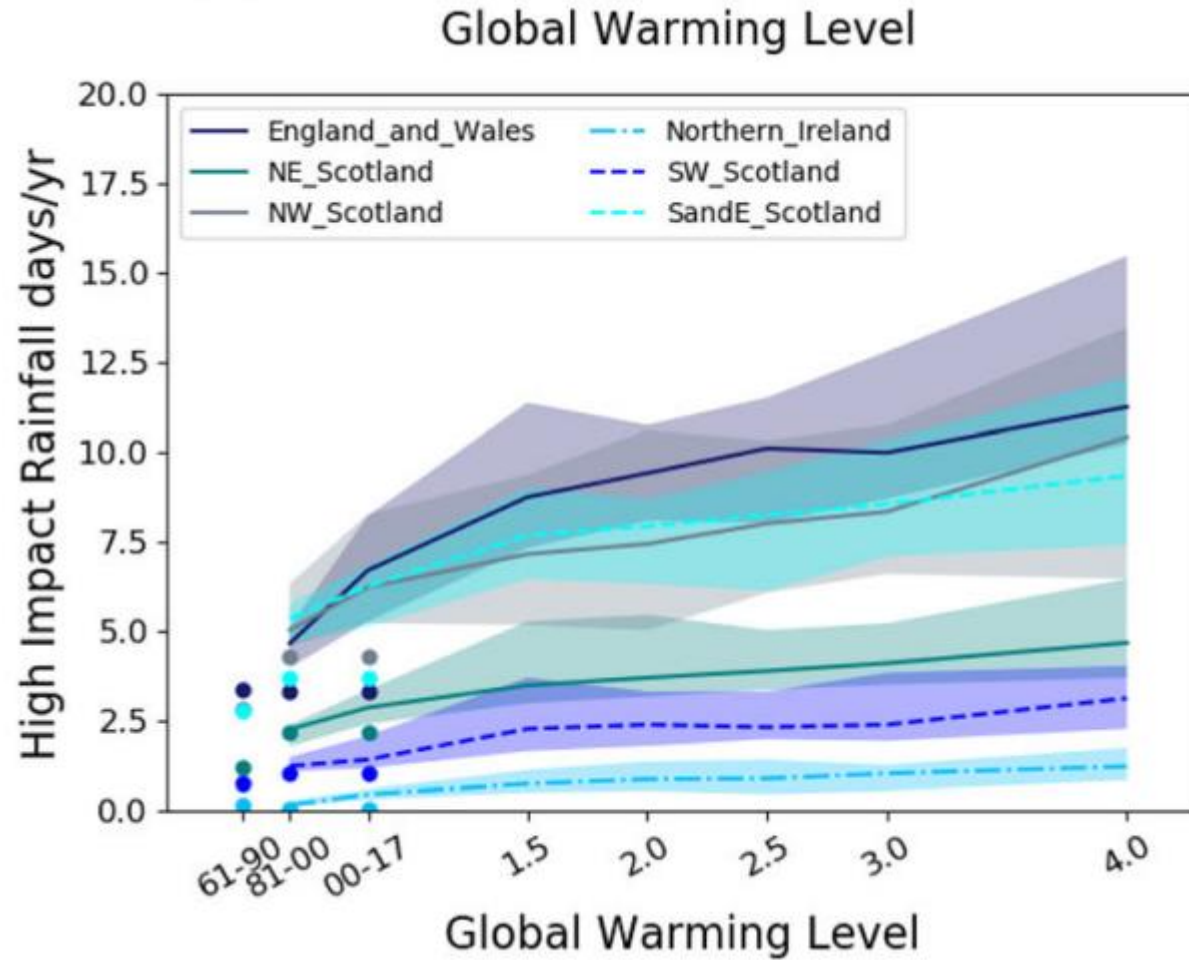
What does UKCP18 tell us about climate change?

- Winter precipitation is expected to increase significantly



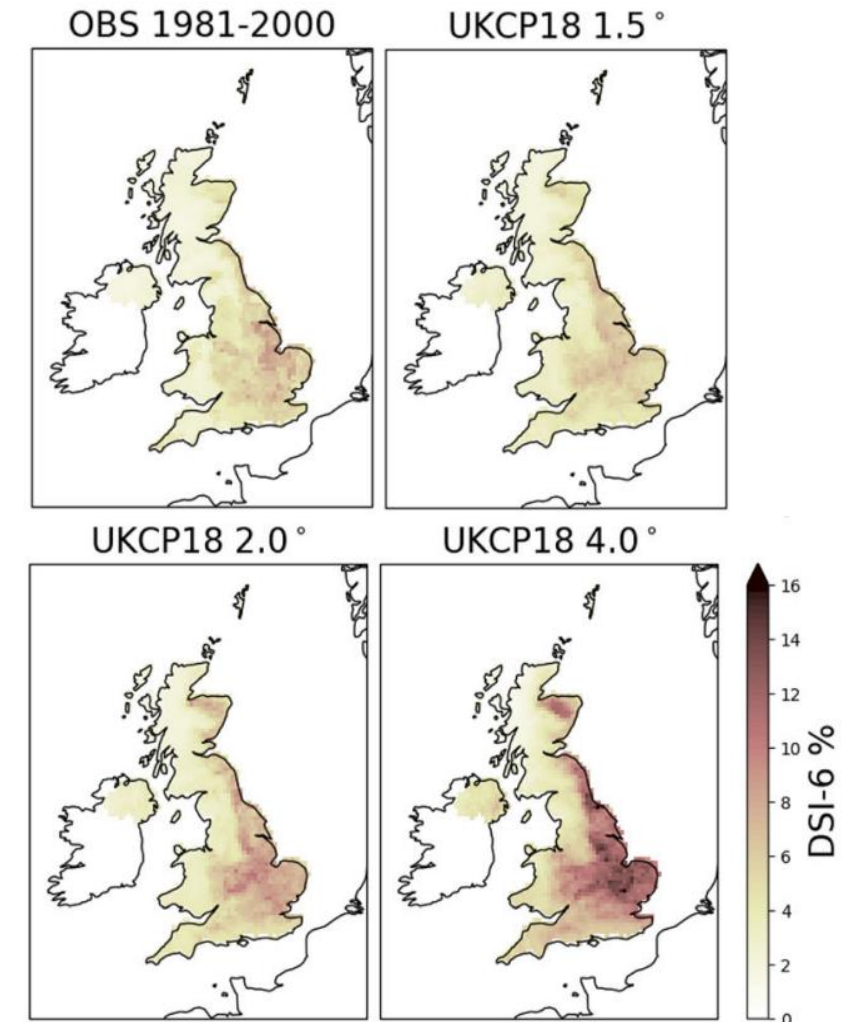
Remember that it is **extremes** that are critical for their impacts on natural and human systems.

High rainfall frequency (daily)



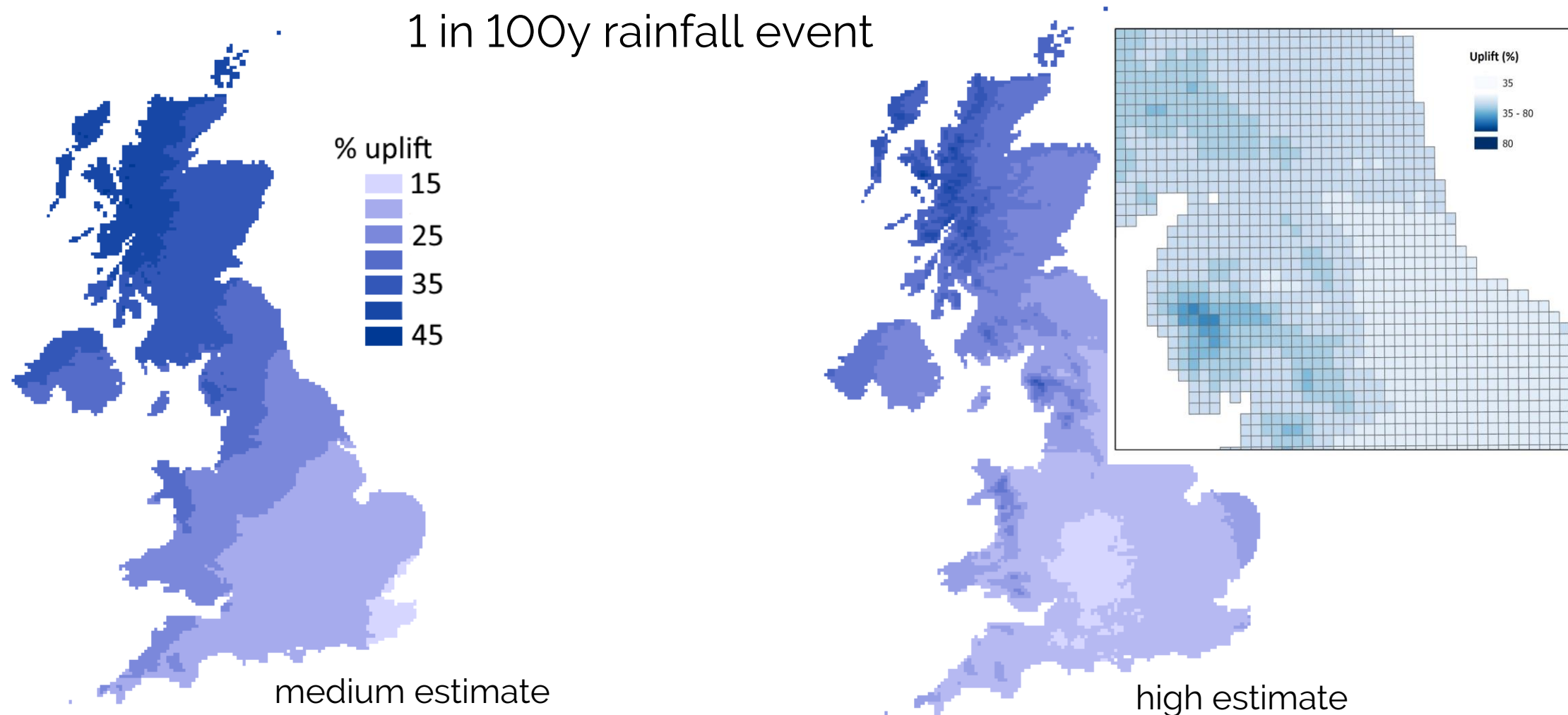
Source: [Hanlon et al. \(2021\)](#)

Drought intensity



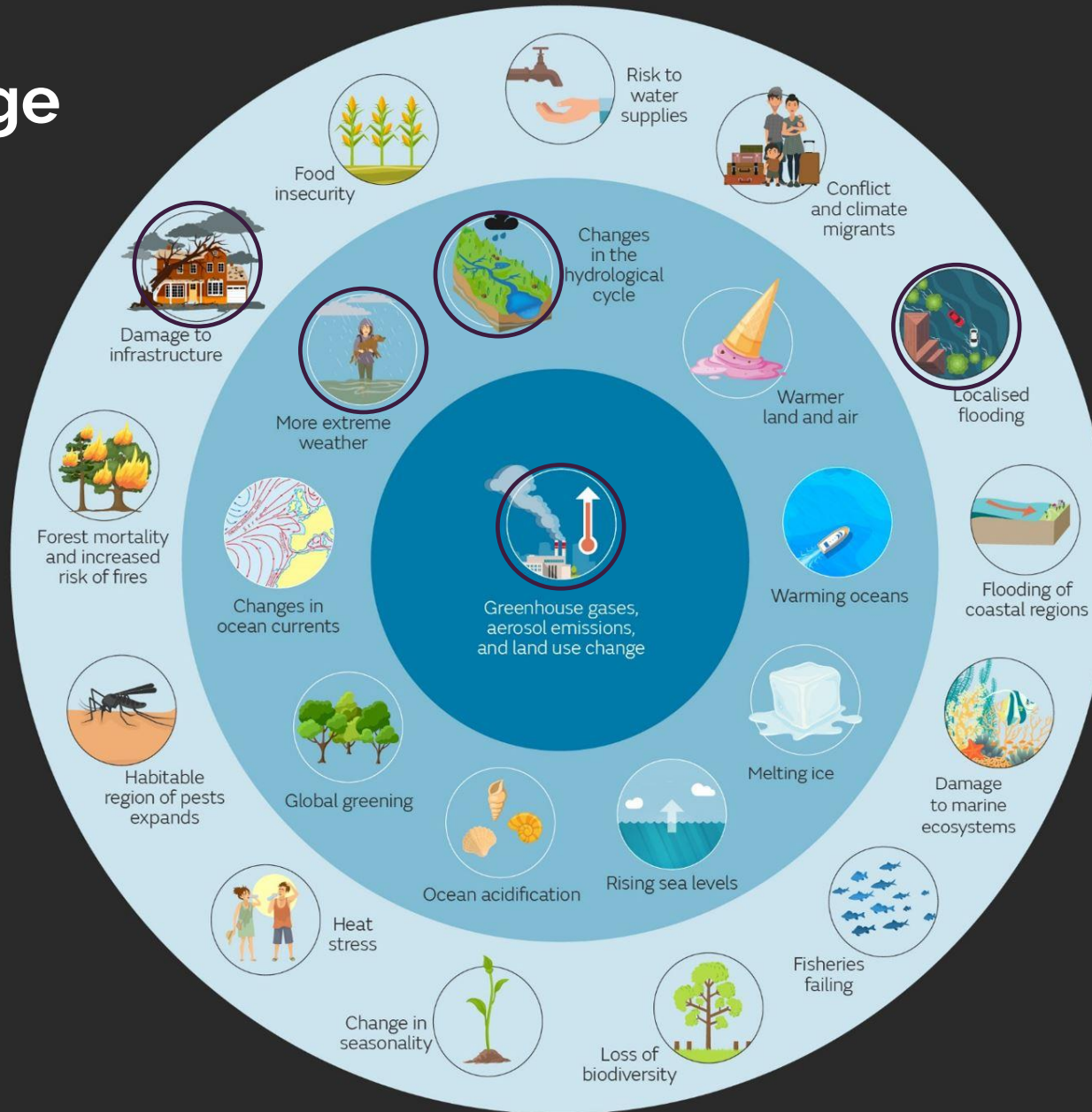
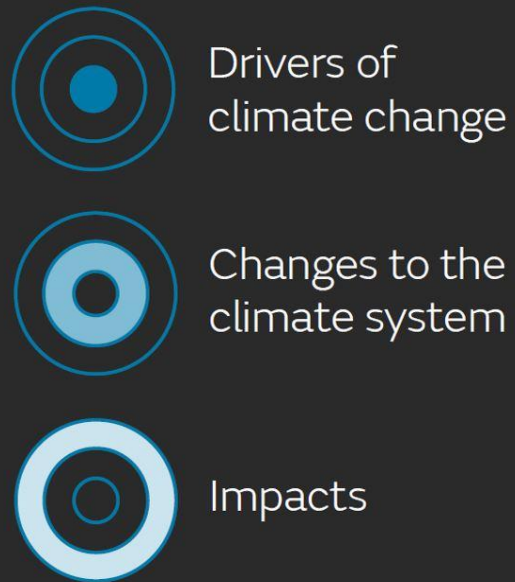
Extreme rainfall frequency (hourly)

1 in 100y rainfall event



4. What might be the impacts of these changes?

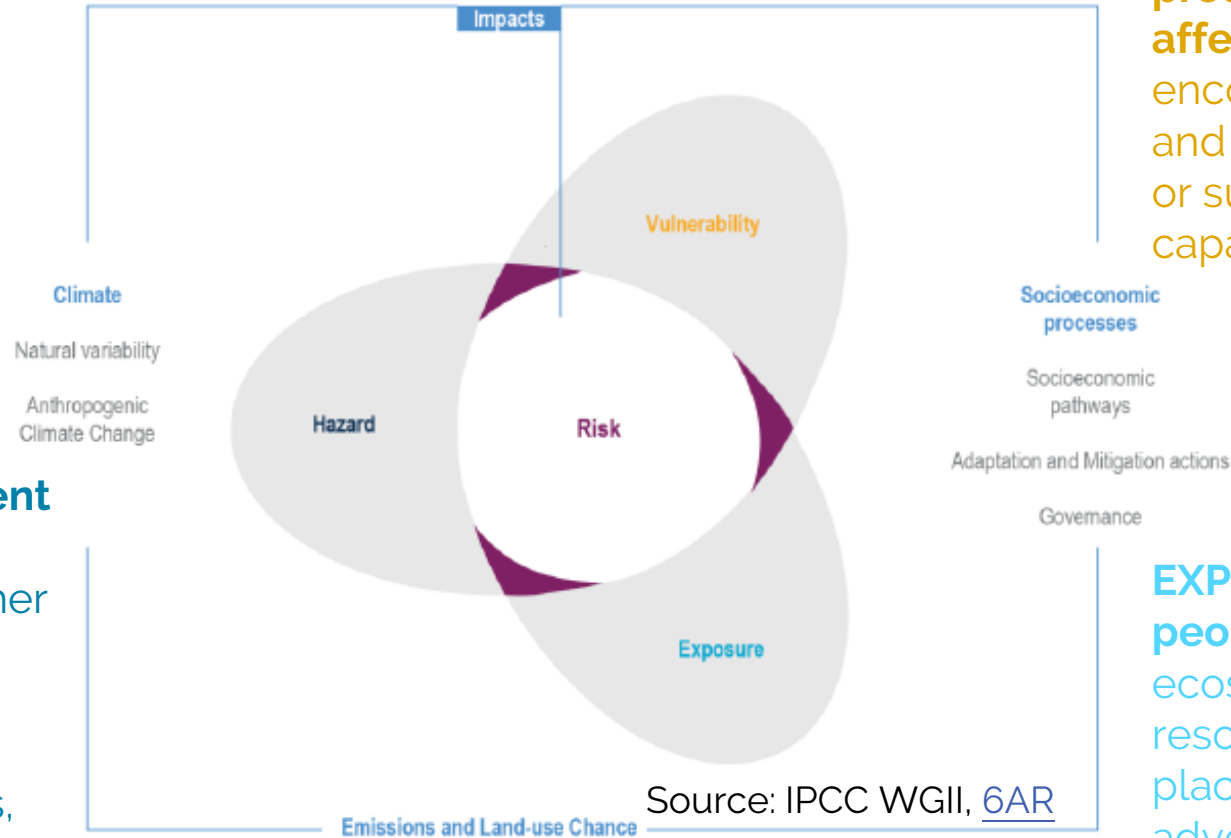
The Effects of Climate Change



What is risk?

The IPCC definition of risk:

HAZARD: The **potential occurrence of a natural or human-induced physical event** or physical impact that may cause loss of life, injury, or other health impacts, as well as damage to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.



VULNERABILITY: The propensity or **predisposition to be adversely affected**. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

EXPOSURE: The **presence of people**, livelihoods, species or ecosystems, services, and resources, infrastructure, or assets in places and settings that could be adversely affected.

Example: Risk from flooding

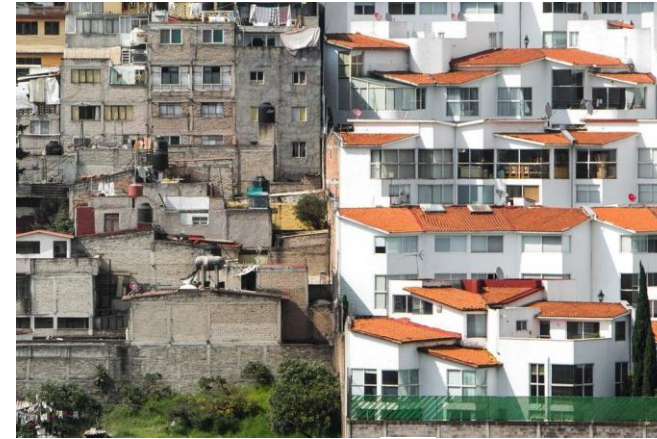


Credit: Michael Tyler (CC)

Hazard: current/future flood



Source: IPCC WGII, [6AR](#)



Credit: mwmbwls, Flickr (CC)

Vulnerability: the characteristics of the population/infrastructure/assets



Exposure: the number of people/ value of infrastructure or assets

River

Source: [geograph](#)



Surface water

Source: [BBC](#)



Number or length of infrastructure assets currently exposed to 'significant' risk of surface water or river flooding in England

Infrastructure Asset	Exposure to surface water flooding (1:30 or greater)	Exposure to river flooding (1:75 or greater)
Rail length (km)	1,691	444
Rail stations (no.)	450	44

Risk of river flooding to railway line and railway stations

- *+4°C in 2100 scenario (England)*
 - a projected 32% increase in length of rail at risk of river flooding by the 2080s, a 45% increase in railway stations at risk.
 - for surface flooding, the increase in risk is 57% for railway stations.

Source: [UK Climate Change Risk Assessment 3](#), Ch4: Infrastructure

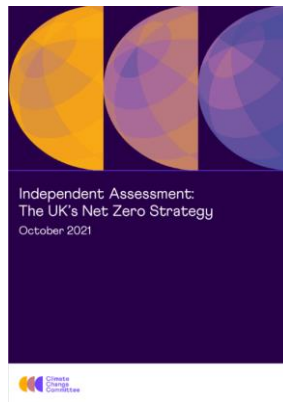
5. What can we do about future changes in rainfall?

Mitigation

Mitigation refers to a human activity that either reduces the sources or enhances the sinks of greenhouse gases (GHGs).

Range of actions include:

- Reduce emissions of GHGs
- Carbon capture and storage
- Carbon trading
- Geoengineering of the climate system



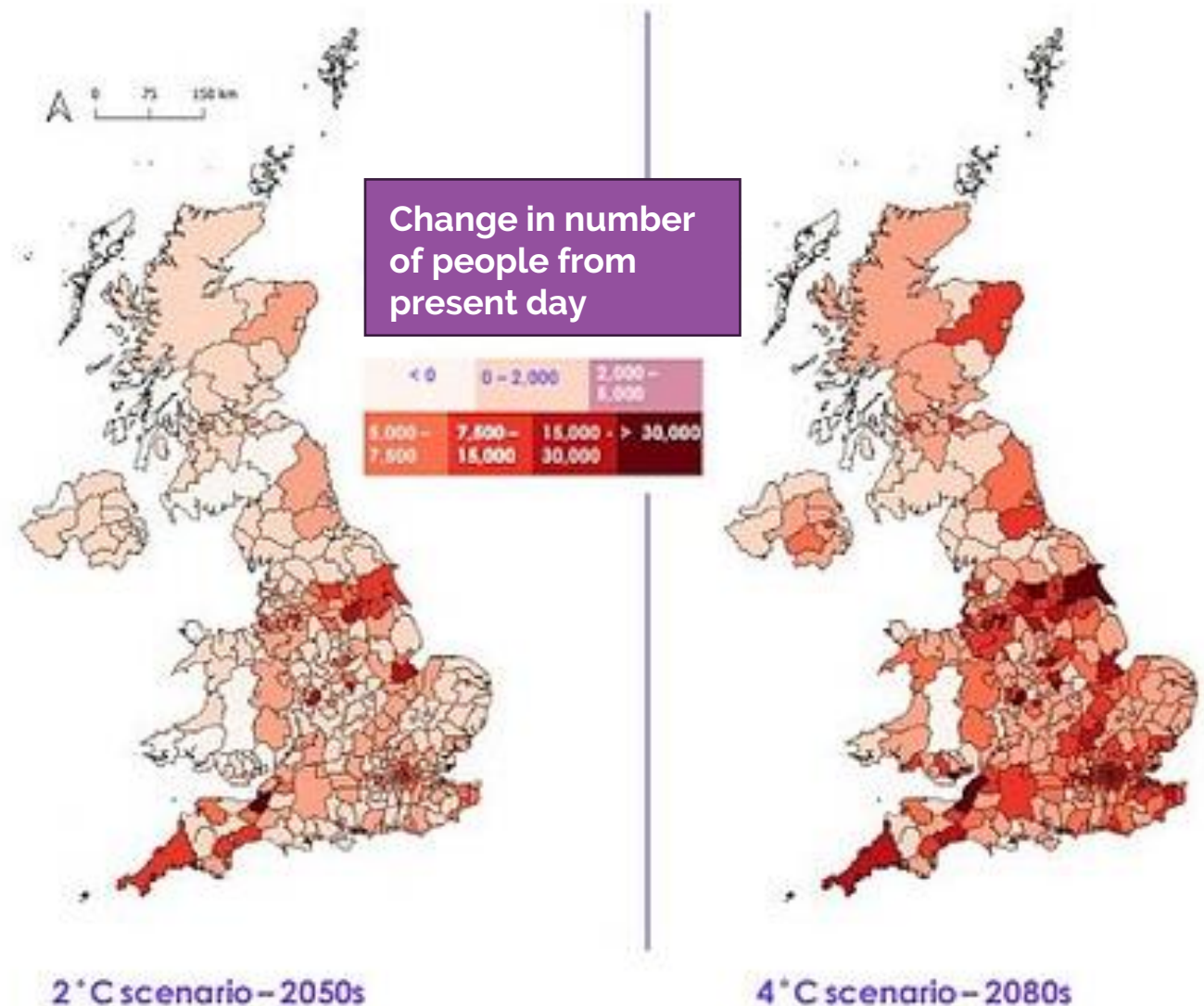
Paris Agreement 2015



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

Limiting climate change
limits risk

Change in number of
people exposed to
significant flood risk (all
sources)



Source: [Climate Change Committee](#) (2021)

Adaptation

Adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities.

Range of actions include:

- Adaptive infrastructure
- Emergency planning
- Behaviour change

Increased sewer capacity



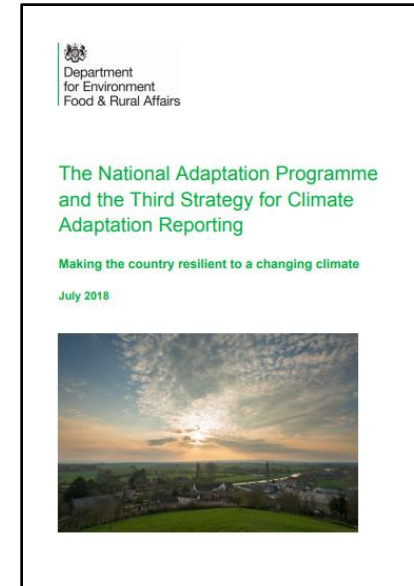
Green roofs



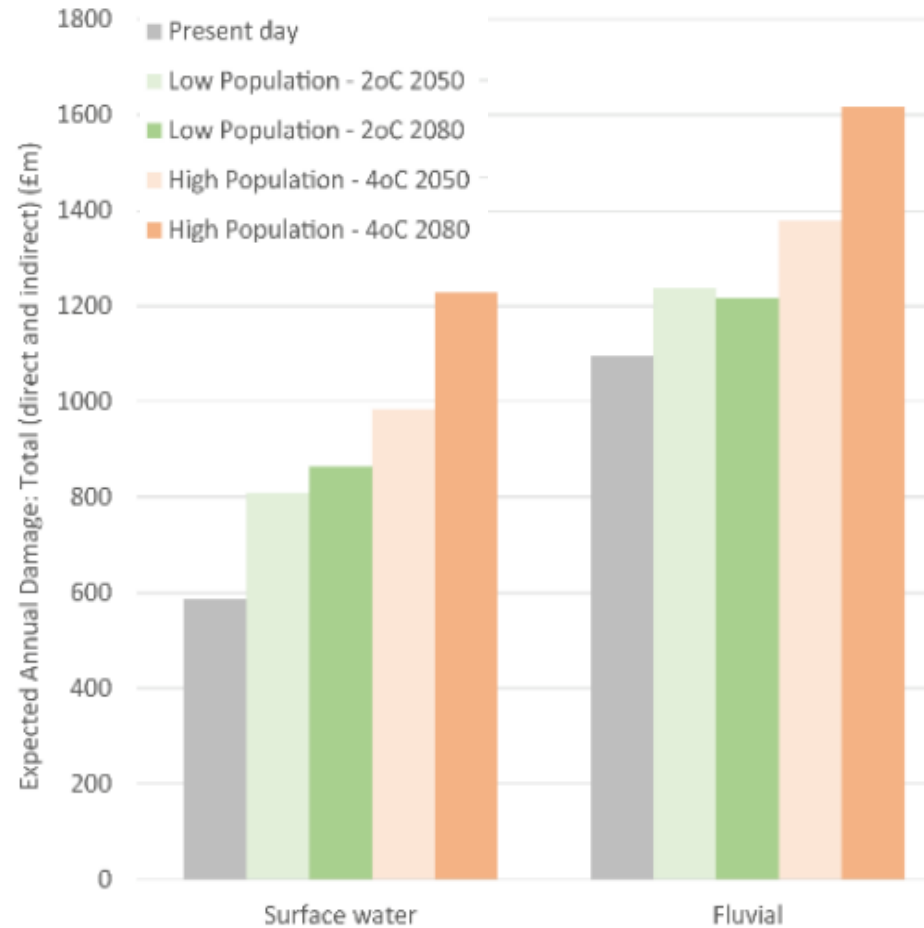
Flood defences



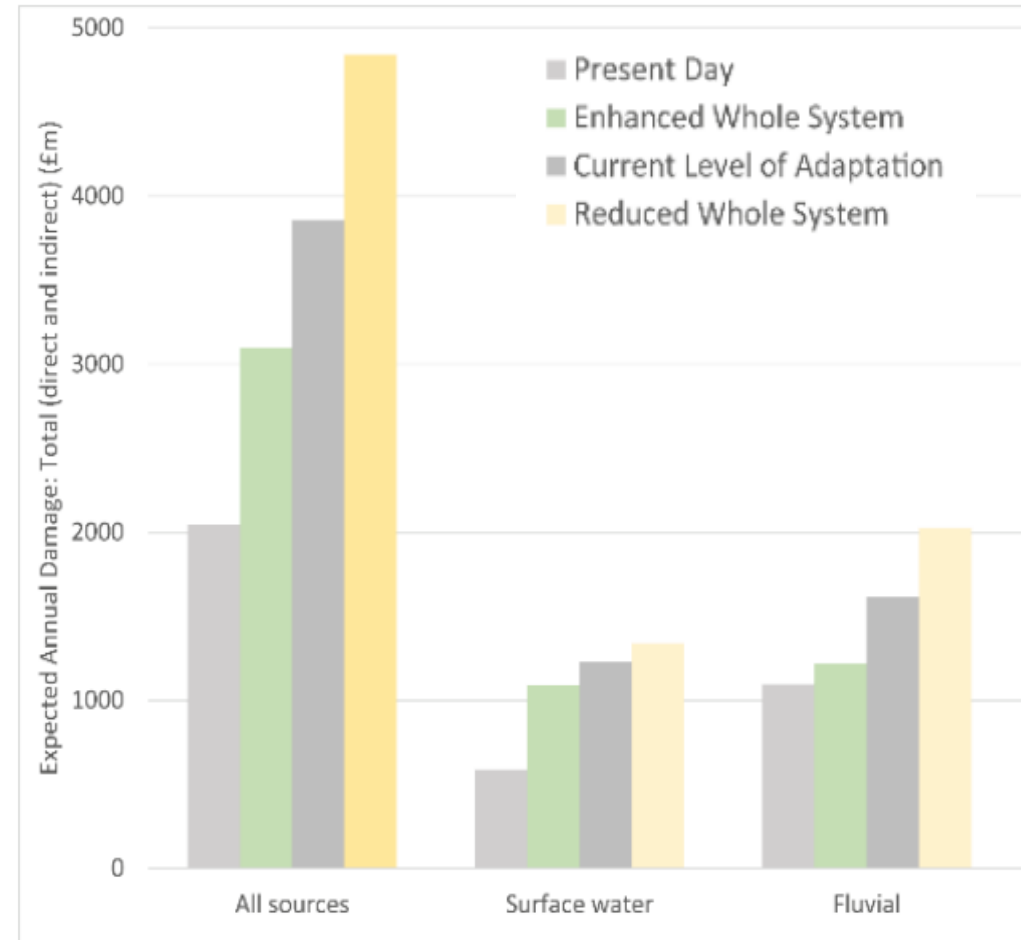
Greening cities



Expected annual damages



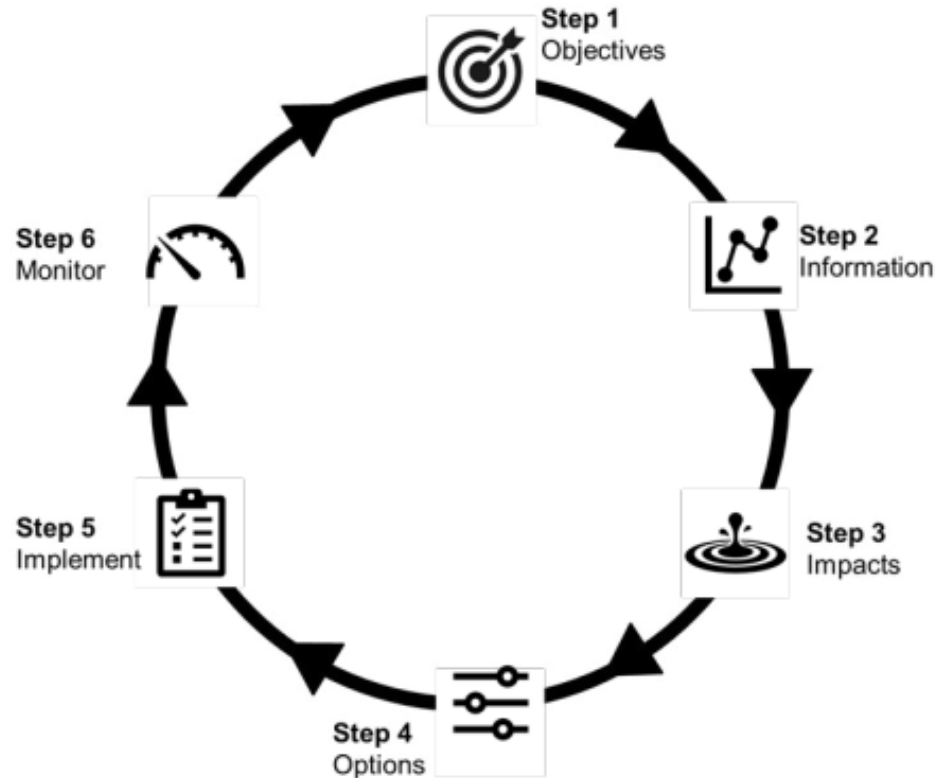
Expected annual damages, 2080s, 4°C, no population growth



Source: [Sayers et al. \(2020\)](#)

A framework to put climate change adaptation into practice

Commonly applied at the local scale:



Step 1: Set adaptation objectives (such as disruption or damages avoided) that align with national and sector plans for climate action.

Step 2: Gather contextual information to establish baseline knowledge and activities plus depth of analysis that is practically feasible.

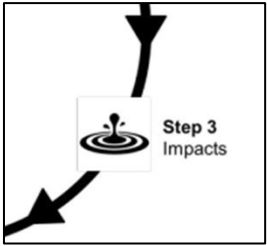
Step 3: Evaluate climate risks to vulnerable people, services and assets (including for mitigation actions) under present and expected climate variability and change.

Step 4: Identify adaptation options that manage or transfer identified climate risks.

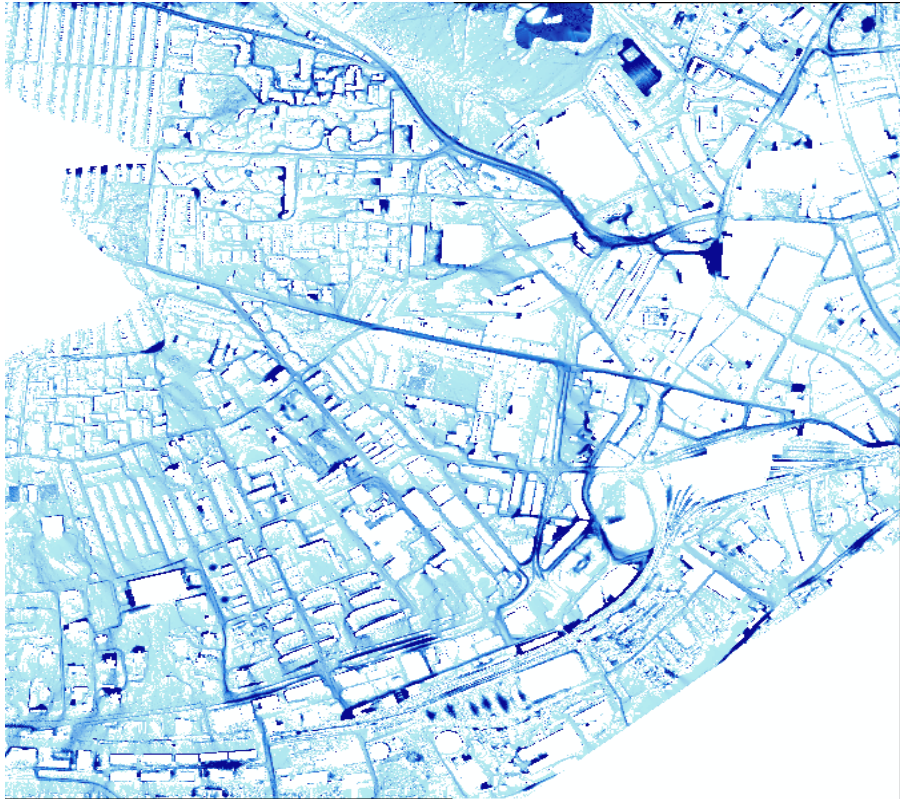
Step 5: Prioritise and implement adaptation actions using defined criteria, then schedule preferred options within planning pathways.

Step 6: Monitor evolving climate risks and evaluate adaptation outcomes.

Source: Asian Development Bank (2023). See [Wilby et al. \(2023\)](#)

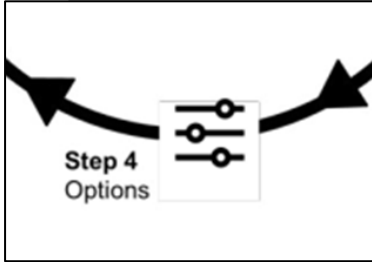


Assessing impacts/risk,...



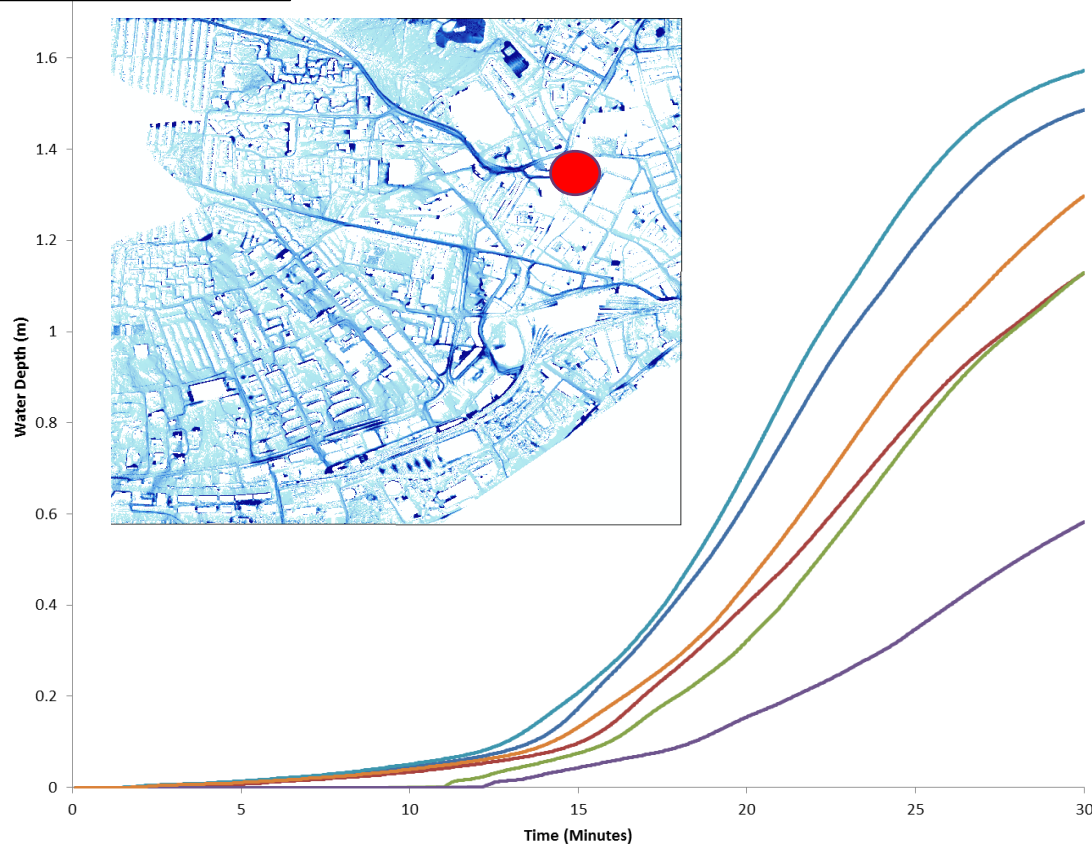
Risk might be assessed using:

- Damage (£)
- Loss of life
- Number of properties inundated
- Number of people affected
- Wider economic costs (£)



Testing different adaptation options

These are some of the interventions that may be considered by our drainage engineer in Newcastle who is deciding how to reduce surface water flood risk.



Are adaptations feasible, consistent with mitigation policy, and robust to uncertainties?



Source: [Reinhard Dietrich](#) 

'Despite encouraging trends, the rate and scale of adaptation progress at the national level is not enough to keep up with growing needs ... Growing climate risks require a step change in adaptation ambition'

UNEP, Adaptation Gap Report 2021

UK CCC: Our assessment has found very limited evidence of the implementation of adaptation at the scale needed to fully prepare for climate risks facing the UK across cities, communities, infrastructure, economy and ecosystems.

The gap between the level of adaptation and the level of risk is increasing, as adaptation action has failed to keep pace with climate risk.

- Future changes in rainfall are supported by multiple lines of evidence
- For the UK, wetter winters, drier summers, greater intensity of summer storms
- Action on emissions will enable us to avoid the worst but failure to do so will require more adaptation. We need to avoid lock-in risks.



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