Met Office

Climate change and its effects on the UK

Professor Adam Scaife
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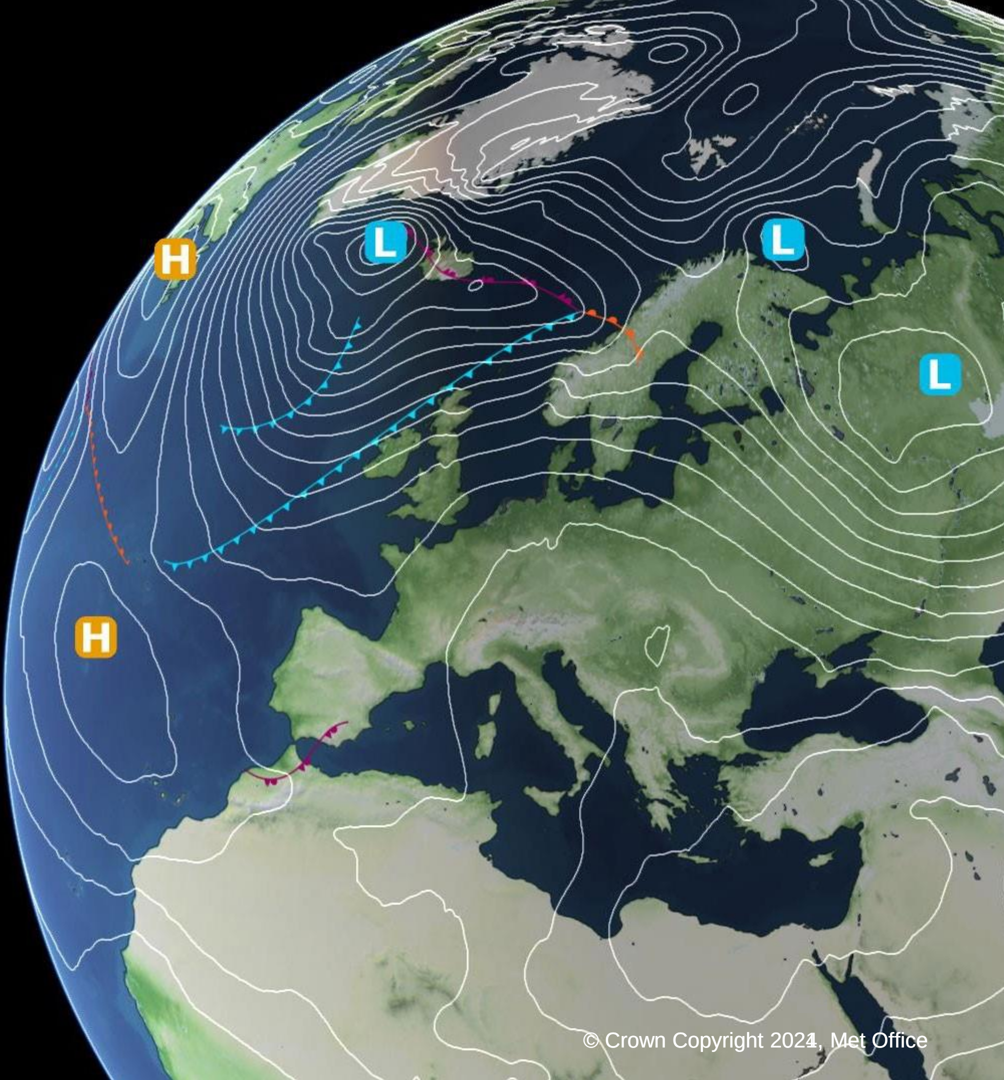
Dept Mathematics, University of Exeter



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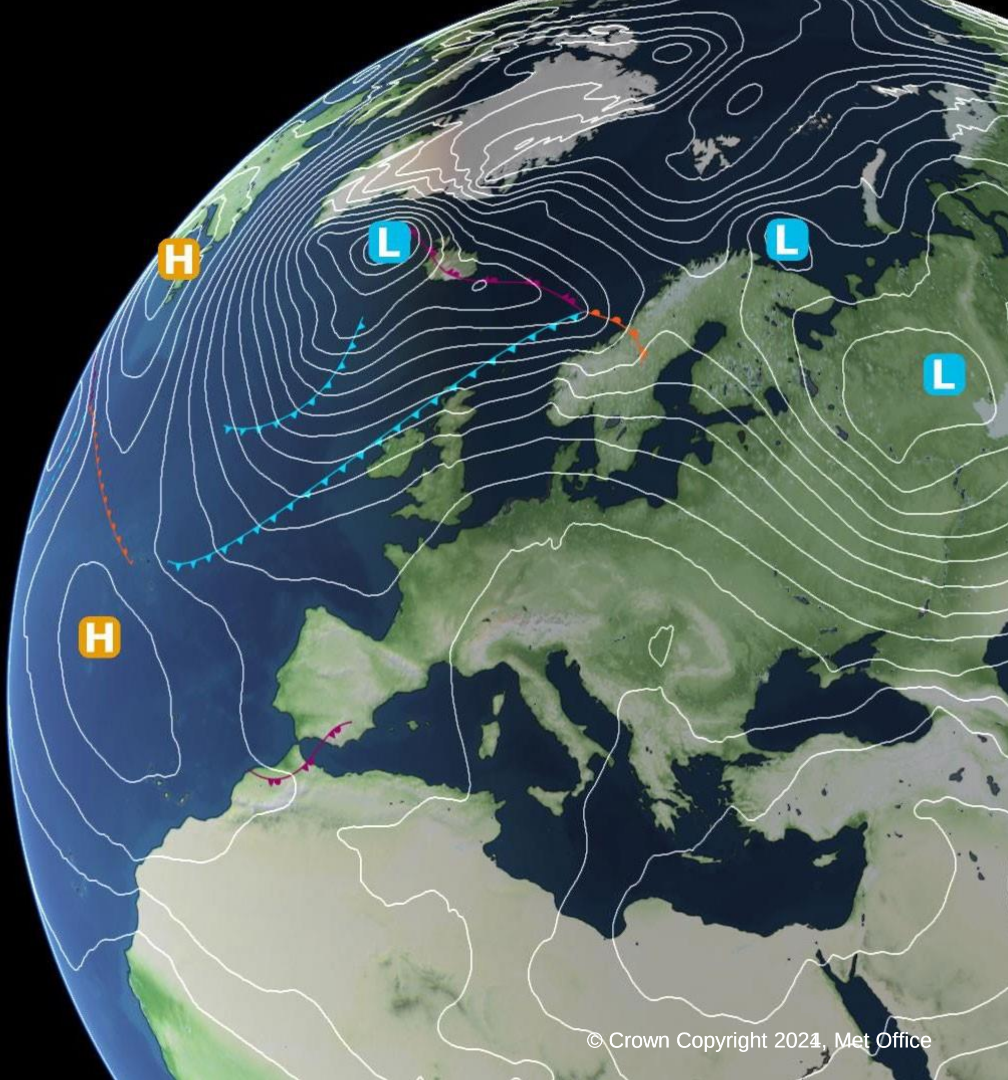
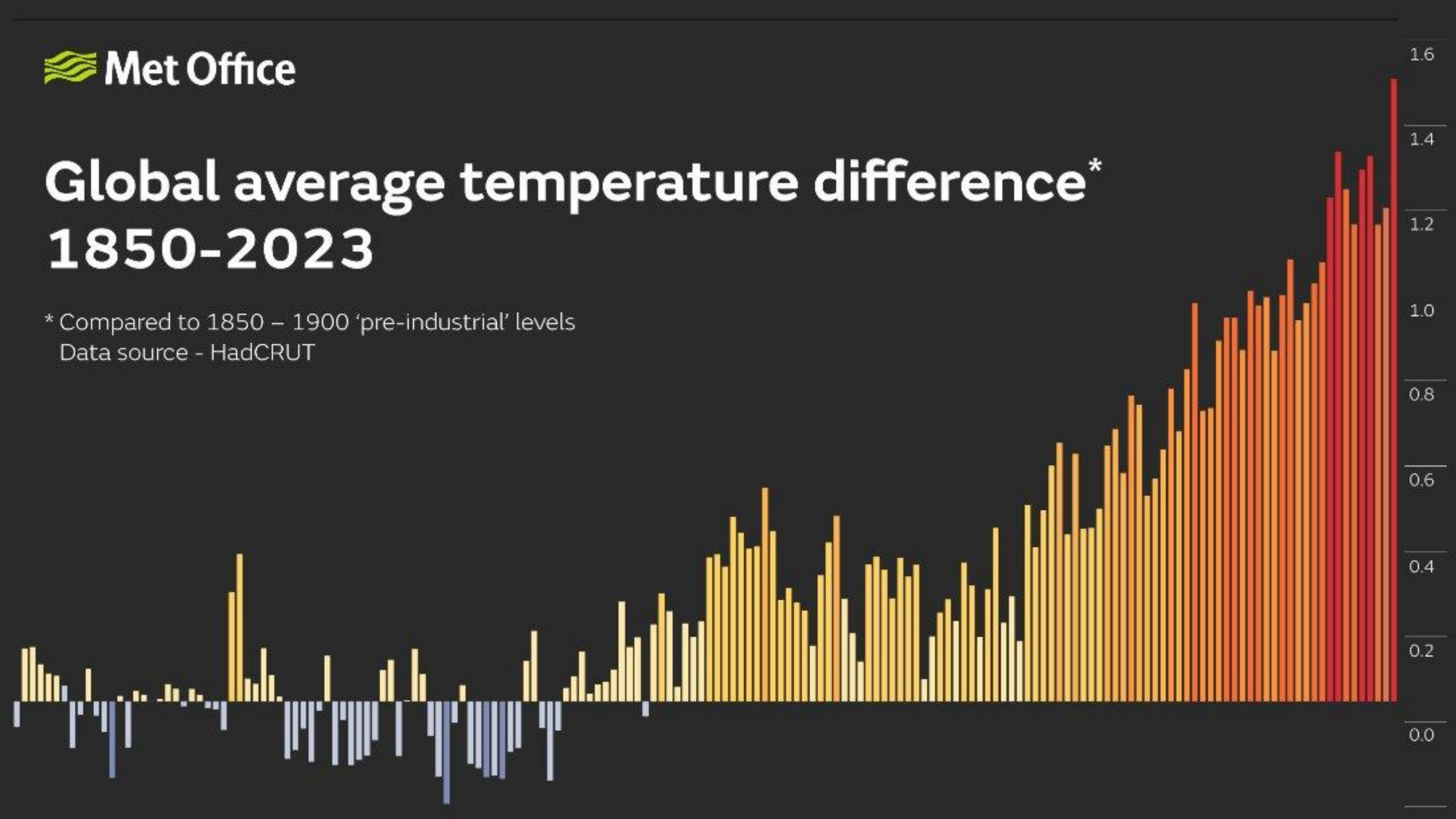
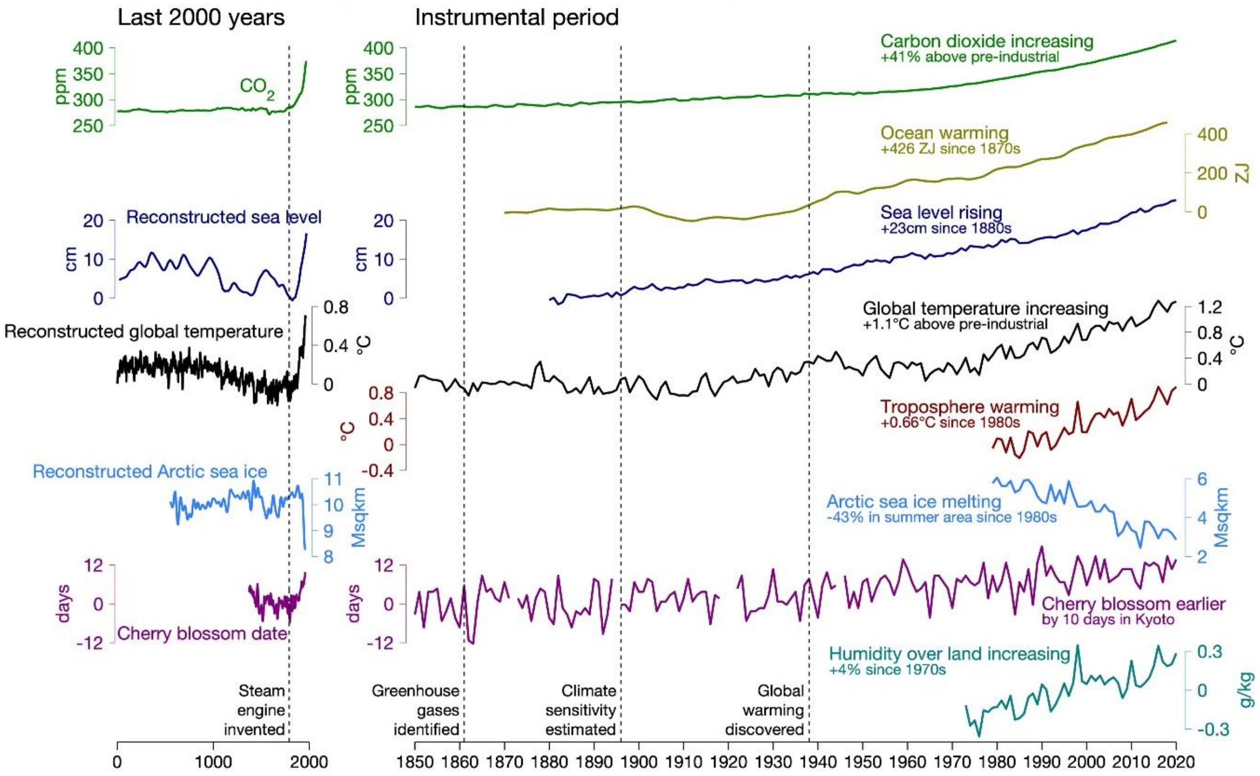
What is the climate change problem?




Met Office
Global average temperature difference*
1850-2023
* Compared to 1850 – 1900 'pre-industrial' levels
Data source - HadCRUT
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0

Changes *observed* across the climate system

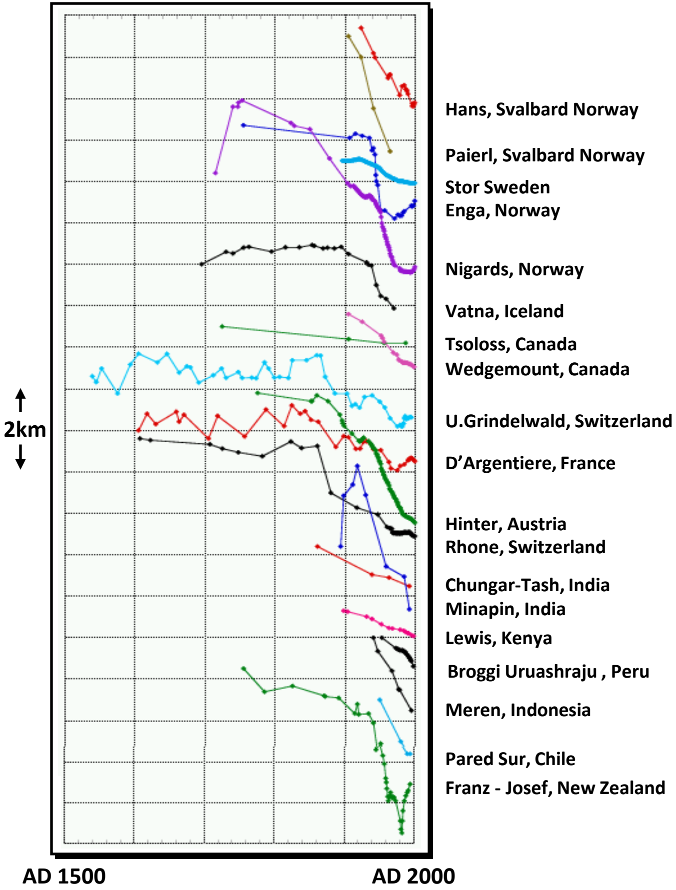


- **Ocean warming and expanding**
- **Global warming stands at about 1.3°C**
- **Arctic sea ice and land ice decreasing**
- **Biological impacts emerging**

Source: Climate Lab Book, 2021

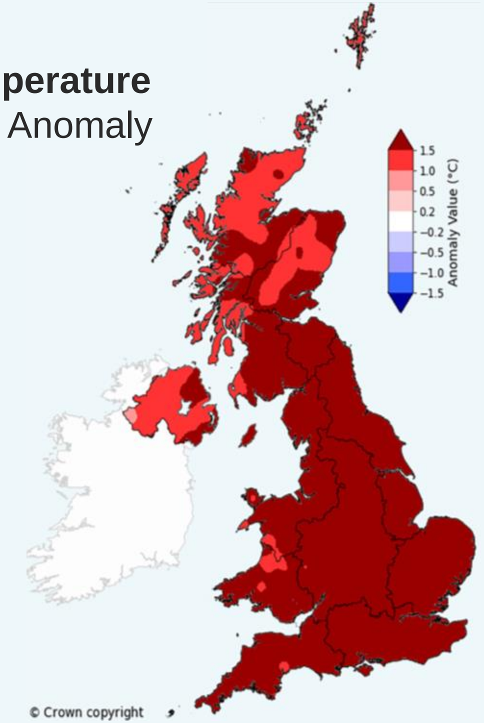
Glaciers

Pasterze Glacier in the Austrian Alps

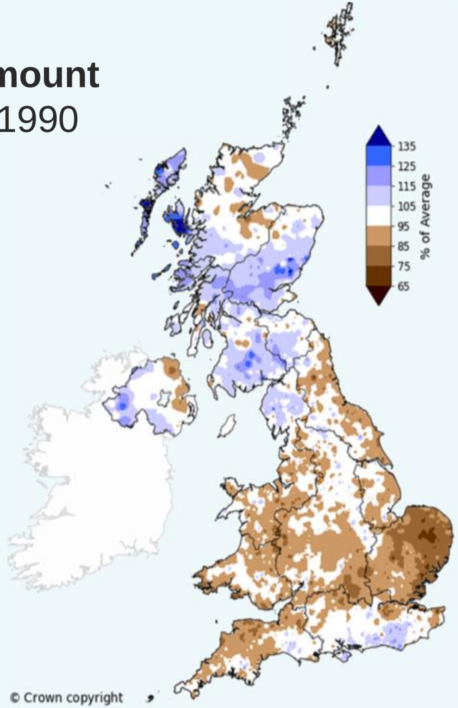


The UK climate is changing too

Year 2022
Mean Temperature
1961-1990 Anomaly



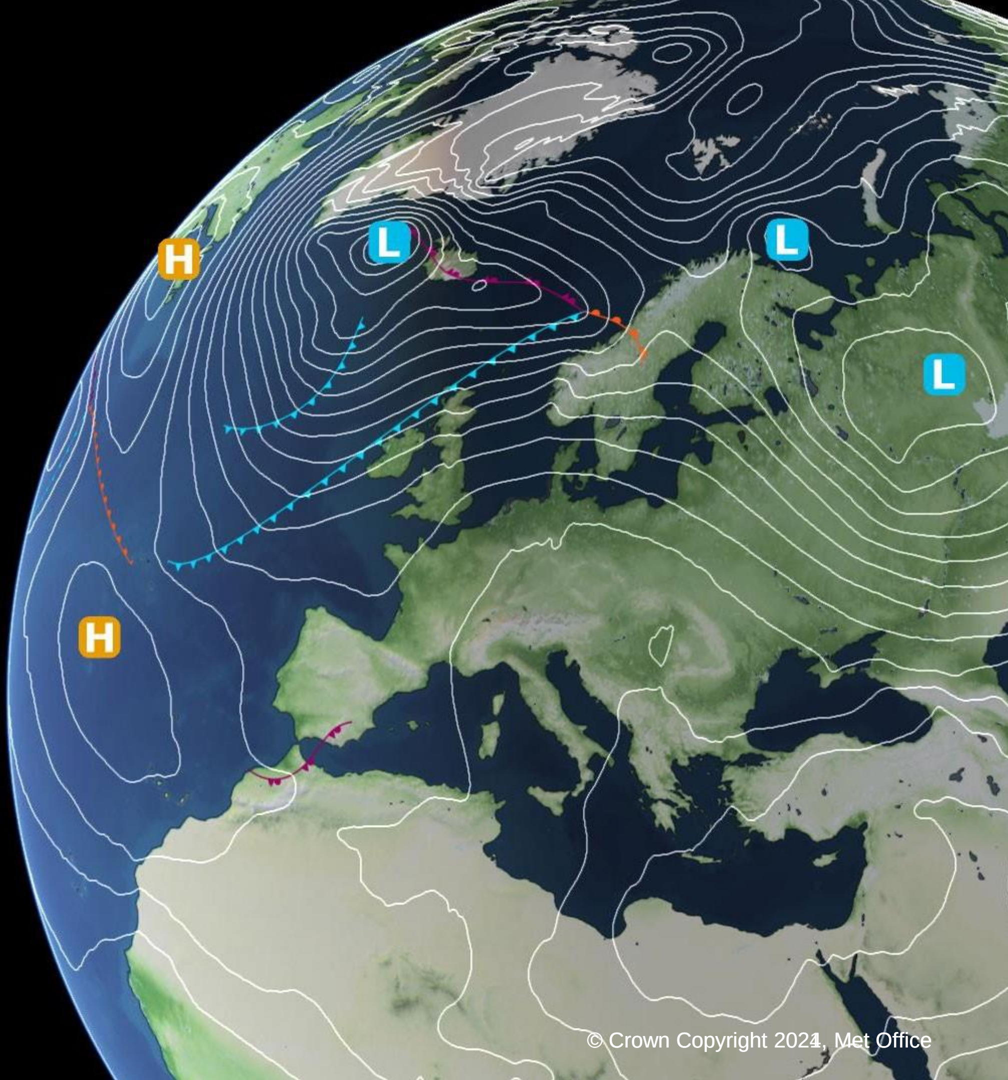
Year 2022
Rainfall Amount
% of 1961-1990
Average



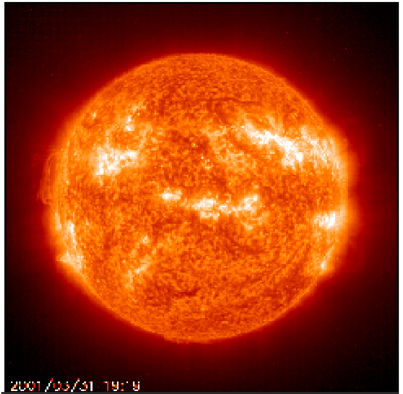
Source: Met Office HadUK-Grid data

Met Office

What is the cause?

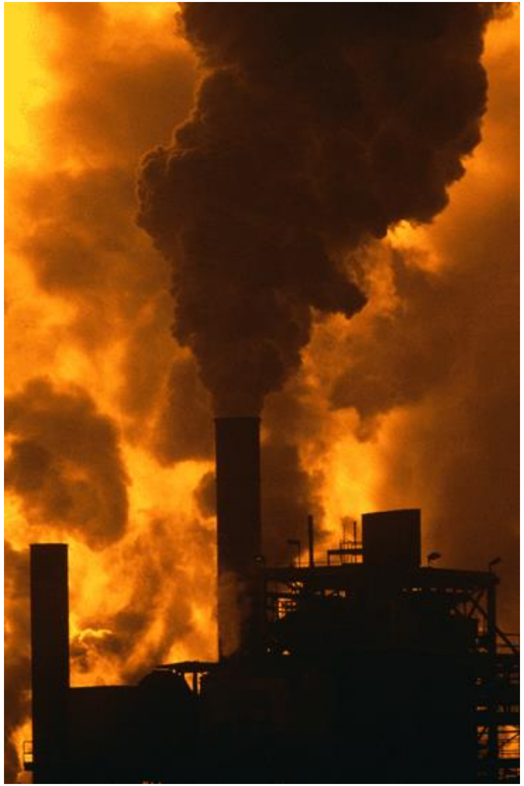


Natural causes of climate change



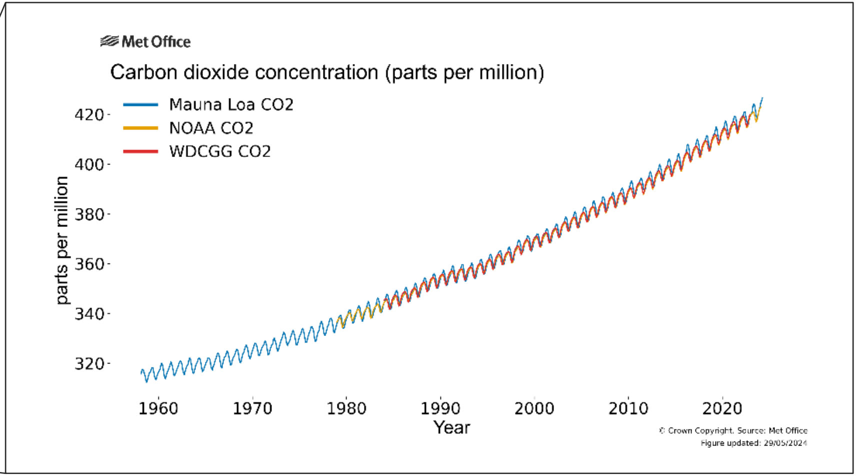
- Long-term changes in Earth’s orbit (Milanković cycles)
- Variation in solar output incident on Earth
- Changes in atmospheric aerosols from large volcanic eruptions

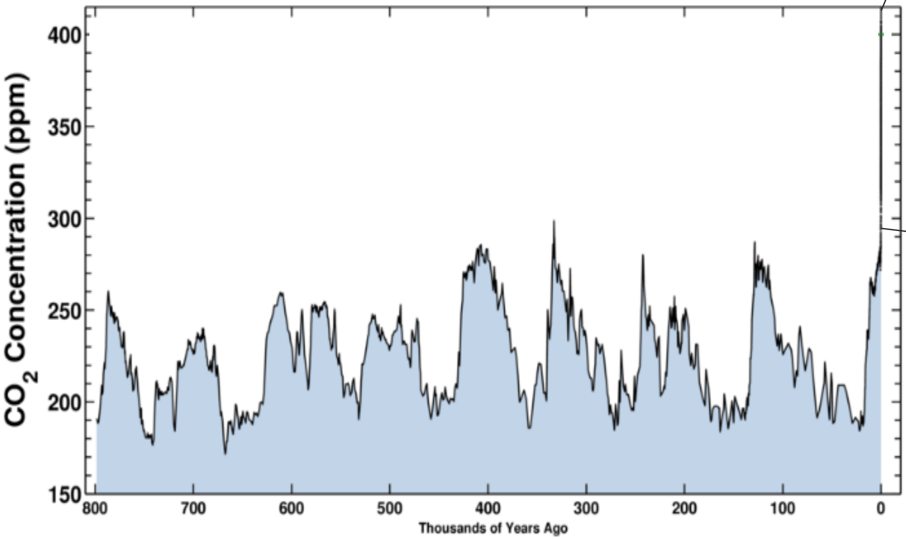
Anthropogenic climate change



- Greenhouse gases – warming
- Sulphur aerosols – cooling
- Direct cooling: scatter/reflect incoming solar radiation
- Indirect cooling: make clouds brighter and long lived – scatter back more solar radiation

Current levels of atmospheric CO_2 are unprecedented





Source: https://scripps.ucsd.edu/programs/keelingcurve/

Since the Industrial Revolution in the 18th century, CO_2 in the atmosphere has risen by more than 45%

Now >410 parts per million (ppm).

Records of Earth's climate, from Antarctic ice cores show that current CO_2 level is higher than at any time in at least the last 2 million years.

Climate Change is not a new idea…

1000s of calculations by hand: 5-6K warming!

THE LONDON, EDINBURGH AND DUBLIN

PHILOSOPHICAL MAGAZINE AND JOURNAL OF SCIENCE

[FIFTH SERIES APRIL 1896]

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS*.

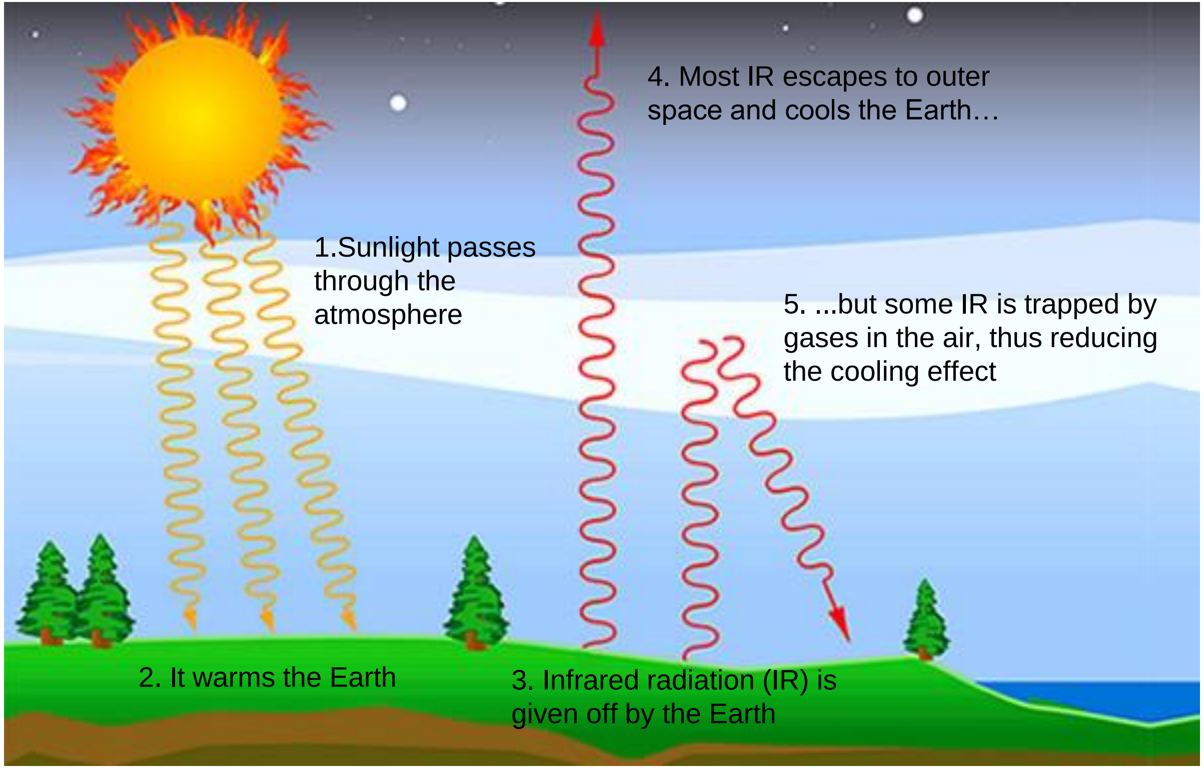
1. Introduction: Observations of Langley on Atmospherical Absorption.

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier ‡ maintained that the atmosphere acts like the glass in a hot house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that 'the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to – 200 °C., if that atmosphere did not possess the

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December 1895. Communicated by the Author.

† "Heat a mode of motion," 2nd ed. p.405 (Lond.,1865).
‡ *Mem. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.
§ *Compress rendus*, t. vii. p41 (1838).

The greenhouse effect



Physics based models of Weather and Climate

Newton's second law

$$\frac{D_r u}{Dt} - \frac{uv\tan\phi}{r} - 2\Omega\sin\phi v + \frac{c_{pd}\theta}{r\cos\phi}\frac{\partial\Pi}{\partial\lambda} = -\left(\frac{uw}{r} + 2\Omega\cos\phi w\right) + S^u$$

$$\frac{D_r v}{Dt} + \frac{u^2\tan\phi}{r} + 2\Omega\sin\phi u + \frac{c_{pd}\theta}{r}\frac{\partial\Pi}{\partial\phi} = -\left(\frac{vw}{r}\right) + S^v$$

$$\frac{D_r w}{Dt} + c_{pd}\theta\frac{\partial\Pi}{\partial r} + \frac{\partial\Pi}{\partial r} = \left(\frac{u^2+v^2}{r}\right) + 2\Omega\cos\phi u + S^w$$

mass continuity

$$\frac{D_r}{Dt}\left(\rho_d r^2\cos\phi\right) + \rho_d r^2\cos\phi\left[\frac{\partial}{\partial\lambda}\left(\frac{u}{r\cos\phi}\right) + \frac{\partial}{\partial\phi}\left(\frac{v}{r}\right) + \frac{\partial w}{\partial r}\right] = 0$$

thermodynamics

$$\frac{D_r\theta}{Dt} = S^\theta$$

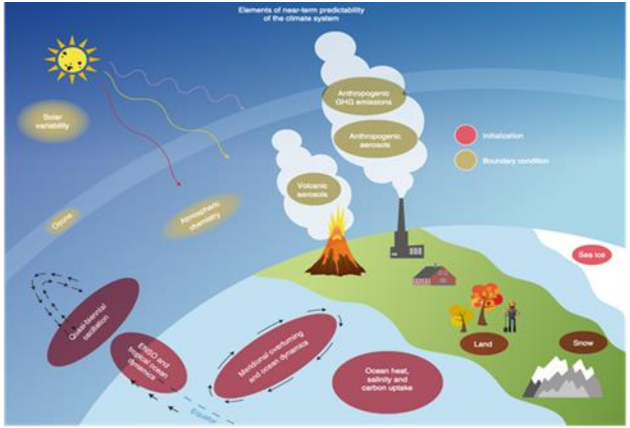
The Navier–Stokes equations for fluid flow are at the heart of climate models. The first three equations represent Newton's second law and give the acceleration of the winds in the east–west (u), north–south (v) and vertical directions (w). The mass-continuity equation ensures that although the density, speed and direction of the air change as it flows around the Earth, its mass is conserved, while the thermodynamic equation allows heat-transfer processes such as heating by the Sun to be included as a parametrized source term (S). We use the same equations to model the dynamics of the ocean, but usually make further simplifying approximations. In the equations, r is the distance from the Earth's centre, Ω is the angular velocity of the Earth's rotation, ϕ is latitude, λ is longitude and t is time. c_p is the specific heat capacity of air at constant pressure, θ is potential virtual temperature, Π is the "Exner function" of pressure and ρ is air density. The subscript "d" refers to dry air.

Scaife et al, Physics World, 2007

5 fundamental equations + ideal gas law

Represented on a 3D grid of points and solved by computer

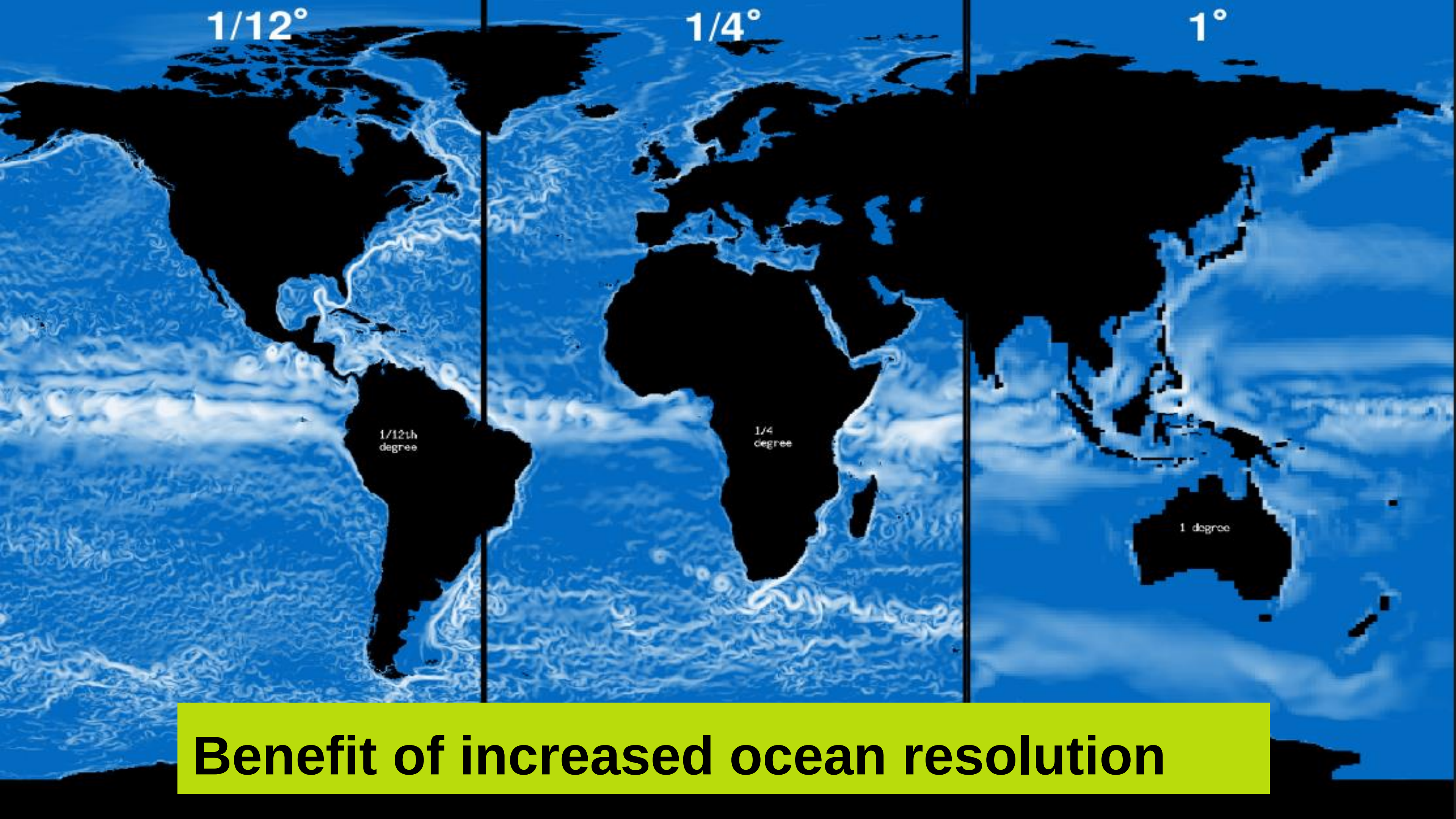
The problem is well defined but the devil is in the detail…



Kushnir et al, 2019

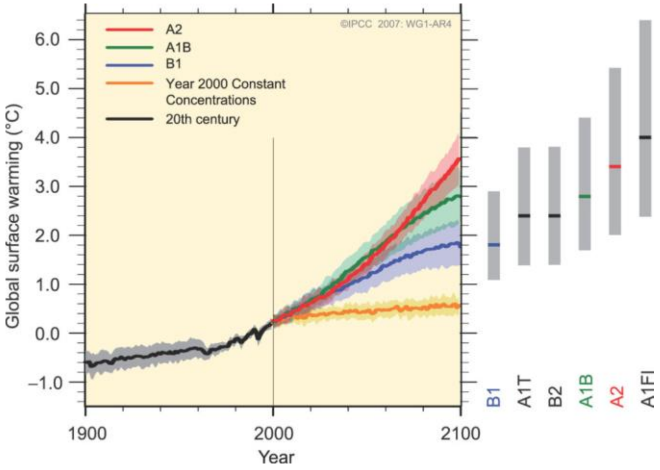
Prescribed external forcing agents

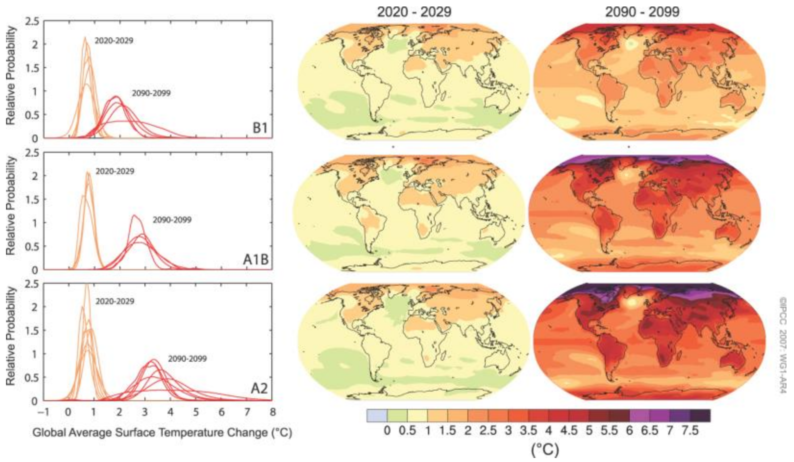
Initialized climate processes



Benefit of increased ocean resolution

Future climate change



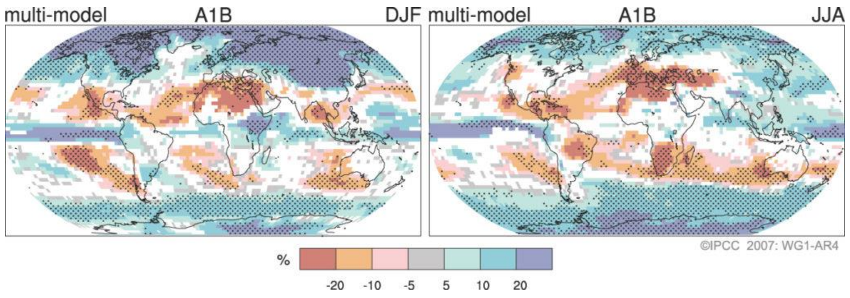


Global temperature rises by several degrees

Warming is larger over land than oceans

Warming is largest over polar regions

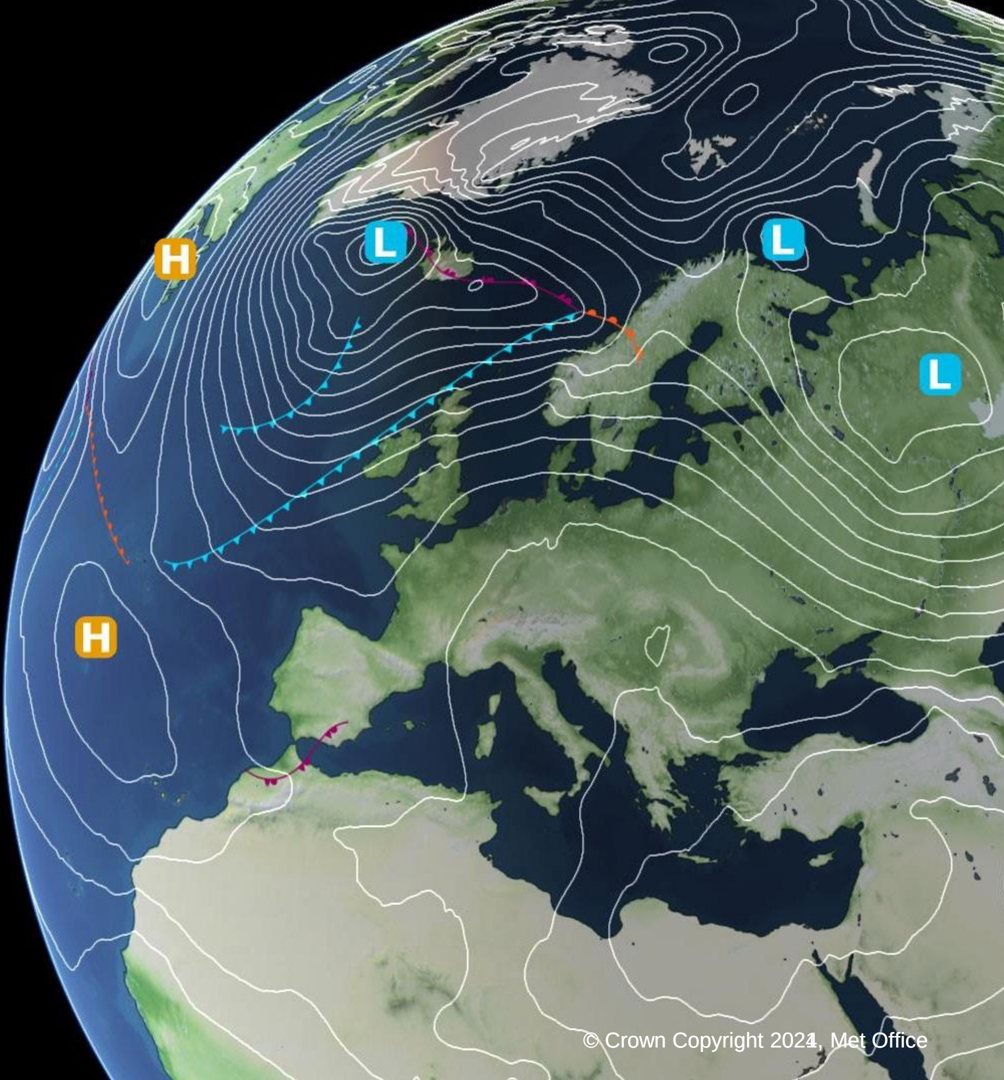
Increased UK winter rainfall



SOURCE: IPCC

Met Office

Why does climate change matter?



A cold December:

December 2010

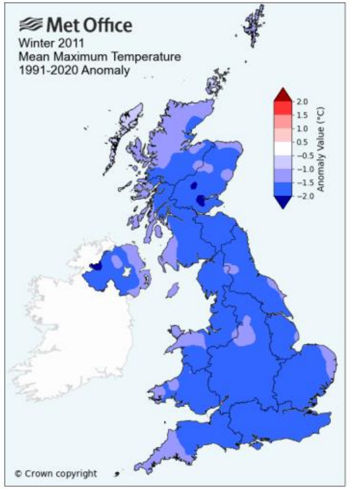
London

Channel 4

December 2010

Manchester

Reuters



UK wide cold snap

London Heathrow terminal shut for several weeks

Widespread disruption

...and a very mild December:

December 2015

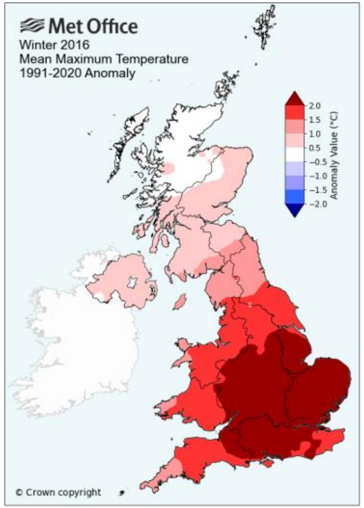
London

The Telegraph Newspaper

December 2015

Manchester

BBC



UK wide heavy rainfall and floods

One of the mildest Decembers on record

Winter average temperature differences are typically only a few degC and are comparable to climate change!!!

Climate change already affects extreme weather across the planet

Siberian heatwave

- Widespread, prolonged event over the first 6 months of 2020 resulting in **wildfires** and **loss of permafrost**
- Event was **many times more likely** due to climate change

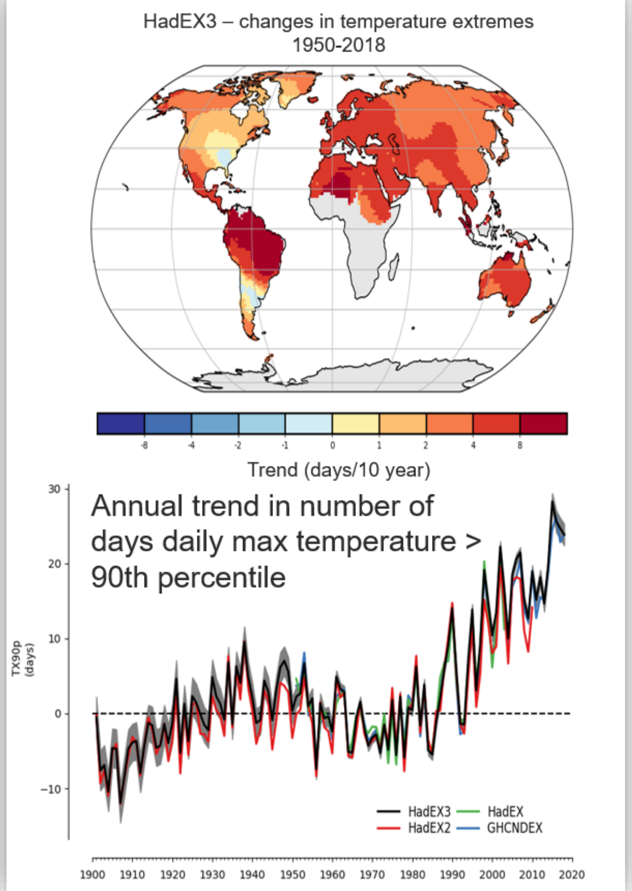
European flooding and heatwave

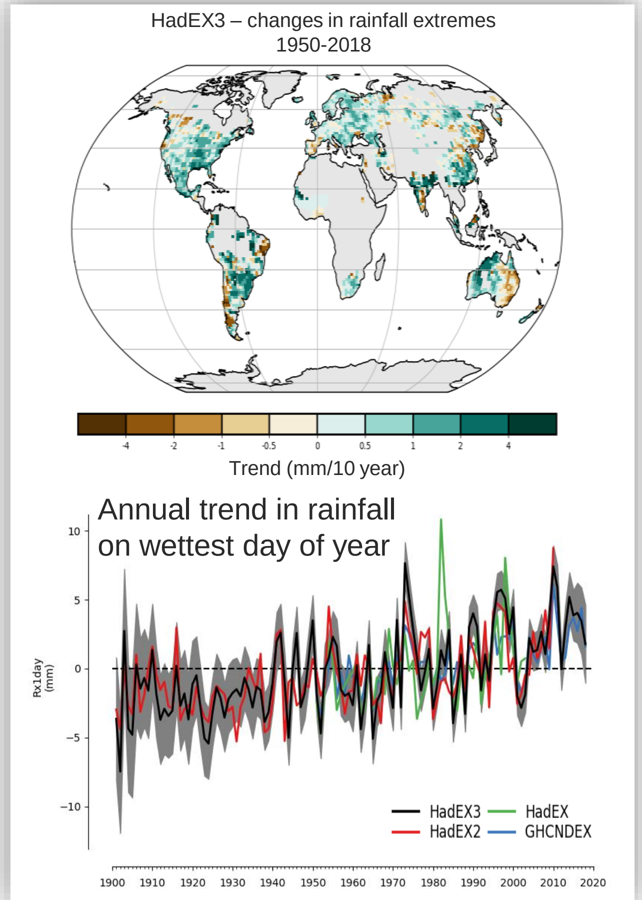
- July 2021 **heavy rainfall event** resulted in extreme impacts, and led to over **200 deaths**
- Event was **several times more likely** due to climate change

North America heatwave

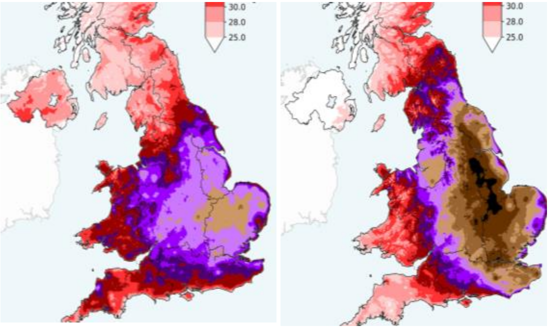
- Record breaking temperatures in June 2021, **49.6°C recorded in Canada**
- **Almost impossible** to hit such record-breaking temperatures in the Western United States **without human-caused climate change**

Observations of extreme weather





The UK Is No Exception



Heatwaves

- The **July 2022 heatwave** saw the **highest temperature ever recorded** in the UK – **40.3°C** at Coningsby, Lincolnshire – and led to over **1000 excess across the four-day period**
- **'Tropical nights'** occurred across parts of south/central England, where temperatures remained above 20°C for a 72-hour period
- By **2050**, hot summers could happen **every other year**

Heavy rainfall

- **October 2023** saw parts of England and Scotland record twice their monthly average rainfall
- **Storm Babet** (18th to 20th October) brought the **third-wettest 3-day period** to England and Wales since 1891
- By **2070**, extreme winter rainfall events, are expected to **increase by up to 25%**

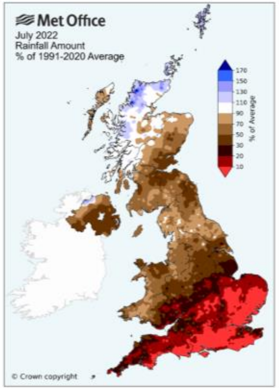
Wildfires

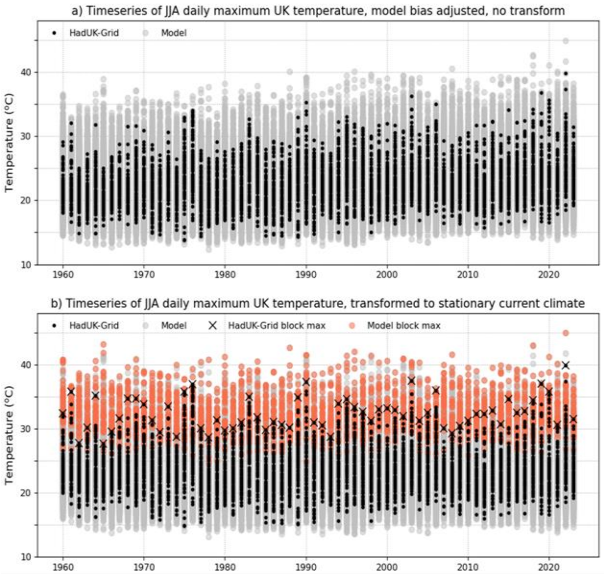
- Figures suggest the number of **UK wildfires has been increasing** in recent years
- Wildfires could be **5 times more likely** by 2100 due to increases in high temperatures and low summer rainfall; conditions highly conducive to wildfires

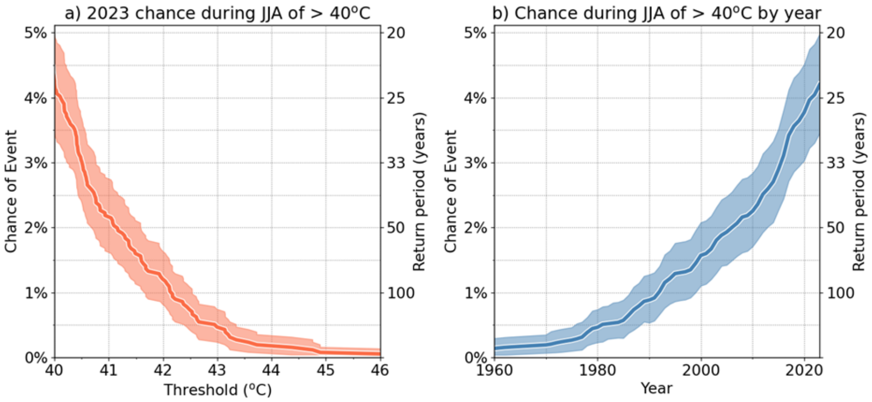
Dramatic increases in the chances of heatwaves

19 July 2022

First occasion UK temperatures exceeded 40C





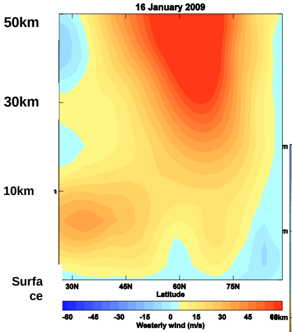


Much larger heatwaves than the current record are possible

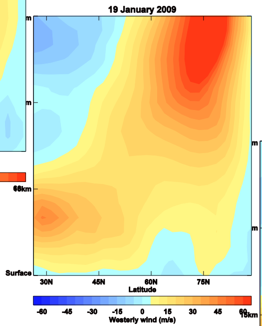
Chance of these events is accelerating!

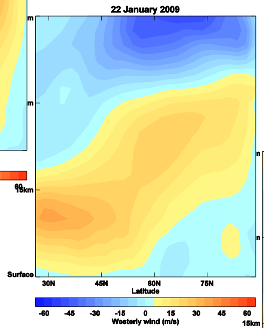
Kay et al., submitted

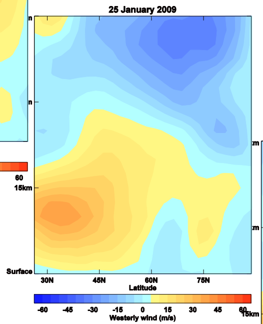
Cold snaps can still happen however

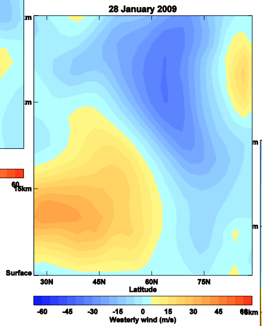


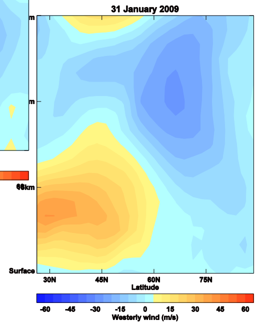
16th Jan











Easterly winds developed aloft

Descended to the surface

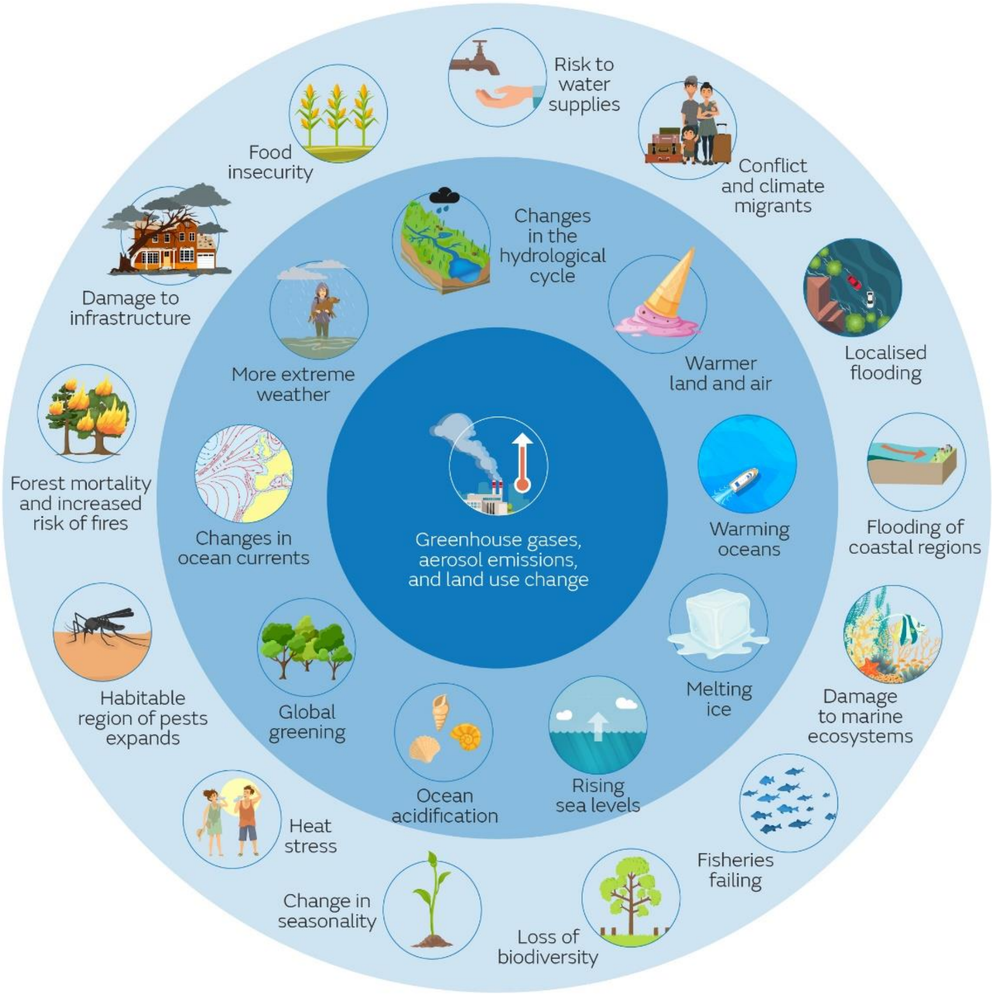
Blew cold air into Europe

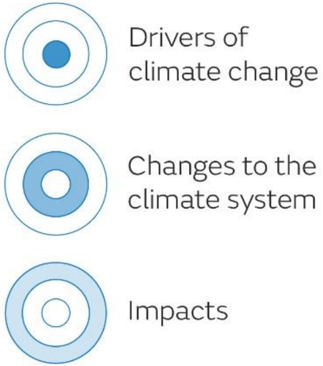
=> heavy snow

Disruption to London transport - Feb 2009

31st Jan

Climate change impacts





Global climate change risks

	Heat stress risk (No. of people exposed to extreme heat)	River flooding (No. of people affected)	Drought (% time cropland experiencing drought)	Wildfires (% land area exposed to 'very high' fire risk)	Biodiversity range loss
Present day	**68 million**	**54 million**	**7%**		
2°C warming	**1 billion**	**97 million**	**16%**	**36%**	**19%**
4°C warming	**3.5 billion**	**211 million**	**30%**	**50%**	**46%**

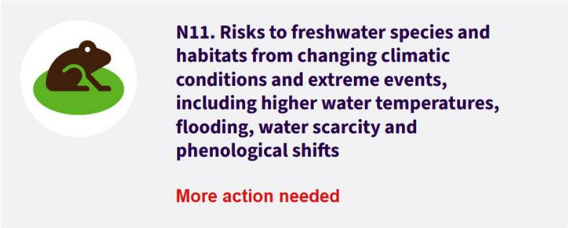
What about UK freshwater impacts?

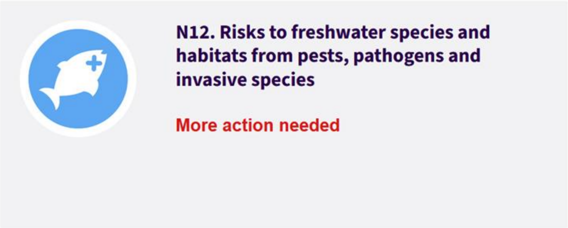
UK Climate Change Risk Assessment

UK Government required by the UK Climate Change Act 2008 to assess the risks and opportunities from climate change every five years and respond via a National Adaptation Programme for England.

Third UK Climate Change Risk Assessment. Independent advisers on climate change, the Climate Change Committee (CCC), prepared an assessment.

Over 450 people from more than 130 organisations contributed and used latest climate projections for the UK from the Met Office.





1. Risks to freshwater species and habitats from changing climatic conditions

Freshwater habitats and species are particularly vulnerable to reduced water availability and higher water temperatures due to climate change.

There is a risk of aquatic species exceeding their thermal tolerance or causing detrimental habitat changes, loss of sensitive species, changes in phenology and species composition. E.g. rising water temperatures in Windermere are associated with a shift towards earlier perch spawning. However, changes in perch spawning have not kept pace with similar shifts in seasonal plankton food resources, with detectable effects on fish development.

Droughts had notable impacts on UK chalk streams, including reductions in invertebrate abundance and species turnover in plant communities, which transitioned from non-aquatic to wetland and classic aquatic plants as flows resumed.

Higher temperatures can also directly or indirectly increase the possibility of water quality problems, for example through reduced oxygen levels, increasing the rates algal growth.

Current and future risks to freshwater habitats is medium by the 2050s, increasing to high for the 2080s under a 4C warming scenario.

2. Risks to freshwater species and habitats from pests, pathogens, INNS

New and emerging pests, pathogens and invasive species have been identified as important risks due to their negative impact on biodiversity. There is increasing evidence that the number of INNS is likely to increase in future.

While climate change is just one factor affecting the arrival and establishment of INNS, it is possible that some currently non-invasive, non-native species in the UK could become invasive with climate change.

Climate change could affect the distribution and spread of various diseases and INNS, changes in the rate at which invaders competitively displace native species, and competition for food with native species.

Over 130 INNS are currently present in freshwater in the UK, including topmouth gudgeon, water primrose, variable-leaved watermilfoil, ruddy duck, American bullfrog and floating pennywort.

The current and future risk is assessed as high for England, due to the greater likely increase in the number of pests, pathogens and INNS.

3. Opportunities to freshwater species and habitats from new species colonisations

The arrival of new species in the UK as the climate changes has the potential to enhance species richness and contribute to community adaptation to climate change.

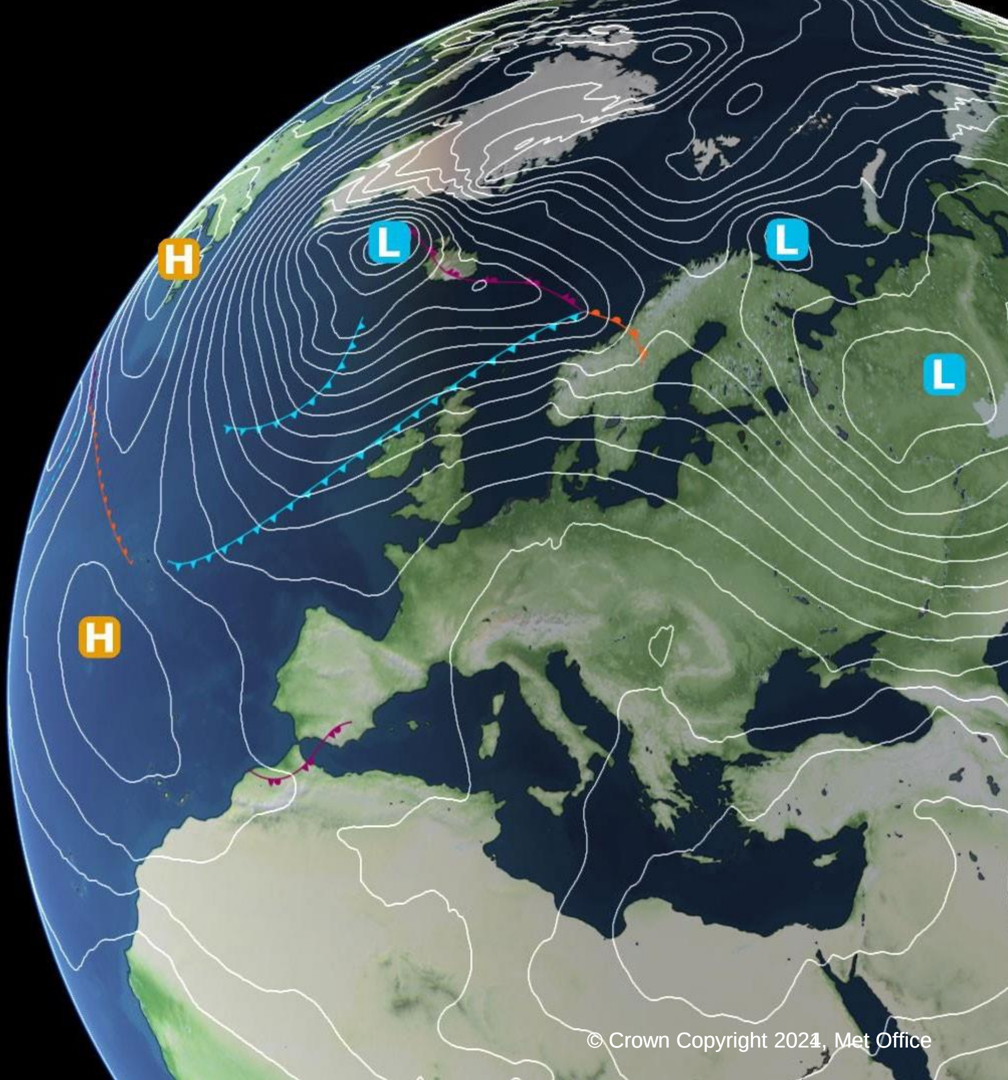
Examples include crustaceans arriving from south-east Europe that serve as prey for fish and mussels and provide habitat to other species.

Some freshwater species that are already present in the UK could also benefit, for example fish such as bream, pike and perch, which tolerate a range of temperatures and seem to be responding positively to warming.

The expansion of native species ranges toward the poles may also bring similar benefits. However, the opportunities from climate change are assessed as low, both currently and in the future, as there is low evidence of these opportunities to date and climate change is likely to a play smaller part in the benefits of colonisation compared to other factors.

Met Office

Climate change: What can we do about it?

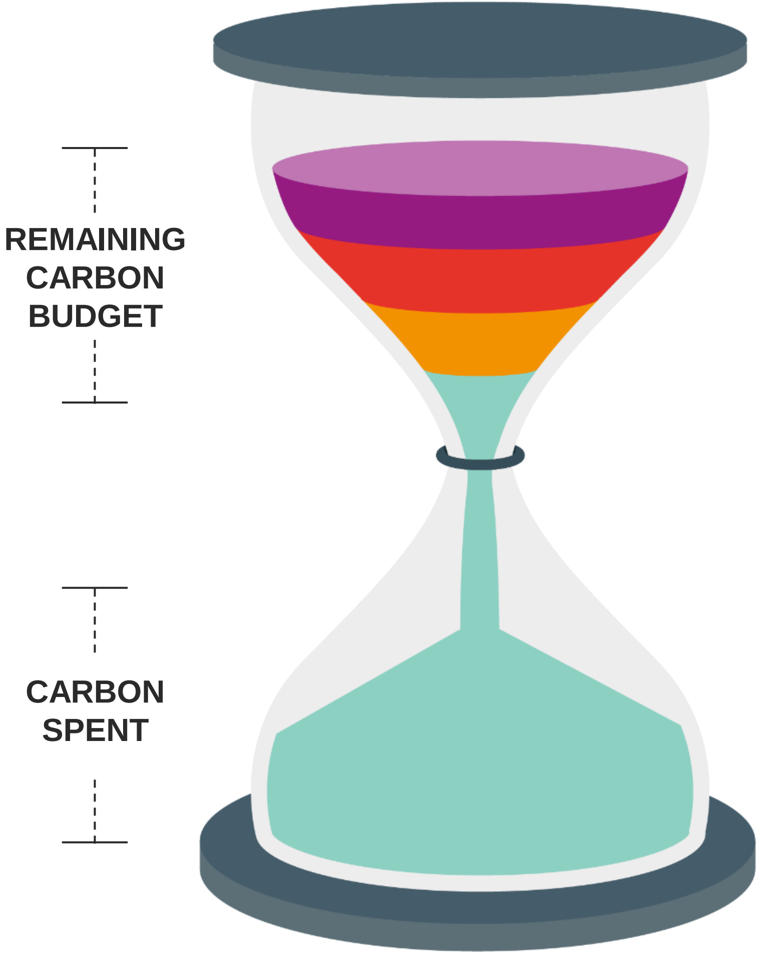


Carbon Budget

The amount of carbon (C) we continue to emit determines how likely we are to limit global warming to within 1.5°C.

Between 1850 and 2022, cumulative emissions from human activities totalled 695 Gt C, or 2550 Gt CO_2.

For a 50% chance of limiting warming to 1.5°C, **we can only emit an additional 75 Gt C** (or 275 Gt CO_2) from the start of 2024. This corresponds to **about 7 years**, at the rate of 2023 emissions.



Remaining carbon budgets to give a 50% chance of limiting warming to…

2°C = 315 Gt C
1150 GtCO_2

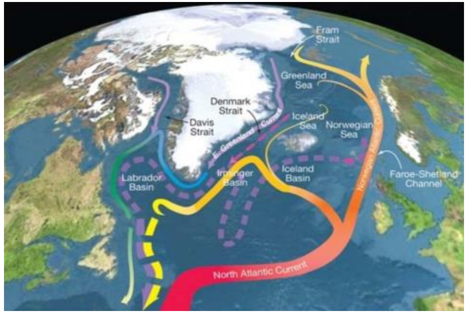
1.7°C = 175 Gt C
625 GtCO_2

1.5°C = 75 Gt C
275 Gt CO_2

695 Gt C or
2550 Gt CO_2

High-Impact, Low-Likelihood events, such as ice sheet collapse and abrupt ocean circulation changes cannot be ruled out




Permafrost Thaw

Boreal forest Dieback

Amazon Dieback

Sahara Greening

West Antarctic Retreat

Greenland Retreat

AMOC

Arctic Sea ice

Change in position of

jet stream

ENSO

Antarctic bottom water

formation changes

Indian/West African

Monsoon

Tackling climate change: mitigation

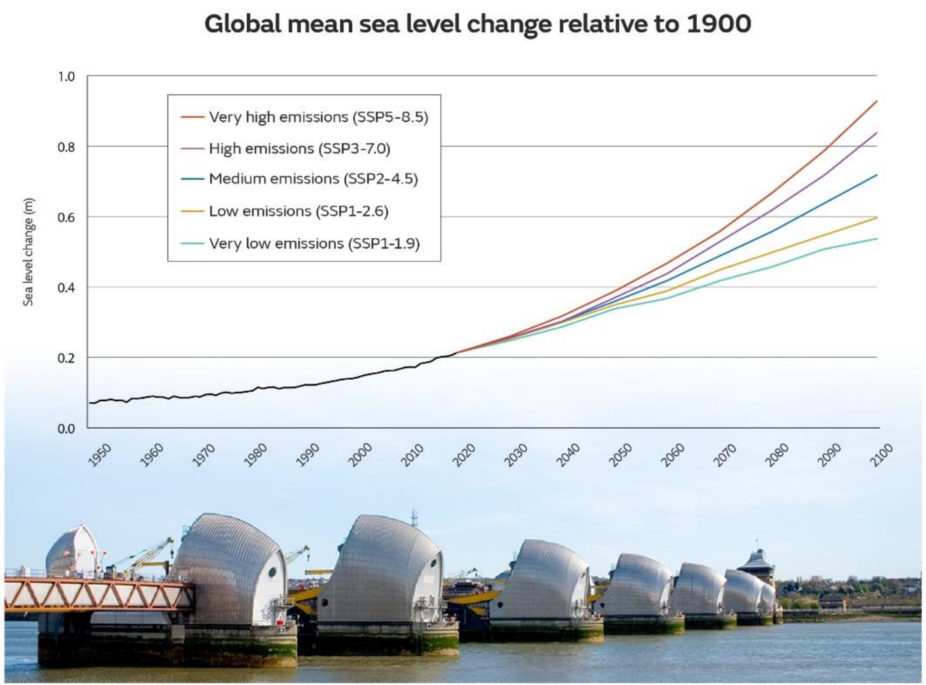
Once the global carbon budget has been used up, we will have to rely on **potentially costly, risky and undeveloped techniques** to actively remove greenhouse gases from the atmosphere.

Promising methods of **Greenhouse Gas Removal (GGR)**

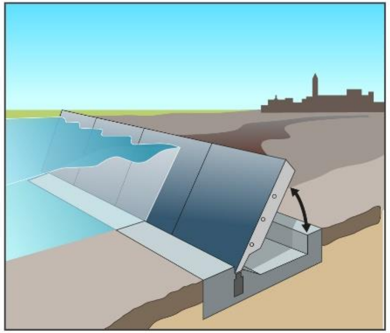
- Bioenergy with Carbon Capture and Storage (BECCS)
- Woodland creation and agro-forestry
- Protection and restoration of natural ecosystems

At some point the level of GGR will not be viable given other demands on land for food production and biodiversity.

Adapting to climate change is essential

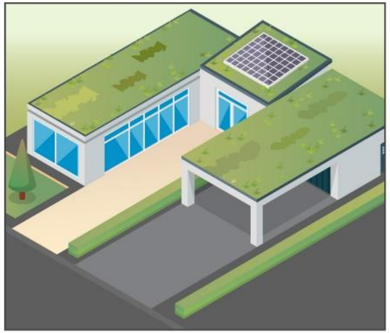


Other examples of adaptation



Flood protection

Reinforced rail network



Sustainable buildings

Water management