CLIMATE CHANGE ADVISORY COUNCIL

Annual Review 2025

Our Changing Climate in 2024

Annual Review 2025:
Our Changing Climate in 2024

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Climate Change Advisory Council
McCumiskey House
Richview, Clonskeagh Road, Dublin 14, D14 YR62

Tel: 01 2680180

Email: info@climatecouncil.ie

www.climatecouncil.ie

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Summary for All

In this first part of the *Annual Review 2025*, the Climate Change Advisory Council examines the most recent developments in the understanding of Ireland's changing climate in the context of broader global climate changes. It considers how the climate is currently changing, projected future changes and the critical need to adapt to these changes.

Globally, 2024 was the warmest year on record and was the first calendar year with a global mean temperature of more than 1.5°C above the 1850–1900 average. The past 10 years (2015–2024) were the 10 warmest years on record. Many notable extreme climate events occurred in 2024 across the world, including severe floods, wildfires, droughts and intense hurricanes. The fingerprints of climate change are increasingly evident in the intensifying magnitude and frequency of certain extreme events, particularly heatwaves and heavy rainfall.

Ireland's climate is also changing, with impacts for people, places and nature: 2024 was the fourth-warmest year on record, and 7 of the top 10 warmest years nationally have occurred since 2005. The spring of 2024 was provisionally the sixth-wettest spring on record, which caused significant disruption to farming activity. Storms Isha, Bert and Darragh brought particularly strong winds, high rainfall, significant flood damage, widespread power outages and reports of coastal erosion. The cascading impacts from power outages, damage to Holyhead Port in Wales and disruption of farming activities by heavy rainfall were widely felt.

Proactive adaptation is urgently needed if Ireland is to improve its preparedness for and response to rapidly emerging climate risks. This must be underpinned by robust climate data and services. With this in mind, the Council recommends that the Government:

- establish a national climate damage register to monitor and record the economic, social and environmental impacts of extreme events in support of more robust preparedness and planning for future extreme events,
- provide the necessary funding and support to sustain and improve the national climate observation system, including monitoring of all critical atmospheric, land and ocean variables.

Summary of Storm Éowyn

Although this publication focuses exclusively on Ireland's changing climate and related events in 2024, it would be remiss not to comment on Storm Éowyn, which hit Ireland on 24 January 2025. Its impacts highlighted critical infrastructure's lack of resilience to extreme weather events and served to amplify the Council's previous recommendations about accelerating investment in and action on climate adaptation.

Storm Éowyn was an exceptionally powerful extratropical cyclone. While approaching Ireland it underwent a phase of explosive intensification, with an exceptional pressure drop of 50 hPa in 24 hours.[1] The storm set new all-time records for measured wind speed in Ireland, with sustained hurricane-force winds of 142 km per hour and gusts of 184 km per hour recorded at Mace Head, Co. Galway.[2] During the storm, the whole of Ireland was placed under a red weather warning.

The impacts of Storm Éowyn were devastating and compounded the impacts experienced during Storm Darragh in December 2024 and the snow and ice hazard event in early January 2025. While the full extent of the damage is yet to be determined, the main impacts were:

- Across Ireland, 768,000 premises were left without power.[a] This compares with 395,000 premises left without power during Storm Darragh and 375,000 during Storm Ophelia in 2017. ESB reported that it took 19 days to fully restore all connections[4] compared with the to 7 and 8 days taken during Storms Darragh and Ophelia, respectively. The role and support of international assistance in the recovery efforts is acknowledged.
- Over 200,000 premises were reported by Uisce Éireann to be without water, with treatment plants and pumping stations also widely affected by power outages.[5] This required water tankers and alternative supply systems to be put in place.
- Internet and phone connectivity were badly affected, with over 1 million telecom users left with no broadband or phone coverage.[6]

a For context, the Central Statistics Office estimated a total number of just over 2.1 million dwellings in Ireland in its 2022 census.[3]

- Widespread damage to agricultural infrastructure (including farm sheds and polytunnels) and also forestry stocks was reported. It is noted that a task force has been established to ensure that storm-damaged forests are managed safely and appropriately.
- Insurance claims arising from the storm are expected to reach €150–200 million.[7]

Storm Éowyn has exposed Ireland's vulnerability and lack of resilience in terms of critical infrastructure and services when coping with extreme climate events. While the wind speeds associated with the storm were unprecedented in the observational record, there is substantial uncertainty about whether the intensity and frequency of storm events is projected to change. The lessons learned from Storm Éowyn will be further reflected on and analysed in the *Annual Review on Resilience*, which is due for publication in September 2025, as well as relevant sectoral annual reviews that will be published over the course of 2025. These publications will incorporate specific recommendations on improving preparedness for extreme events, increasing the resilience of critical infrastructure and delivering effective post-hazard support services and assistance to communities.

Abbreviations

AMOC	Atlantic Meridional Overturning Circulation
CMIP	Coupled Model Intercomparison Project
CMIP5, CMIP6, CMIP7	Coupled Model Intercomparison Project Phase 5, Phase 6, Phase 7
EPA	Environmental Protection Agency
IPCC	Intergovernmental Panel on Climate Change
LTA	long-term average
NCCRA	National Climate Change Risk Assessment
WIRE	Weather Impact Register

Contents

Key observations (global)

- The global mean surface air temperature was 1.55°C (with a margin of uncertainty of ±0.13°C) above the pre-industrial level in 2024, surpassing 2023 to become the warmest year on record. The past 10 years (2015–2024) have not just been the warmest decade but have each individually been among the warmest 10 years in the 175-year observational record. This is without precedent in the instrumental record.
- Global greenhouse gas emission reduction commitments are not consistent with the Paris Agreement's long-term temperature goal.[b] The latest scientific evidence shows that the world is heading to average heating of up to 3.1°C by the end of the century compared with pre-industrial levels if current policies are implemented.
- The fingerprints of climate change are increasingly evident in the intensifying magnitude and frequency of certain extreme events, particularly heatwaves and heavy rainfall. The severe effects of climate change seen across many parts of the world in 2024 are the new reality and a forewarning of the future without rapid and sustained emissions reductions.

Key observations (Ireland)

- The average air temperature in Ireland in 2024 was 10.72°C. This makes 2024 the fourth-warmest year on record in Ireland, with 7 of top 10 warmest years on record now having occurred since 2005.
- The spring of 2024 was the sixth-wettest and second-warmest meteorological spring on record. The high volume of spring rainfall had profound effects on farm operations in Ireland during 2024. Difficulties in accessing fields led to knock-on impacts on fodder stocks, slurry storage, crop sowing and harvesting and grazing. A World Weather Attribution study, which analysed the storm events and accumulated seasonal rainfall from October 2023 to March 2024 in the UK and Ireland, estimates that wet periods such as this are four times more likely to occur in today's climate, and that average precipitation was observed to have become approximately 30% more intense during stormy days.
- Attribution research has identified the emergence of a climate signal in long-term data and quality-assured observations of precipitation and temperature across the island of Ireland. The research identified the largest changes in annual mean temperature, and noted the emergence of unusual changes in spring, summer and autumn mean

b Article 2 of the Paris Agreement aims to strengthen the global response to the threat of climate change by holding the increase in the global average temperature at well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels.

temperatures. For spring, Dublin and inland stations tend to show warming of more than 1°C per degree warming in annual global mean surface temperature.

- Storm Darragh was the strongest storm experienced in Ireland in 2024.[c] Violent storm-force winds resulted in 395,000 households, farms and businesses losing power with impacts cascading to other sectors. Damage to Holyhead Port in Wales exposed the vulnerability of Ireland to impacts on trade from extreme climatic events beyond its borders.
- Although rainfall was below average overall, 2024 was marked by several heavy rainfall events. Three stations recorded their wettest November day on record during Storm Bert, with severe flood events being experienced in towns and villages in Counties Donegal, Kerry, Cork, Limerick and Galway.
- The owners of 1 in 20 buildings in Ireland currently have difficulty accessing flood insurance. The estimated average annual cost of inland (river and surface water) flooding is €101 million. Severe losses can be much higher than this, with a €510 million loss expected about once every 25 years.
- The mean rate of absolute sea level rise in Europe is exceeding the global mean and accelerating. The currently observed rate (since 1970) of sea level rise in Ireland is approximately 3–4 mm per year, and an overall rise of approximately 1 m is expected by 2100 with considerable local variation. This will lead to increased risks from storm erosion and flooding, with considerable localised impacts. Importantly, a faster rise in sea levels cannot be ruled out, because of a limited knowledge base and uncertainty concerning the processes controlling the melt of the Greenland and Antarctic ice sheets.[10]

Key recommendations

1. The Council calls for the Government and relevant agencies to establish a national climate damage register to monitor the impacts of extreme events in a uniform and standardised manner and in support of more robust preparedness and planning for extreme events. This should be integrated with other relevant activities such as the National Climate Change Risk Assessment.
2. The Government must ensure that the funding and necessary support, underpinned by appropriate legislation where relevant, are in place to sustain and improve the national climate observation system. This will allow consistency with a sustained national contribution to the Global Climate Observing System, and the system should include all critical atmospheric, land and ocean variables.

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c It should be noted that the existing storm patterns in Ireland are dominated by low pressure systems moving west to east, together with northward-moving extratropical systems. As sea surface temperatures continue to rise, hurricane frequency is projected to increase, developing from the mid-Atlantic, closer to Ireland.[8,9]

1. Introduction

This publication summarises the most recent developments in the understanding of Ireland's changing climate in the context of broader global climate changes. It examines how the climate is currently changing and considers projected future changes. This information underpins the urgency of both adaptation and mitigation actions in the global and Irish contexts and the critical need for Ireland to be more resilient to extreme weather events. It is based on recent developments and information sources, including international and national 'State of the Climate' reports and other relevant research.

2. Latest scientific evidence for observed climate change

2.1. State of the global climate

The State of the Climate 2024 report by the World Meteorological Organization showed that records were yet again broken in 2024 for greenhouse gas concentrations, global and regional surface temperatures (Figure 1), ocean heat and acidification levels, sea level rise, Antarctic sea ice cover and global glacier retreat.[11]

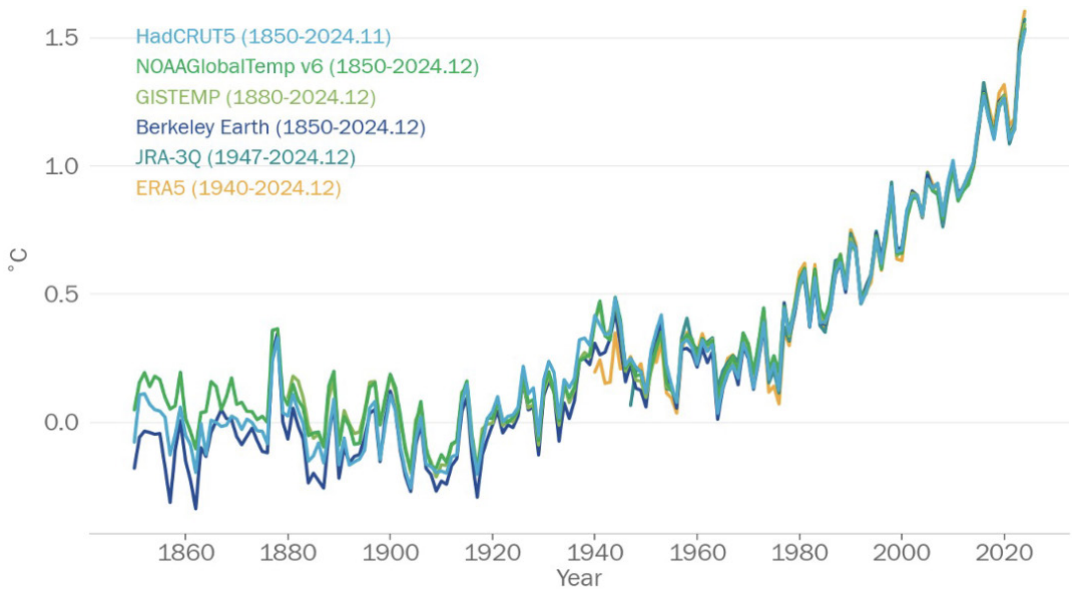

Figure 1: Annual global mean temperature anomalies (relative to 1850–1900) from 1850 to 2024 from six datasets.
(Source: State of the Climate 2024.[11])

Key messages from the 2024 report[11] are that globally:

- 2024 was the warmest year on record, replacing 2023 as the previous warmest. Global mean surface air temperature was 1.55°C (with a margin of uncertainty of ±0.13°C) above the pre-industrial average.
- The past 10 years (2015–2024) not only constitute the warmest decade but have each been among the warmest years in the 175-year observational record. Such an occurrence is without precedent in the historical record.
- Concentrations of the three greenhouse gases in the atmosphere reached record high levels in 2023 and real-time data indicated that they continued to rise in 2024. Greenhouse gas emission reduction commitments are not consistent with the Paris Agreement temperature goals.[12] The latest scientific evidence shows that the world is heading to average heating of up to 3.1°C by the end of the century compared with pre-industrial levels if current policies are implemented.[13]
- Sea level rise continued to accelerate. From 2014 to 2023, global mean sea level rose at a rate of 4.7 mm per year. This is more than double the rate of sea level rise from 1993 to 2002. This reflects continued ocean warming and thermal expansion, as well as the melting of glaciers and ice sheets.
- Ocean heat content in 2023 reached the highest annual value in the 64-year observational record. Preliminary data from the early months of 2024 indicate that ocean heat content in 2024 remained at levels comparable to those seen in 2023. Global ocean warming rates show a particularly strong increase in the past two decades, and ocean warming is considered to be a change that is irreversible on centennial to millennial timescales.
- Antarctic and Arctic sea ice extent were both well below average in 2024. Antarctic sea ice reached its second-lowest extent in the satellite record (1979–2024), the lowest being in 2023. Arctic sea ice reached its seventh-lowest extent in the satellite record in 2024.

The report states that the record-breaking rainfall and flooding, rapidly intensifying tropical cyclones, deadly heat, relentless drought and raging wildfires seen in different parts of the world are the new reality and a forewarning of the future (Box 1).

Box 1: Have we surpassed the lower limit of the Paris Agreement long-term temperature goal?[11]

The first full calendar year in which the global average temperature exceeded 1.5°C above pre-industrial levels was 2024. One or more individual years exceeding 1.5°C does not necessarily mean that 'pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels', as stated in the Paris Agreement, is out of reach. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as a change in the state of the climate that persists for an extended period, typically decades or longer.[14] Therefore, the exceedance of 1.5°C and 2.0°C warming levels referred to in the Paris Agreement should be understood as an exceedance over an extended period, typically decades or longer, although the agreement itself does not provide a specific definition.[11] The need to focus on sustained trends over time is also necessary to account for the effects of inter-annual variability. Therefore, the lower temperature limit of the Paris Agreement has not yet definitively been surpassed, but the first annual exceedance is worrying.

Europe is recognised as the fastest warming continent, with extreme heat becoming more frequent and precipitation extremes increasing in severity.[15] Data and reports from the Copernicus Climate Change Service[16] show that the global average temperature breached 1.5°C above the pre-industrial level for each month in 2024 according to several datasets.

The severe effects of climate change seen across many parts of the world during 2024 are a stark warning of how the future will look with long-term warming over and beyond the 1.5°C threshold. Extreme weather events continued to destroy lives and livelihoods, with economic losses and damages yet to be fully assessed. For example:

- Wildfires devastated Canada in the summer of 2024, following on from a record season of wildfires in 2023. It is estimated that an area of over 5.3 million hectares burned in 2024 compared with the 10-year average of just over 3.5 million hectares.[17]
- The United States and the Caribbean were badly impacted by a number of major hurricanes in 2024. Hurricane Beryl in July was the earliest Atlantic category 5 storm on record and affected several Caribbean countries, particularly Grenada and St Vincent and the Grenadines. Hurricane Helene in September led to catastrophic flooding in the interior south-east of the United States along with causing major damage at landfall, while Hurricane Milton in October caused major storm surge, wind and flood damage in Florida. While there is no agreement among researchers as to whether climate change is producing or will produce a higher number of hurricanes, it is enhancing the conditions that will promote higher rainfall accumulations from hurricanes in the North Atlantic.[8]
- Floods in central and southern Europe from September to November 2024 were unprecedented in terms of rainfall volume and damage caused. Totals for 5-day rainfall exceeding 400 mm occurred in northern Austria, eastern Czechia (Czech Republic) and south-western Poland, far above previous records at many locations. In Spain, more than 220 deaths were reported as a result of flash flooding in October and November, with the equivalent of a year's worth of rainfall received in 8 hours at a weather station in Chiva in southern Spain on 29 and 30 October.[18]
- Severe drought in southern Africa prompted five countries in the region to declare a national disaster by July 2024.[19] February 2024 was the driest February in southern Africa for a century.[12]

2.2. State of Ireland's climate

This subsection summarises the main findings from Met Éireann's *Annual Climate Statement for 2024* and monthly weather statements and climate statements for each season for 2024.[20] For meteorological and climatological purposes, the Irish seasons are classified into 3-month periods: winter – December to February; spring – March to May; summer – June to August; and autumn – September to November.

The winter of 2023/24 and the spring months of 2024 were characterised by mild and wet conditions, with the exception of January when below-average rainfall and temperatures were experienced in most parts of Ireland. Six named storm events affected Ireland in winter 2023/24. Spring 2024 was the second-warmest spring on record, with May 2024 being the warmest May on record. Provisional gridded rainfall data suggest that spring 2024 was the sixth wettest on record. The summer months were cool and relatively dry overall. Autumn was mild and dry overall with two named storms directly affecting Ireland. December was mild and dry with Storm Darragh being the main storm event to directly affect Ireland (Figure 2).

January

16-day absolute drought recorded at Moore Park, Co. Cork

15.4°C

Highest temperature for January recorded at Belmullet, Co. Mayo

February

>150%

Nine stations recorded **over 150%** of their February long-term average (LTA) rainfall

Two recorded **over 200%**

March

29 rain days

29 rain days recorded at Shannon airport, Co. Clare, and Ballyhaise, Co. Cavan

Third wettest March recorded at Dublin airport

April

132.9mm

Highest monthly rainfall recorded at Johnstown Castle, Co. Wexford: its **4th wettest April** since 1941 and **189%** of its LTA for April

May

13.08°C

Warmest May recorded in Ireland

Average air temperature*

June

No extremes recorded

July

No extremes recorded

August

2nd wettest

Second wettest August on record at Newport, Co. Mayo

Wettest August since 1992 at Belmullet, Co. Mayo

September

17.2mm

Only **15%** of the 1981–2010 LTA monthly rainfall recorded at Mace Head, Co. Galway

October

54.2mm

Highest daily rainfall for October recorded at Sherkin Island, Co. Cork

November

Three stations recorded their **wettest November day** during Storm Bert**

19.2°C

Highest November temperature since 1961 recorded at Phoenix Park

December

141 km/h

Highest gust reported at Mace Head, Co. Galway, during Storm Darragh

Figure 2: Calendar of extreme weather observed during 2024.

Notes: *1.74°C higher than the 1991–2020 long-term average and only the second time that a May average temperature exceeded 13°C, the first being May 2008. **57.4 mm at Knock Airport, Co. Mayo, 41.7 mm at Oak Park, Co. Carlow, and 41.2 mm at Finner, Co. Donegal.

(Sources: Met Éireann, Past Weather Statements[20] and Climate Statement for May 2024.[21])

Notable temperature and rainfall highlights from 2024 include the following:

- The average annual air temperature for Ireland in 2024 was 10.72°C, which is 1.17°C above the 1961–1990 long-term average (LTA) or 0.55°C above the most recent 1991–2020 LTA, albeit 0.49°C cooler than 2023, which was the warmest year on record.[22] Figure 3 shows annual average temperature anomalies from 1900 to 2024.
- Of the top 10 warmest years, 7 have now occurred since 2005, with 2023, 2022, 2007, 2024 and 1945 being the 5 warmest years on record. None of the top 10 coolest years have occurred since 2000.
- Spring 2024 was the second warmest on record, while winter (December 2023 to February 2024) was the eighth warmest. May 2024 was the warmest May on record, and February and November were in the top ten warmest on record.
- Sea surface temperatures across the North Atlantic continued at or near record high levels. This contributed to higher than average mean temperatures and increased moisture content in the atmosphere over Ireland.
- Research published in 2024 has found a significant increase in the prevalence of extreme temperatures in Ireland. For example, one study reports that a temperature event of 33°C in Dublin's Phoenix Park has gone from being a 1 in 180-year event in 1942 to a 1 in 9-year event in 2020.[23]

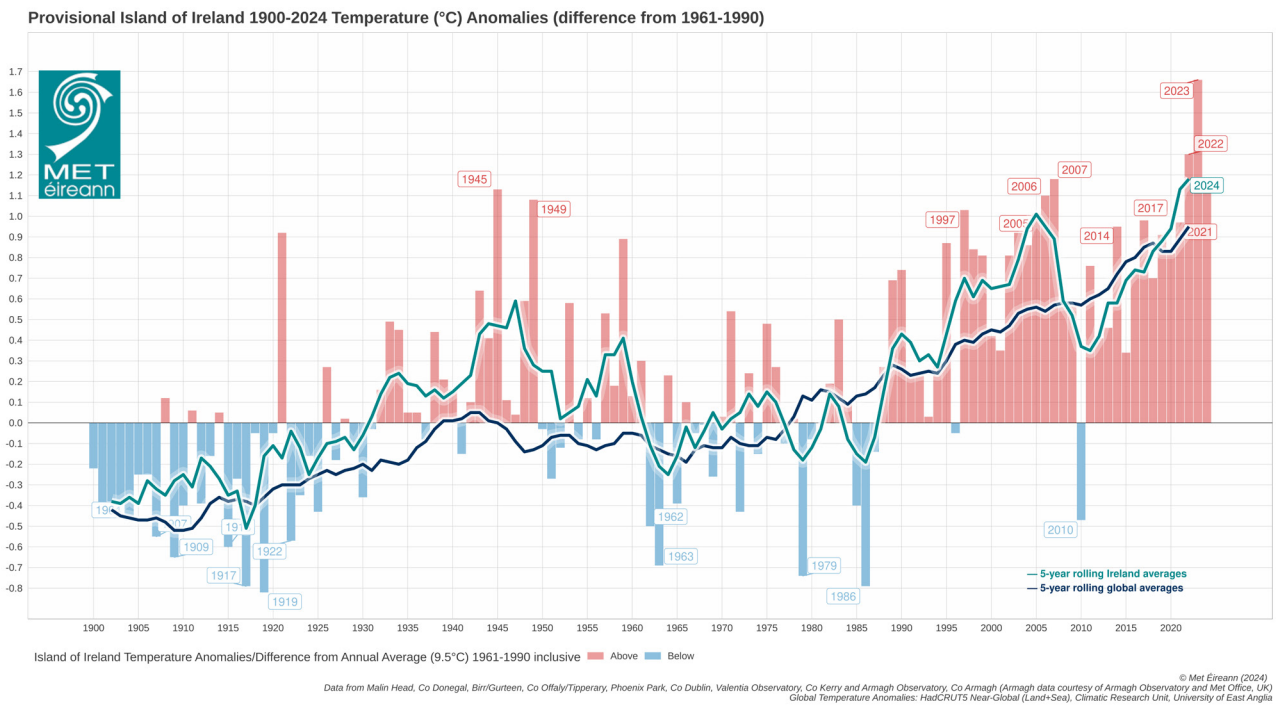

Figure 3: Annual temperature anomalies compared with the annual average temperature from 1961 to 1990 inclusive.
(Source: Met Éireann.)

- The provisional 2024 average annual rainfall total in Ireland was 1,204.9 mm. The wettest year remains 2023 with 1,511 mm and the driest remains 1971 with 912 mm.
- March 2024 was eighth-wettest March on record and the meteorological spring 2024 was the sixth-wettest spring on record (Box 2).
- Although 2024 was drier than average, there were many instances of locally heavy or intense rainfall that led to flooding.
- There were 15 separate dry periods in 2024 (absolute droughts, partial droughts and dry spells). Of these, there were 14 dry spells at 13 stations, an absolute drought at one station (Moorepark, Co. Cork) and no partial droughts.

Box 2: Impacts of high spring rainfall on agriculture

The exceptionally high volume of rainfall experienced in winter 2023/24 and during the spring of 2024 profoundly impacted farm operations. Particular challenges were experienced with field preparation and sowing crops, which extended housing periods for ruminant animals and resulted in a late start to the 2024 grazing season.[24] This led to impacts on stocks of fodder, slurry storage capacity and potential declines in crop harvests, and placed additional pressures on the health and well-being of farmers. From a public health perspective, evidence of health risks needs to be quantified where possible, especially when costly interventions are required. This will require investment in health surveillance to support this process.

A World Weather Attribution study[25] shows how climate change had a strong influence on the autumn and winter rainfall that led to these agricultural impacts. Wet periods such as the October 2023 to March 2024 season have become four times more likely to occur in today's climate, and average precipitation was observed to have become approximately 30% more intense during stormy days. If warming reaches 2°C, similar periods of rainfall that can saturate soils and cause large agricultural losses will become much more common and are expected to occur about once every 13 years. Moreover, these agricultural losses can have significant cascading impacts on individuals, communities and the Irish economy more broadly.

2.2.1. Storm events

Seven named storms directly affected Ireland in 2024,[2] bringing heavy rainfall and storm-force winds. This is consistent with an annual average of seven storms directly affecting Ireland since the naming of storms began in 2016 (Figure 4). In the absence of a national climate damage register, it is difficult to compare trends in the impacts of storm events from year to year. However, in 2024, Storms Isha, Bert and Darragh brought particularly strong winds, high rainfall, significant flood damage, widespread power outages and reports of coastal erosion (Box 3).

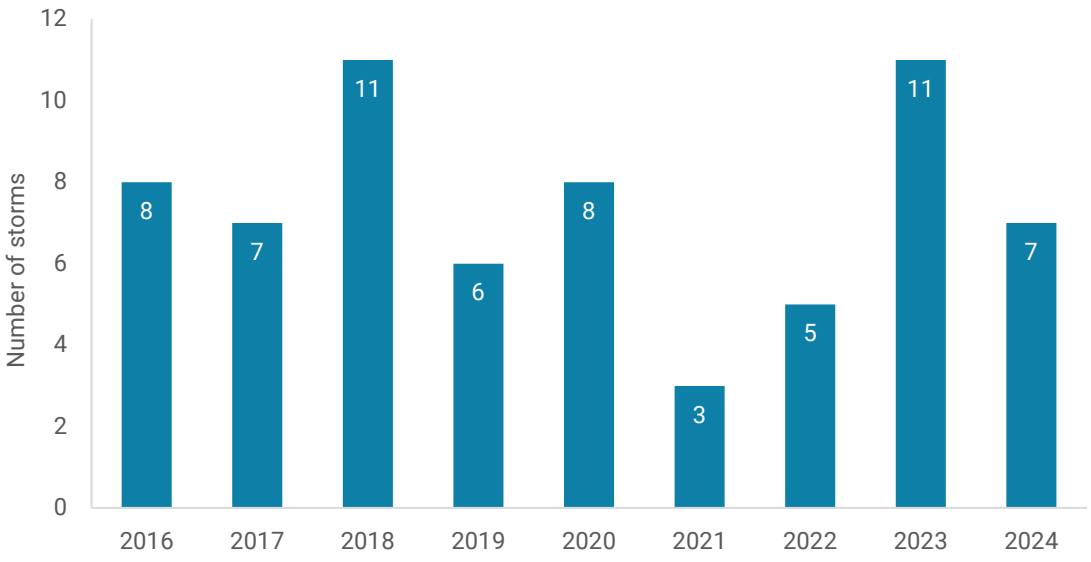

Figure 4: Trends in the number of storms directly affecting Ireland from 2016 to 2024.

Box 3: Impacts from Storm Bert and Storm Darragh

Prior to Storm Éowyn, Storm Darragh was the strongest storm experienced in Ireland since Storm Ellen in 2020 and it brought violent storm-force winds in December 2024. It caused widespread travel disruption and resulted in approximately 395,000 households, farms and businesses losing power.[26] This also led to cascading impacts on other sectors, including communication networks and water treatment and supply. Ireland's vulnerability to transboundary extreme weather events was highlighted by the damage to the ferry terminal berth at Holyhead Port (in Wales) due to high winds, which caused the port to close for over 1 month. This caused widespread disruption to supply chains and logistics and to ferry passengers during the busy Christmas period.

Storm Bert, described by Met Éireann as a multi-hazard weather event, affected Ireland on 23 November 2024. It resulted in a status red rainfall warning for Counties Cork and Galway and brought severe rainfall and storm-force winds. Storm Bert resulted in power outages for approximately 60,000 households, farms and businesses and some roads in western areas were left impassable because of flooding.[27] Severe flood events were observed at Killibegs, Co. Donegal, and in towns along the River Feale such as Abbeyfeale, Co. Limerick, and Listowel, Co. Kerry.[28]

These storms highlighted the widespread lack of resilience across Ireland to severe storms and the massively impactful chains of effects associated with our highly vulnerable electricity system. The creation of resilient electricity systems is imperative to support the transition to greater use of electricity in transport, heating and other aspects of everyday life. Consumer confidence in resilient electricity supply systems will be a vital component in this energy transition.

The events experienced during Storm Bert highlighted Ireland's ongoing vulnerability to flooding. A Central Bank of Ireland report from 2024[29] further showcased the cost of flooding in Ireland and the high portion of the cost that is uninsured. Its headline findings were as follows:

- The owners of 1 in 20 buildings have difficulty accessing flood insurance today.
- The estimated average annual cost of inland (river and surface water) flooding is €101 million. Severe losses can be much higher than this, with a €510 million loss expected about once every 25 years.
- Ireland is likely to see significantly more rainfall-related extreme events in the future, due to climate change increasing the likelihood of flood events and potentially widening the flood insurance gap.

2.2.2. Sea level rise

Ireland is highly exposed to climate impacts on coastal environments, with all major cities and many regional population centres located by the sea.[30,31] Sea levels are projected to rise under all future climate scenarios and have been rising at an accelerating rate since 1990.[32] The currently observed rate (since 1970) of sea level rise in Ireland is approximately 3–4 mm per year.[32] Current evidence suggests that Ireland will be affected by sea level rise that will reach up to 1 m by the year 2100 due to climate change.[33] This will lead to increased risks from storm erosion and flooding, with considerable localised impacts. Importantly, faster rises in sea level cannot be ruled out, due to a limited knowledge base and uncertainty concerning the processes controlling the melting of the Greenland and Antarctic ice sheets.[10] The findings of new research, linked to the observation of ice melting mechanisms in western Antarctica, could potentially begin to improve the projection of future changes in ice sheets.[34–36]

The first European assessment report on sea level rise[37] highlighted that the mean rate of European absolute sea level rise slightly exceeds the global mean and is accelerating. It detailed the main coastal impacts of sea level rise including increased likelihood of floods, shoreline retreat via coastal erosion, damage to infrastructure and freshwater shortages due to saltwater intrusion. It further noted the potential for human interventions and urban expansion to exacerbate these impacts.

Severe continued coastal erosion was reported in Wexford[38] and Portrane in County Dublin[39] during storm events in 2023 and 2024, resulting in the loss of coastline and damage to access roads and properties. These are two instances of increased erosion, at rates reaching approximately 1 m per year, recorded around Ireland's coasts. The uptake of the recommendations from the scoping report of the Inter-Departmental Group on National Coastal Change Management Strategy[33] is critical to ensure that impacts from sea level rise and coastal erosion rates are addressed.

2.3. Attribution studies – linking climate change and extreme events

The field of event attribution science – linking climate change and individual extreme events – continues to evolve, and advances in attribution methods now make it possible to isolate the influence of climate change on a complex range of extreme weather events. In a 2024 report,[40] the World Weather Attribution team analysed the role of climate change in intensifying the ten deadliest extreme weather events that took place in the period 2004–2024 and the vulnerability and exposure factors that turned these hazards into disasters. The events include three tropical cyclones, four heatwaves, two heavy rainfall events and one drought. These events caused more than 570,000 deaths.

The World Weather Attribution team also analysed a broad range of events from 2024. The vast majority of the notable extremes examined were found to have been made more likely and/or more extreme due to climate change (Figure 5). Exceptions were the cold Scandinavian winter and the drought in south-eastern Africa, which were made less likely and/or severe. Otherwise, a broad range of tropical storms, heatwaves, droughts and extreme precipitation events were found to have been made more likely and/or severe due to climate change.

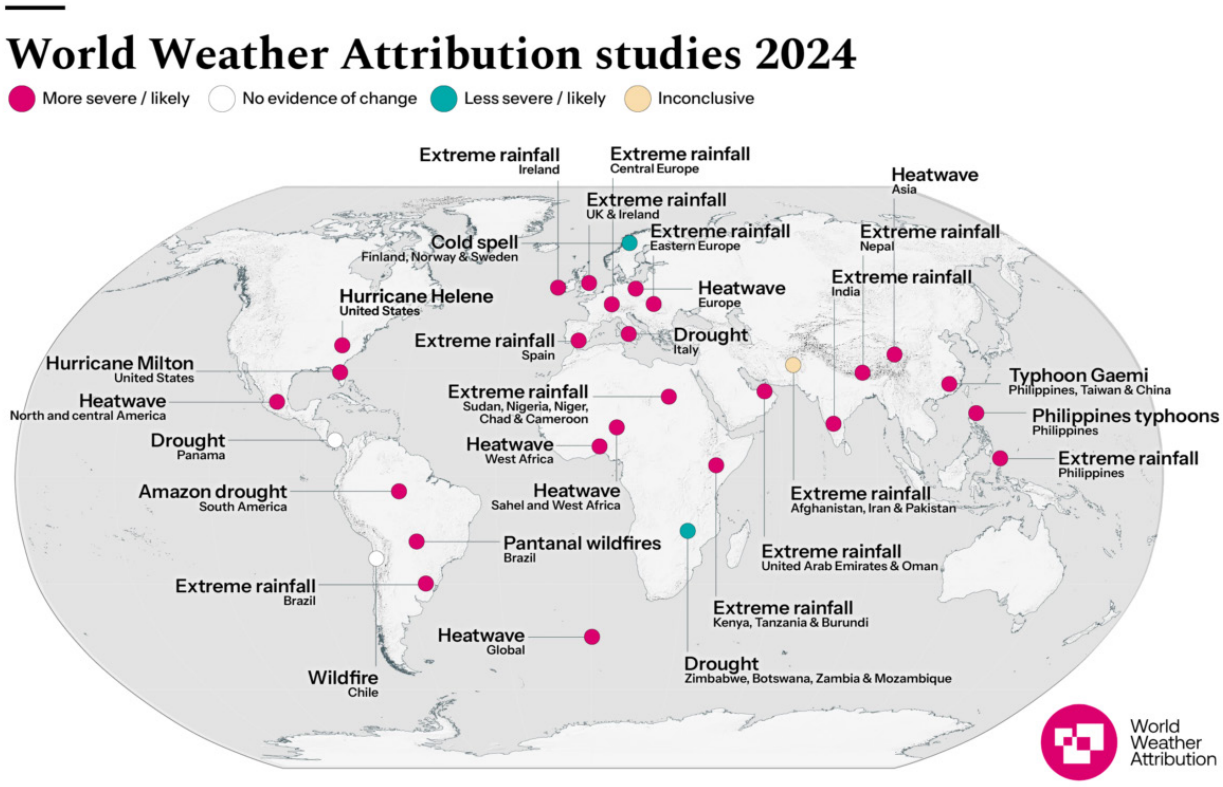

Figure 5: Extreme weather events that were analysed in 2024 by World Weather Attribution.
(Source: World Weather Attribution: https://www.worldweatherattribution.org/when-risks-become-reality-extreme-weather-in-2024/)

In Ireland, climate attribution studies have examined the impact of climate change on two recent extreme weather events, and the key findings from these reports[25,41] were summarised in detail in the Council's *Preparing for Ireland's Changing Climate: Annual Review 2024*.[42]

The studies showed with high confidence that (1) the 2-day precipitation event that flooded Midleton in October 2023 was made more than twice as likely to occur and 13% more intense due to climate change; and (2) human-induced climate change made the heavy storm downpours that caused flooding across Ireland and the UK between October 2023 and March 2024 about 20% more intense. In terms of the likelihood of such an event occurring, the study found that storms as intense as those that occurred in the 2023/24 season occurred about once every 50 years in the pre-industrial climate.

However, in today's climate, similarly intense storm rainfall is expected to occur about once every 5 years.

An additional attribution study by a group from Institut Pierre-Simon Laplace in Paris, France, found that December 2024's Storm Darragh was driven by very exceptional meteorological conditions, whose characteristics can be ascribed to human-driven climate change.[43] The study concluded that windstorms similar to Storm Darragh are more intense (up to 2 hPa deeper), up to 4 km/hour (5%) windier over the Atlantic coasts of Ireland and France, and up to 5 mm/day (up to 10%) wetter at present than they would have been in the past.

Despite advances in attribution studies, there is limited evidence for windstorms and convective storms. The IPCC[10] predicts with at best medium confidence that northern Europe will be affected by fewer but more powerful windstorms. There is *low confidence* in past changes in maximum wind speeds and other measures of the dynamical intensity of extratropical cyclones. Future wind speed changes are expected to be small, although poleward shifts in the storm tracks could lead to substantial changes in extreme wind speeds in some regions (*medium confidence*). There is *low confidence* in past trends in characteristics of severe convective storms, such as hail and severe winds, beyond an increase in precipitation rates. Event attribution science is a valuable tool for linking climate change and a complex range of extreme weather events. The Council welcomes the further development and operation of event attribution science in Ireland through strengthened collaboration between relevant national and international agencies. This will inform the evidence base, the general public and policymakers of which events are being made more or less likely because of ongoing climate change.

3. Future climate projections, monitoring and impacts for Ireland

As the impacts of climate change worsen, climate services and consideration of climate risks are increasingly needed to inform decision-making. In the Irish context, the provision of adequate climate services is particularly important to support the development of the second iteration of sectoral adaptation plans by September 2025. The Government's decision to establish a National Framework for Climate Services (2022) was taken with this need in mind. The first-ever National Climate Change Risk Assessment (NCCRA), to be published in Q2 2025, is also of crucial importance in ensuring that critical risks are identified and proactively managed through the sectoral adaptation plans and related actions.

3.1. Information and systems to support preparedness for extreme events

There is limited timely and systematic information available on the economic, social and environmental impacts caused by specific extreme weather events in Ireland. The impacts of these events on critical infrastructure and services, the built environment and productive assets such as agricultural land and forestry are also likely to become increasingly severe. Impacts affect a diverse range of stakeholders including local authorities, Government departments, semi-state entities that manage critical infrastructures, private sector entities, farmers and householders. Information on the costs of these events is also spread across a wide range of stakeholders such as local authorities, insurance companies and semi-state agencies, which creates the need for a uniform and standardised approach to monitoring impact metrics (Box 4).

Box 4: The Weather Impact Register app – an example of a local authority initiative to understand the impacts of extreme weather events[44]

At the local authority level, efforts have been made to develop the Weather Impact Register (WIRE) app to record, view and analyse the impacts from extreme weather events on a spatial level through its geographic information system-based map viewer and data dashboard. It allows local authorities to upload information on the impacts of extreme weather events in the categories of infrastructure, services and the environment and record this spatially on the ArcGIS platform. However, the WIRE app has only been piloted and tested at this stage and is yet to be rolled out widely among local authorities.

The Council has identified that a better knowledge base on the damages and costs of extreme climate events in Ireland is required. It is necessary for the Government and relevant agencies to strengthen collaboration and build on promising initiatives such as the WIRE app and existing information that is collected on the costs of extreme events by insurance companies. The establishment of a national climate damage register would serve to improve our understanding of extreme weather events and their impacts and support more robust preparedness and planning for future extreme events. Moreover, a damage register would be complemented by continued and enhanced monitoring of core environmental data, including coastal erosion from national to local scales. Strong monitoring systems and the establishment of high-quality, homogeneous datasets are essential for establishing the accurate projection/forecasting and modelling of extreme events and likely impacts. The damage register should also play an important role in monitoring how climate risks identified in the NCCRA risk register are quantified and addressed at both temporal and spatial scales.

3.2. Projections

3.2.1. National climate change projections

TRANSLATE is an established national programme funded and led by Met Éireann that brings together members of the Irish climate change community to develop and mainstream national climate change scenarios for effective, climate-smart decision-making at national and local levels. The TRANSLATE programme informs and underpins many essential national and local climate directives. It feeds directly into the National Framework for Climate Services[a] to support climate service development, coordination and standardisation across the country. It underpins projections for Climate Ireland, the national portal for climate adaptation.[45] It is embedded within the National Adaptation Framework and the NCCRA and as a result supports local climate action plans and sectoral adaptation plans mandated by the Government.

In 2023, Met Éireann released the first iteration of the TRANSLATE climate change scenarios under TRANSLATE-1.[46] These scenarios provide standardised, high-resolution, accessible and bias-corrected climate scenarios for Ireland for the first time and are easily accessible through the Climate Ireland platform.[b]

a https://www.met.ie/nfcs

b https://www.climateireland.ie/

TRANSLATE-1 uses an ensemble of existing Coupled Model Intercomparison Project (CMIP) Phase 5 (CMIP5)[47] global and EURO-CORDEX[48] models that are downscaled over Ireland in line with international best practice, ensuring that projections are consistent with other countries and represent state-of-the-art climate science, while remaining situated within the local Irish context. The TRANSLATE scenarios sample uncertainty from both future emissions and the climate system response to those emissions, ensuring that decision-makers have access to projections for a broad range of plausible futures. These standardised climate scenarios provide the most comprehensive picture of Ireland's future changes in temperature and precipitation to date, across a range of scenarios, or representative concentration pathways (RCP2.6, RCP4.5, RCP8.5), up to the end of the century. For the first time in Ireland, climate information on threshold-based global warming levels (1.5°C, 2°C, 2.5°C, 3°C, 4°C) has been provided. TRANSLATE is freely and easily accessible in multiple formats by all users to ensure that the standardised data can be utilised across the country and across user skill levels.

The next phase of TRANSLATE, TRANSLATE-2,[49] due to be completed in July 2025, will expand the existing TRANSLATE portfolio to include the additional variables wind speed, relative humidity and solar radiation, enabling the production of additional climate indicators for adaptation planning. It will also begin the update of the underlying global climate models from CMIP5 to CMIP6[50] in line with the IPCC Sixth Assessment Report,[51] taking advantage of the updated standardised future scenarios (shared socioeconomic pathways). TRANSLATE-2 aims to address impacts and risk as well as data, largely in the form of creating event-based climate storylines for Ireland. Data from TRANSLATE-2 will be freely available from both Met Éireann and Climate Ireland.

TRANSLATE-3, due to begin in September 2025 (and run until 2029), builds and expands on the previous TRANSLATE iterations. It has three core pillars: (1) underpinning data, (2) understanding risks arising from climate extremes and 3) developing scalable and reproducible climate services. It aims to expand the national dataset to include annual to decadal information as well as updating the climate change scenarios. It will take a lens to extreme events and evaluate how these could change in the future and their associated impacts. From this underpinning work climate services will be produced to showcase how this information can be tailored to meet user requirements.

3.2.2. International climate change projections

Met Éireann is a partner in both the Earth system modelling consortium EC-Earth and the regional climate modelling consortium HCLIM. Both are European climate modelling consortia consisting of national weather services and universities, one of them simulating changes in the global Earth system (EC-Earth) and the other simulating the regional impacts of global change (HCLIM).

At the European level, coordinated experiments to undertake regional downscaling continue under the auspices of EURO-CORDEX.[c] These model runs are freely available and are downscaled from a broad range of driving earth system models that participated in CMIP5. EURO-CORDEX is currently in the process of updating from CMIP5 to CMIP6. When completed, the TRANSLATE ensemble will be expanded to include members from this European resource.

The CMIP is a collaborative framework designed to improve knowledge of climate change. These models underpin the various IPCC iterations. CMIP Phase 7 (CMIP7) is the latest development phase

c EURO-CORDEX is the European branch of the international Coordinated Regional Climate Downscaling Experiment initiative, which is a programme sponsored by the World Climate Research Programme to organise an internationally coordinated framework to produce improved regional climate change predictions for all land regions worldwide.

that has been designed to support specific user needs, including supporting the needs of the IPCC Seventh Assessment Report assessment cycle, and will help to further refine the understanding of past, present and future climate changes.[52] The small, targeted 'fast-track' experiment sets, in addition to the growing number of model intercomparison projects, reflect extensive feedback from the modelling centres and wider user community.

3.3. Monitoring

Met Éireann, in collaboration with partners, continues to improve Ireland's climate observation networks. In October 2023, a new weather radar system was installed at Shannon Airport.[53] This modern radar now provides more accurate rainfall information to the weather forecasters, the public and researchers. This new weather radar is the first step in Met Éireann's strategic development plan to upgrade and expand the national weather radar network over the next 10 years. During this period, the number of radars will triple, from two to six, covering key areas across the country to ensure optimal real-time rainfall monitoring coverage and forecasting accuracy.

The year 2023 also saw the automation of almost 80 climate monitoring stations throughout Ireland. This not only improved the resolution of climate information being monitored but also provides near real-time weather information to support emergency management, including the issuing of weather warnings. Met Éireann also commenced a rainfall automation project that, in tandem with the radar expansion, will better capture rainfall in near-real time.

The Irish Global Climate Observing System National Committee, consisting of members from Met Éireann, the Marine Institute, the Environmental Protection Agency (EPA) and Teagasc as well as remote sensing experts, continues to review the status of essential climate variables for Ireland, ensuring their sustained long-term measurement and alignment with international standards. The Irish Soil Moisture Observation Network[54] coordinates soil moisture measuring networks in Ireland, including in collaboration with the UK Cosmic-ray Soil Moisture Monitoring Network for sites in Northern Ireland. Over the past year further enhancements have been made to the network to improve the monitoring of soil moisture throughout Ireland. Soil moisture, an essential climate variable, plays a crucial role in environmental processes such as the water cycle, weather and climate, vegetation growth, and groundwater availability.

Met Éireann, in partnership with the Commissioners of Irish Lights, is expanding the nearshore wave, sea level and meteorological observations, with six wave buoys deployed to date and another 14 in planning over the next 24 months. Through the Office of Public Works-led National Flood Forecasting and Warnings Service Steering Group, Met Éireann and the Office of Public Works are undertaking a review of river level and flow monitoring of Ireland's hydrometric network to improve flood forecasting capability.

For tidal level measurements Met Éireann is working with the Marine Institute on improving the availability of tidal data from around the Irish coast.

Ongoing research funded by the EPA through the HydroDetect project is developing an updated reference hydrometric network for monitoring and detecting changes in river flows (floods, droughts, season flows) across Ireland.[55] Other research being undertaken by the EPA- and Met Éireann-funded HydroDARE project is developing approaches to the attribution of changes detected in hydrological extremes to enhance the ability to discern a climate change signal in floods and droughts.[56]

It is recommended that the Government ensure that funding and necessary support, underpinned by appropriate legislation where relevant, are in place to sustain and improve the national climate observation system. This will allow consistency with a sustained national contribution to the Global

Climate Observing System, and the national system should include all critical atmospheric, land and ocean variables.

3.4. Climate impacts for Ireland

Globally, the past 10 years (2015–2024) have been the 10 warmest years on record.[57] Ireland's overall warming trend continues in line with global trends, with 7 of the top 10 warmest years in Ireland having occurred since 2005.[22] The latest Irish climate change projections indicate further warming in the future. This temperature change means that the likelihood of extreme weather events occurring has increased. Irish rainfall patterns are expected to change, with an increase in both dry periods and heavy rainfall events. Global sea levels continue to rise. As a result, storm surge and coastal flooding risk around Irish coasts is expected to increase along with 'compound events' involving a combination of heavy rainfall and high tides. It is currently unclear how the frequency and intensity of storms impacting Ireland will change with climate change. There is high confidence, however, that maximum rainfall rates associated with these storms will increase with warming.[22]

The projected impacts of climate change on eight key sectors[d] in Ireland were identified in Volume 3 of *Ireland's Climate Change Assessment*, which was published in early 2024,[58] and these were included in *Preparing for Ireland's Changing Climate: Annual Review 2024*.[42] The first NCCRA is being led by the EPA and is expected to be published in Q1 2025.[59] It is critical that the next sectoral adaptation plans and revised Strategic Emergency Management Framework address the climate risks and impacts identified in a comprehensive and coordinated manner over both the short and longer term.

The higher the annual global and European temperatures get, the greater the risk of exposure to potential climate tipping points. One such example of a tipping point risk for Ireland is critical change in the circulation of the Atlantic Meridional Overturning Circulation (AMOC). One branch of this ocean circulation flows from the Gulf of Mexico towards the north-east Atlantic off Ireland's Atlantic coast. It helps to create Ireland's temperate climate. While observations over recent decades indicate a quasi-stable or slightly weakening AMOC, scientific research indicates a risk that the AMOC may weaken significantly this century, with the potential for collapse also supported within the range of estimates. If there were to be a collapse in the AMOC, winters would become considerably colder and summers warmer, and there is likely to be an increase in storminess and potential implications for sea levels. Continued research is under way to try and provide more clarity on the likely future behaviour of the AMOC and its potential impact on Europe and Ireland.

d The eight sectors are (1) Ecosystems – marine, terrestrial and freshwater; (2) Agriculture, Forestry and Land Use; (3) Coastal Environments; (4) Water; (5) Built Environment, Heritage and Rural Communities; (6) Critical Infrastructure; (7) Health and Well-being; and (8) Business, Industry and Tourism.

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