Appendix 1f: Climate & Meteorology

A1f.1 Introduction

The variability of the UK climate is largely due to its position on the edge of the Atlantic Ocean with its relatively warm waters, yet close to the continental influences of mainland Europe. Changes in topography and land use over relatively short distances, together with a long coastline and numerous islands, all add to the variety of weather. A network of coastal and marine stations and buoys around the UK monitor different meteorological parameters including air temperature, rainfall, wind speed and direction, and visibility, informing weather forecasting systems as well as the development of climate models projecting future changes to the UK climate.

A1f.2 UK context

The UK lies in the middle northerly latitudes, an area of convergence for major air masses – this leads to diverse and rapidly changeable weather conditions. Numerous eastern moving depressions meet the UK in the west leading to a gradient of relatively high wind speeds and precipitation in the exposed west and relatively low wind speeds and precipitation in the sheltered south and east. The upland nature of much of the west coast also contributes to this west-east gradient, with orographic effects generating enhanced precipitation, particularly in the north-west. The UK is subject to a strong maritime influence which can be felt most strongly at the coast and on island locations (e.g. Orkney, Shetland), and has the effect of reducing the diurnal and annual temperature ranges at these locations.

The climate of the UK and North-West Europe is relatively mild for the latitude because of the Atlantic Meridional Overturning Circulation (AMOC), or more specifically, the easterly arm of the Gulf Stream, the North Atlantic Drift. These warm waters originate in the Gulf of Mexico and prevailing south-westerly winds bring with them mild, humid air (see McCarthy *et al.* 2020). The current state of the AMOC and potential future changes relating to anthropogenic climate forcing are described in Section A1f.11.

The North Atlantic Oscillation (NAO) influences the prevailing meteorological conditions of the north Atlantic region and is reviewed in Hurrell *et al*. (2003) and IACMST (2005). The NAO is generally expressed as an index based on the pressure difference between the Azores high and the Icelandic low pressure areas. When the pressure difference is large, with a deep Icelandic low and a strong Azores high, the NAO is said to be in a positive phase and is negative when the opposite occurs. When in a positive phase, the storm tracks moving across the north Atlantic are stronger, bringing depressions north-eastwards into Europe. A positive NAO index is, therefore, associated with an increase in wind speeds from the west, together with an increase in temperature and rainfall in northern Europe in winter (Hurrell *et al.* 2003, Thompson & Wallace 2000). The index is most relevant in winter when the pressure gradients are at their strongest (IACMST 2005). In summer, the NAO is weaker, leading to weaker temperature anomalies that are similar to the winter NAO, and is more spatially restricted (Bladé *et al.* 2012a, b). In recent decades, the NAO has been found to explain over 30% of variation in monthly sea surface temperature and has also been linked with variations in wind strength and direction, and rainfall. Changes in NAO account for 40-50% of the variability in winter sea surface temperatures in the southern North Sea (IACMST 2005). Improved long-range forecasting capabilities are now allowing higher levels of prediction skill in forecasting the surface NAO, winter storminess, near-surface temperature, and wind speed, all of which are of value for planning and adaptation to extreme winter conditions (Scaife *et al.* 2014). The multi-decadal variation in the NAO may both mask or enhance anthropogenic warming, which is expected to continue into the coming decades (Iles & Hegerl 2017).

The UK Met Office provides meteorological information on coastal and marine areas from data collected on a network of coastal land stations (27 in UK), island stations (2), light vessels (5 in the English Channel), radar stations (15) and marine buoys (approximately 20, primarily to the west of the UK and Ireland)[1]. The various UK Hydrographic Office (UKHO) Pilot publications covering UK waters also provide details of typical offshore conditions. The meteorology and climate of the UKCS is also summarised in *Charting Progress 2: the State of UK Seas* (Defra 2010), prepared by the UK Marine Monitoring and Assessment Strategy (UKMMAS) community and the OSPAR Quality Status Report (OSPAR 2010). Information, principally from these sources, has been used to present the average meteorological condition at the coast and for each Regional Sea in the sections which follow.

A1f.2.1 Meteorological conditions at the coast

Air temperature

Air temperatures at the coast vary according to exposure, elevation and latitude, though seasonal variation leads to a winter minimum and summer maximum with the coldest months being January and February and the warmest July and August. The sea has an ameliorating effect on air temperatures within approximately 20 miles of the coast resulting in reduced summer but warmer winter conditions. This effect is exemplified on the south-western peninsula and UK islands (e.g. the Outer Hebrides, Orkney, Shetland) which experience an annual temperature range of just 9°C between the mean temperature of the warmest and coldest months of the year – the maritime influence also results in a low diurnal temperature variation (Met Office 2013). The relatively high winter minimum temperatures at the coast are visualised in Figure A1f.1. Winds from the south and west often bring warmer conditions, while those from the north and east bring cooler air, and high pressure over central Europe can generate particularly cold winter and warm summer spells (UKHO 1999).

Precipitation

Rainfall follows a seasonal cycle of high winter falls and low summer falls, though there is significant variability throughout the year. Precipitation at any given location is influenced by a number of local factors, and may vary at the coast (as elsewhere) according to exposure to the prevailing wind, elevation and proximity to high ground. In the UK, rainfall is highest in the north-west and west throughout the year due to the relative exposure of these areas to eastern tracking weather systems (Figure A1f.2) and the orographic effects of mountains areas which have a primarily western distribution.

Wind

Like precipitation, a winter maxima for wind speed is expected for most of the UK (Figure A1f.3). The north and west (Regional Seas 4, 5, 6, 7, 8, 9, 10 and 11) are exposed to eastern-tracking weather systems coming in over the North Atlantic, exposing these areas to some of the highest wind speeds in the UK (e.g. North Rona, Orsay, Cape Wrath). The south and east of the UK are comparatively sheltered (particularly Regional Seas 2 and 3) with mean winter

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[1] https://www.metoffice.gov.uk/weather/specialist-forecasts/coast-and-sea/observations/

wind speeds not exceeding 15 knots (8m/s) at most locations (e.g. Spurn Point, Great Yarmouth, Southampton, Leuchars). In late winter and spring a high pressure cell may occur over mainland Europe, increasing the incidence of easterly and north-easterly winds which may persist for a few days to several weeks (UKHO 2013).

Wind at the coast is largely controlled by air pressure gradients, though local topographic conditions can also provide a considerable influence; for instance, winds may strengthen when channelled down narrow inlets or weaken over waters in sheltered areas (UKHO 2012). In coastal areas of Regional Seas 7 and 8, mountainous topography and numerous islands generate highly variable local wind effects and funnelling may increase wind strength in steep-sided sounds and lochs. South-westerly winds tend to be deflected south by the islands of Jura, Mull, Islay and the Kintyre peninsula (UKHO 2004). The south and east of Regional Sea 7 may be partly sheltered from westerly winds by Northern Ireland; and the northern mainland by the Outer Hebrides (UKHO 2004). Localised gusts and squalls in the lee of high ground may be experienced, for example, sudden changes in wind direction are a feature of the indented coast of the Moray Firth in Regional Sea 1 (UKHO 2013).

A1f.2.2 Meteorological conditions at sea

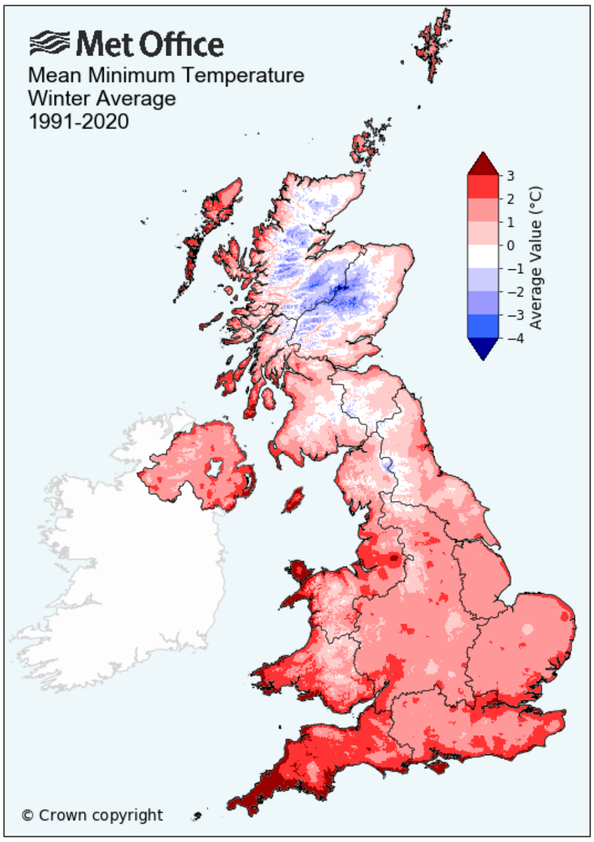
Meteorological considerations at sea are of strategic importance to a range of offshore industries, particularly those associated with renewable energy. The DECC Atlas of UK Marine Renewable Energy[2] produced in 2008 provides information relevant to wave, tidal and wind energy. In light of subsequent improvements in wind modelling, computing powers and data availability, The Crown Estate published a 2015 wind dataset[3], with improved resolution (horizontal resolution of 4.4km over much of the UKCS and 1.5km for areas of 40m water depth or less), and based on 30 years of data (December 1984-November 2014). From this data, the average wind speeds at 110m (hub height) across much of the UKCS are indicated in Figure A1f.4. Most offshore areas have average wind speeds in excess of 10m/s but to the north, average wind speeds are in excess of 11m/s. Near the coast the average wind speeds are generally lower. On exposed coasts, such as the east coast of England the wind speeds are generally in excess of 8m/s and in more sheltered and complex areas such as the islands off the west coast of Scotland the wind speeds are lower; in excess of 6m/s (Standen *et al*. 2015).

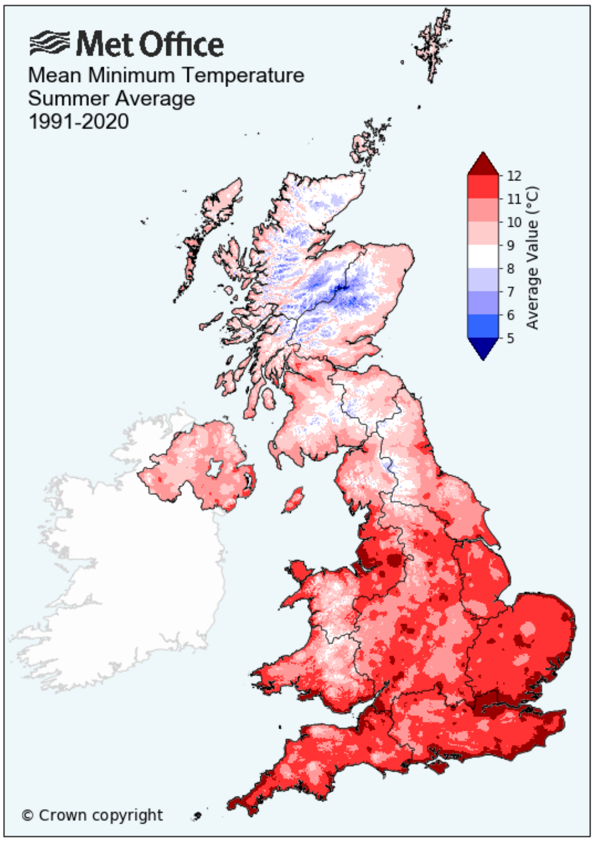
[2] https://www.renewables-atlas.info/
[3] https://www.marinedataexchange.co.uk/ItemDetails.aspx?id=4383

Figure A1f.1: Mean daily minimum and maximum air temperatures (1991-2020)

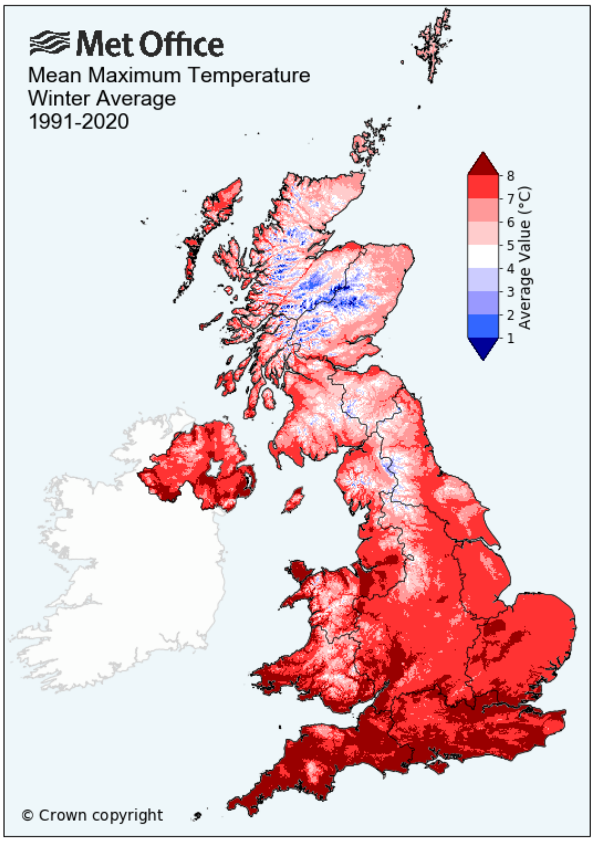
Winter **Summer**

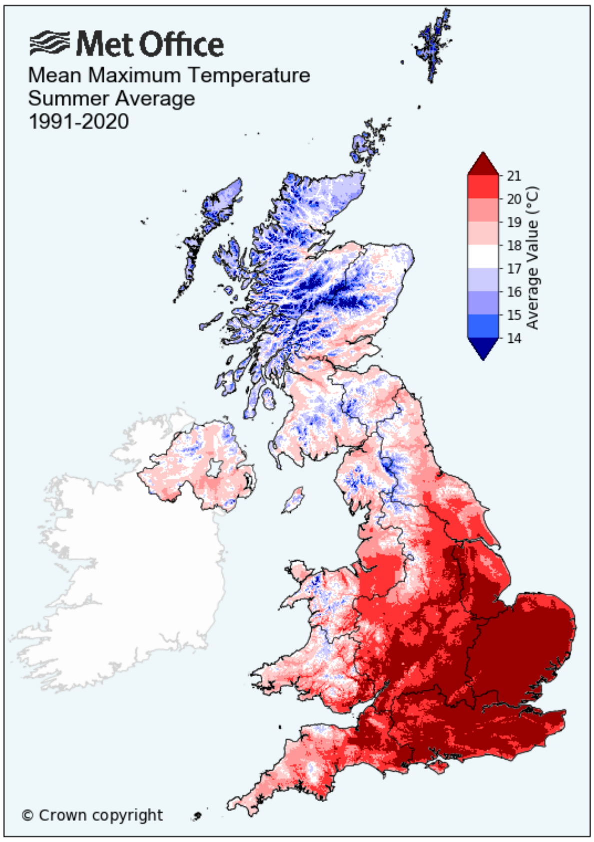
Minimum air temperature





Maximum air temperature

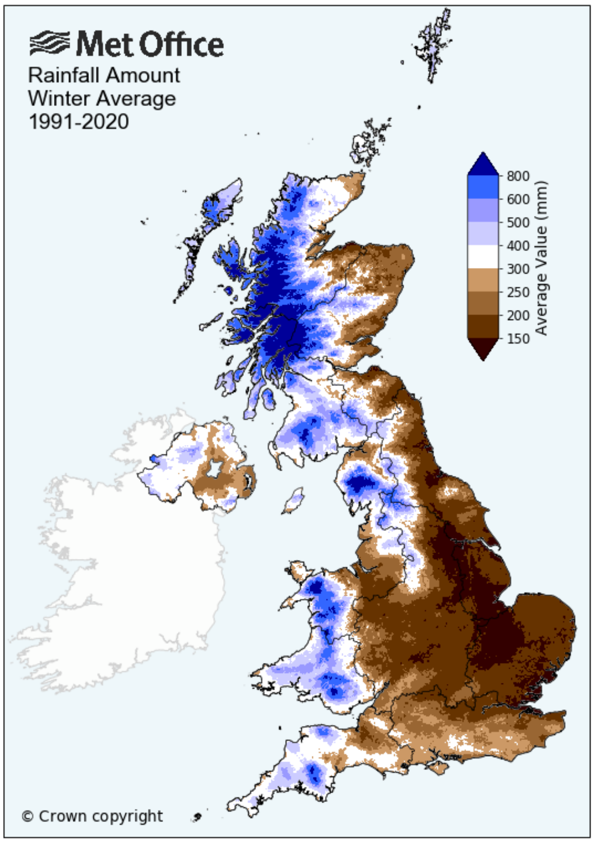




Source: Met Office: https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/

Figure A1f.2: Average precipitation (1981-2010)

Winter



Summer

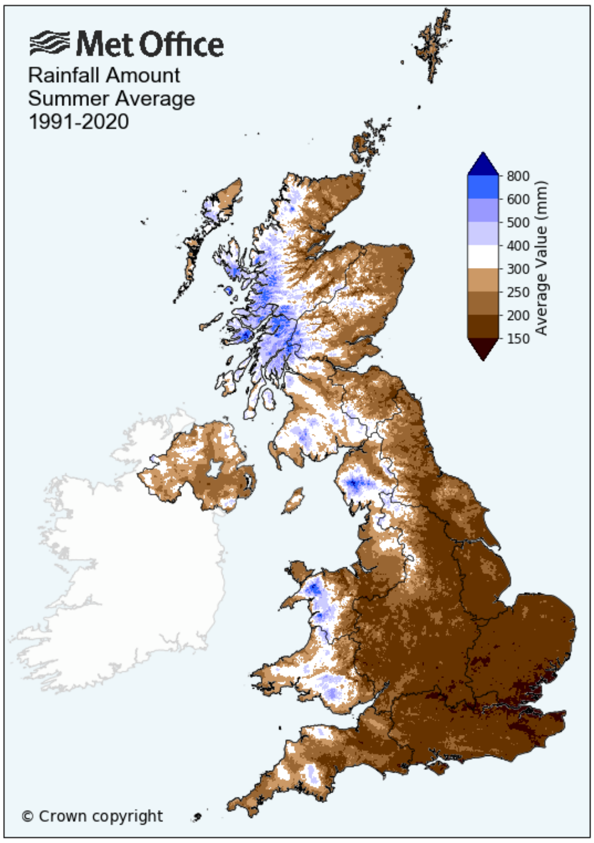
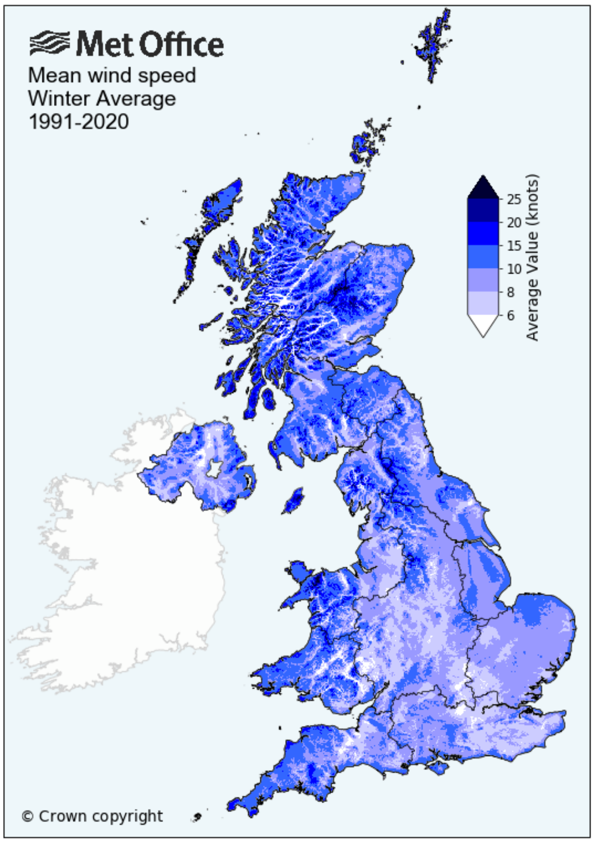
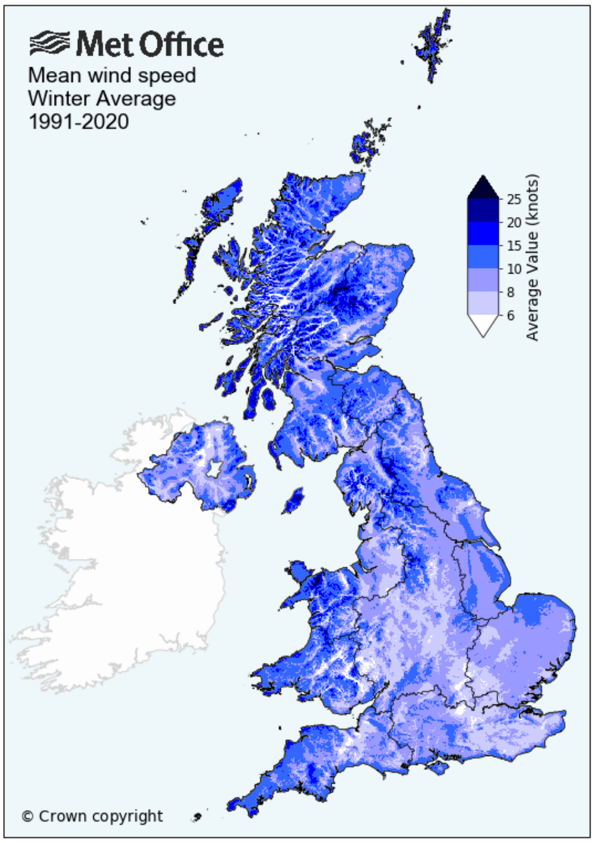


Figure A1f.3: Average wind speed (1981-2010)

Winter

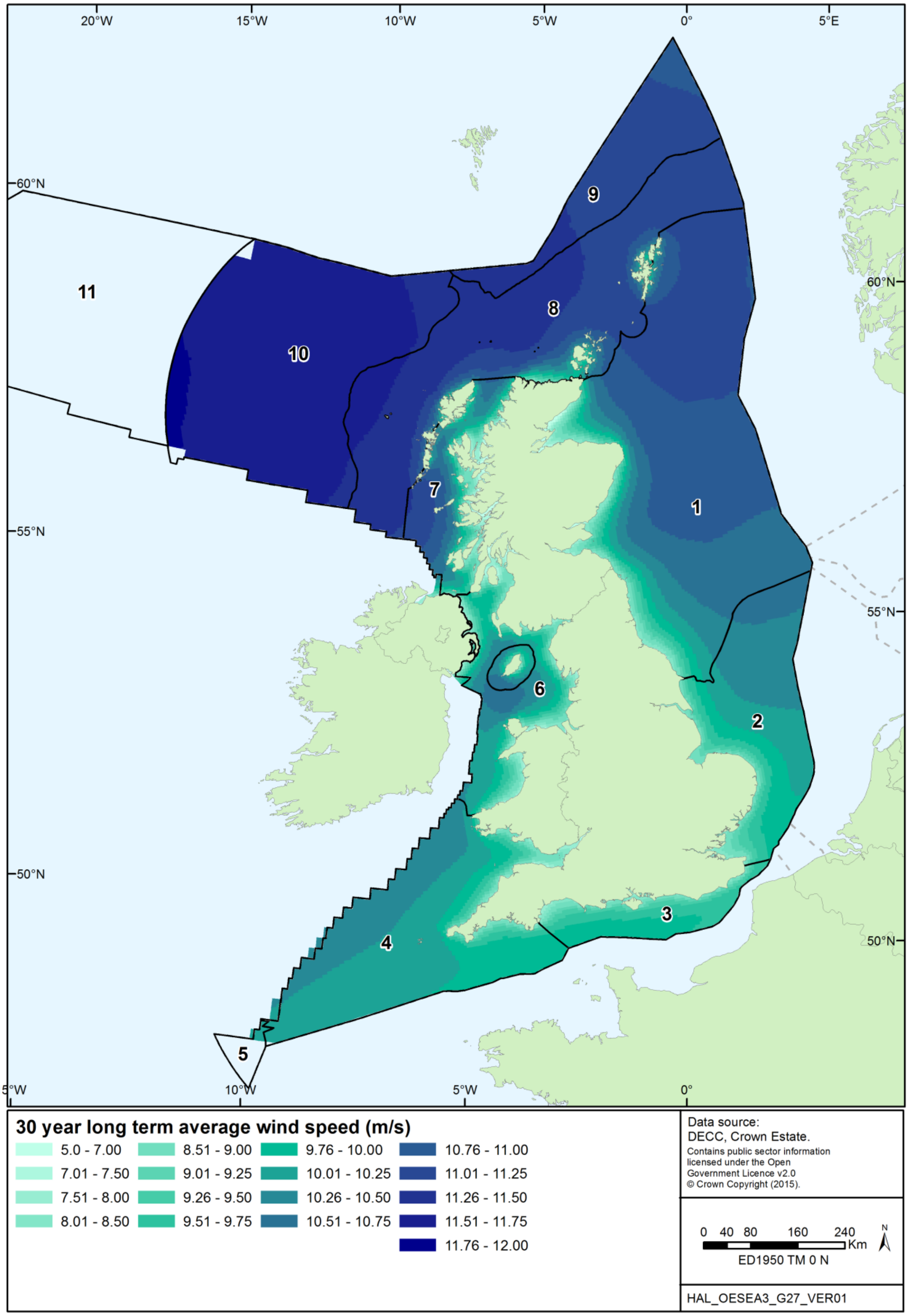


Summer



Source: Met Office: https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/

Figure A1f.4: Average wind speed (m/s) at 110m, 1984-2014



A1f.3 Regional Sea 1

Air temperatures at sea tend not to vary beyond the range 0-19°C with the exception of extended durations of easterly winds which can lead to extreme cold in winter and warm conditions in summer. The mean air temperature over the sea is between 4 and 6°C in January in the south, reducing to between 1 and 2°C in the north. In July, temperatures are greater in the south (*ca*. 16°C) than the north (*ca*. 13°C).

Annual rainfall across the North Sea varies between 340 and 500mm, averaging 425mm. Rainfall tends to increase with distance offshore (401-600mm) between 53 to 54°N, increasing significantly in the east. For much of the rest of the North Sea and Moray Firth rainfall is in the range 201-400mm (OSPAR 2000). Rainfall follows a seasonal trend analogous to that observed onshore, with the percentage chance of rainfall being 13 and 18% in the south-east and north-west respectively in July, and about 20% and 30% in winter months for the same areas. April to June tend to be the driest months, with October to January being wetter (UKHO 2013). Thunderstorms are infrequent, and snow showers vary markedly from as few as 5-7 days per year in the south, to 10-12 days in the central North Sea, and 30-40 in the north (UKHO 2012, 2013).

The prevailing winds are from the south-west and north-north-east. South and south-easterly winds may become established for as long as several weeks if an anticyclone develops over Europe (UKHO 2013). The frequency of gales exceeding force 7 (14m/s) in winter is less in the south (20%) than in the north (>30%), and wind speeds tend to be greater over the open sea than at the coast with the exception of Shetland owing to the lack of shelter from mainland UK (UKHO 2012). Wind strengths in winter are typically in the range of Beaufort scale 4-6 (6-11m/s) with higher winds of force 8-12 (17-32m/s) being much less frequent. Winds of force 5 (8m/s) and greater are recorded 60-65% of the time in winter and 22-27% of the time in summer. In April and July, winds in the open, central to northern North Sea, are highly variable and there is a greater incidence of north-westerly winds.

Fog is associated with wind directions of between south-east and south-west, and can reduce visibility to less than 1km 3-4% of the time. Moist south winds may bring coastal fog to Scotland in summer, and sea fog, or haar, may develop with south-east winds (UKHO 2012). Radiation fog can form for 3-6 days per month between October and April and tends to occur during the night, being dispersed by the sun on all but the coldest days (UKHO 2013).

A1f.4 Regional Sea 2

Air temperatures offshore are generally at their lowest in January and February (mean 4°C to 6°C) and highest in July and August (*ca*. 16°C). Rainfall decreases in a south-north direction. To the north of the Dover Strait an annual rainfall of between 601-1,000mm is expected, reducing to 401-600mm in the outer Thames Estuary and as far as north Norfolk. North and east of north Norfolk, to the boundaries of Regional Sea 2, annual rainfall of between 201-400mm is expected. Snow or sleet is recorded in the south mainly from December to April but perhaps as early as November, and can be expected for 5 to 7 days a month for January and February (UKHO 2013).

Winds in Regional Sea 2 are generally from between south and north-west; however, in spring the frequency of those from the north and east increases. Wind strengths are generally between Beaufort scale 1-6 (1-11m/s) in the summer months with a greater proportion of strong to gale force winds of force 7-12 (14-32m/s) in winter (UKHO 2013). In January, 20% of winds can be expected to exceed force 7 (14m/s), reducing to 2-4% in July. Easterly winds are not common and can bring exceptionally cold weather in winter.

Fog can affect the east coast and seas of England with visibility of less than 1km 3-4% of the time, and is associated with winds between the south-east and south-west. At the coast radiation fog can form for 3-6 days per month between October and April which tends to occur during the night. Visibility in excess of *ca*. 8km is experienced in January on about 55% of occasions, increasing to *ca*. 80% in summer (UKHO 2013).

A1f.5 Regional Sea 3

The average winter air temperature offshore is 9°C in the south-west and 5.5°C in the north-east. Summer temperatures reach *ca*. 16°C for the entire area.

Rainfall is experienced on about 15 to 18 days per month in winter and 10 to 11 days in summer, although rainfall duration and intensity tend to be highly variable (UKHO 1997). Some of the highest rainfall in the seas around the UK is experienced in the English Channel and mean annual rainfall figures for Regional Sea 3 vary between 601 and 1,500mm (OSPAR 2000).

The prevailing wind direction varies between south-south-west and north-west, with north-easterly winds increasing in late winter and spring. In autumn and winter, winds of force 5 (8m/s) or greater occur around 65% of the time in the west, and 50% in the east, falling to 25% and 15% respectively in the summer (UKHO 1996). In January, gales of force 7 (14m/s) or greater occur between 20 and 25% of the time to the east of the region, increasing to 25-30% in the west. In July such gales are experienced on only 2% of occasions (UKHO 1996), these may be more severe when associated with northerly winds (UKHO 1997). Funnelling of south-westerly and north-easterly winds may occur in the Dover Strait and be associated with short lived winds of force 5 to 6 (8-11m/s, UKHO 1997).

Fog occurs in winter between 2 and 5% of the time in the south-west and north-east respectively, while in summer fog occurs 3% of the time over the whole area on average. Visibility in excess of *ca*. 8km is expected 75% to 55% of the time in the south

A1f.6 Regional Seas 4 & 5

Mean air temperature in the north of Regional Sea 4 is 7°C in January and 14°C in July, increasing to 9°C and 16°C in the south of the region and in Regional Sea 5 in the same months. To the west, the average air temperature is 10.5°C in January and 16°C in July. The air is generally colder than the sea from October to March and warmer from April to August (UKHO 1999).

Rain occurs at sea on around 22 days per month in winter in the west and 15 days per month in the east. In summer, rainfall occurs on average 13 and 9 days in the west and east respectively (UKHO 1996).

The prevailing wind directions are between south-south-west and north-west, although the frequency of north-easterly winds increases in late winter and spring. Winds of force 5 (8m/s) or greater occur between 65% and 50% of the time in autumn and winter and 25% and 15% of the time in summer (UKHO 1996). In January, winds of force 7 (14m/s) or greater occur between 20% and 25% of the time to the east of the region, increasing to 25-30% in the west. In July, such wind speeds are experienced on 2% of occasions (UKHO 1996).

Radiation fog commonly affects the Bristol Channel in winter. Further south, fog may form on the coast in summer, most commonly in association with south-westerly winds. At sea, fog occurs most frequently in late spring and summer when warm, moist west to south-westerly winds blow over a relatively cold sea. Fog-like conditions (visibility less than 1km) may be experienced where precipitation near fronts is encountered (UKHO 1996).

A1f.7 Regional Sea 6

The mean air temperature is 7°C in January and 14°C in July. The air is generally colder than the sea from October to March and warmer from April to August, with a general difference of 1°C and 2°C respectively in the Irish Sea (UKHO 1999).

Rainfall at sea can be expected on *ca*. 18 days per month in winter and 10-15 days in summer though the intensity and duration of rainfall can vary greatly from day to day (UKHO 1999).

Winds are generally from the west and south-west for most of the year, though in spring there is an increased incidence of winds from all directions. In winter, there is a 20% chance of winds exceeding force 7 (14m/s) to the east of the Isle of Man, increasing to 25% to the west, north and south of the island. In summer this figure is reduced to 2%.

Fog is most frequent in April to October and is most often associated with south-westerly winds. Fog is much less common (2-5%) in June and also expected only 2% of the time in January (UKHO 1999). Visibility is in excess of *ca*. 8km for 80-85% of the year.

A1f.8 Regional Sea 7

The mean air temperature in January varies from 7°C in the west to 5°C in the east, increasing in July to 12°C and 14°C in the north and south respectively (UKHO 2004).

Precipitation can be expected on as many as 25 days per month in winter and, in summer, around 20 days in the north-west and 15 days in the south and east. The duration and quantity of precipitation is highly variable from day to day (UKHO 2004). Snow is generally only encountered between December and March (inclusive).

The prevailing winds are generally from west to south. Winds of force 5 (8m/s) or greater are reported around 70% of the time in the west during winter months, and around 60% of the time in the east. In July, winds of force 5 or greater are experienced between 30% and 35% of the time in the east and west of the area respectively. Wind is most variable in April when there is an almost equal proportion of wind from all directions, though still with a west and south-west maxima (UKHO 2004).

The greatest likelihood of fog over the open sea is in summer during periods of south-westerly winds. Summer fogs may be expected around 3-5% of the time, and on less than 2% of occasions in winter (UKHO 2004).

A1f.9 Regional Sea 8 & 9

The mean winter air temperature varies from 7°C in the west to 5°C in the east. In summer, mean temperatures vary from 12°C in the north and 14°C in the south (UKHO 2004).

Precipitation in the west of Regional Sea 8 can occur on as many as 25 days per month in winter and on 15-20 days per month in summer (UKHO 2004). In the east, precipitation may be experienced around 20% of the time in winter in winter months and 12% in summer (UKHO 2012). Quantity and duration of rainfall is highly variable.

Winds are principally from the west to south-west. In winter months, winds of force 5 (8m/s) or greater are reported around 70% of the time in the west and around 60% in the east. In summer, winds of force 5 or greater are experienced 30% of the time in the west and 25% of the time in the east (UKHO 2012, 2004). In April wind direction is highly variable though winds from the west and south-west are still most frequent (UKHO 2004).

The greatest likelihood of fog is in summer (April-September) when moist air moves in from the south (UKHO 1997b) and is most likely associated with winds from the southwest. Fog may be experienced around 3-5% of the time in summer and less than 2% of the time in winter (UKHO 2004).

A1f.10 Regional Seas 10 & 11

Mean air temperature at sea is 7°C in winter and 12°C in summer. The sea tends to be warmer than the air throughout most of the year. Rainfall can occur on as many as 25 days per month in winter and 20 days in late spring to early summer in the north-west and 15 days in the south and east. Duration and quantity of precipitation is highly variable.

Wind speed and direction are variable, but winds blow most frequently from the west and south in all seasons. Cold easterly winds may develop in winter and spring for a few days to several weeks if a high pressure cell occurs over north-west Europe. Winds of force 5 (8m/s) or more occur on 70% of occasions in winter and 15% in summer. Winds exceeding force 7 (14m/s) occur 30-35% of the time in winter and 5% or more in summer.

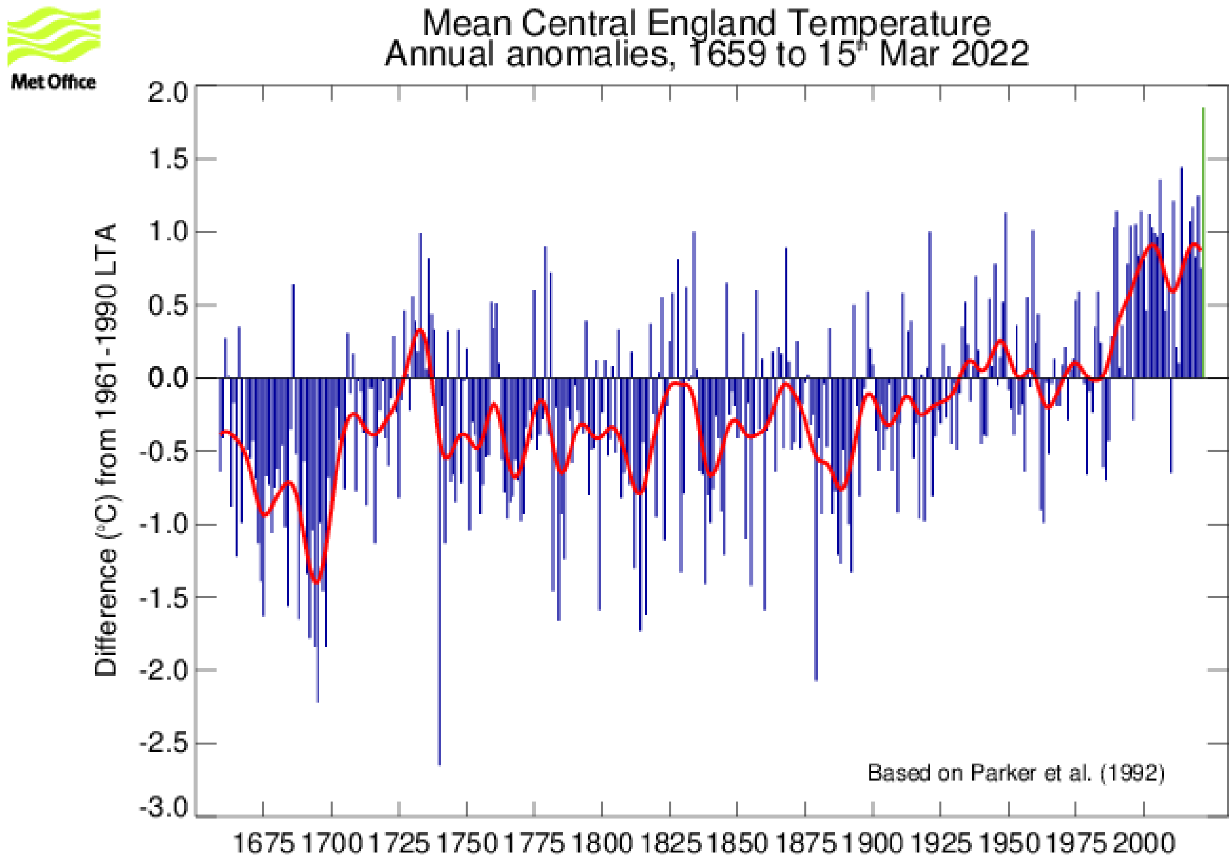
Visibility tends to be good or very good throughout most of the year, exceeding *ca*. 8km on about 79-84% of occasions in winter and 77-82% in summer.

A1f.11 Evolution of the baseline

Climatic data relating to rainfall and temperature are available for the UK from a comprehensive range of monitoring stations dating back to 1914 (Perry 2006). The Central England Temperature (CET) dataset is the longest instrumental record of temperature in the world with daily (since 1772) and monthly (since 1659) temperatures representative of a roughly triangular area of the UK enclosed by Lancashire, London and Bristol (Met Office Hadley Centre observations datasets - http://www.metoffice.gov.uk/hadobs/hadcet/, accessed May 2021). Time series data from this source (Figure A1f.5) show recent warming also witnessed in global surface temperature datasets (IPCC 2013). For the UK, there has been an increase in surface temperature since the 1970s, with 2010-2019 being on average 0.9°C warmer than the 1961-1990 average, and 0.3°C above the 1981-2010 average, and all of the top 10 warmest years (and none of the coldest) in the UK have occurred since 2002 (Kendon *et al.* 2020).

Available trends in marine air temperature, based on the ERA-Interim re-analysis of air temperature fields at a two metre reference height (Dee *et al.* 2011), show an increase in temperature for much of UK waters for the 30 year period of 1988-2017, however the majority of these increases are not significant (Tinker & Howes 2020).

Figure A1f.5: Mean CET annual anomalies, 1659 to March 2022



Notes The graph shows annual anomalies relative to the 1961-1990 average. The red line is a 21-point binomial filter, which is roughly equivalent to a 10-year running mean. Source: Met Office Hadley Centre observations datasets website - http://www.metoffice.gov.uk/hadobs/hadcet/

A1f.12 Environmental issues

It is extremely likely that the dominant cause of observed global warming since the mid-20th century has been caused by the anthropogenic production of greenhouse gases (GHGs), with global mean surface temperatures for the decade 2006-2015 being 0.87˚C higher than the average over period 1850-1900 (Masson-Delmotte *et al.* 2018), and other meteorological parameters such as precipitation also having been affected (e.g. there is high confidence after 1951 that precipitation has increased over mid-latitude land areas of the northern hemisphere). It is also considered likely that further changes in temperature, rainfall and incidence of extreme weather (e.g. heavy precipitation, drought, warm spells/heat waves) will occur in the course of the next century. It is considered virtually certain that the upper ocean has warmed since the 1970s, and that mean ocean surface temperature has increased at a rate of 0.11ºC (0.09-0.13°C) per decade (Pörtner *et al.* 2019), and very likely that other changes such as in salinity representing alteration in evaporation and precipitation trends have taken place.

Future warming is considered to be strongest in tropical and northern hemisphere subtropical regions. Of relevance to the UK and wider North West Europe, a weakening of the Atlantic Meridional Overturning Circulation (AMOC) is projected for the coming century of between 11% and 34% depending on the RCP considered, but with low confidence in projections beyond the 21st century (Stocker *et al.* 2014). While collapse of the AMOC is not considered to be likely by the end of the century, biases in climate models (Liu *et al.* 2017) may affect that estimation, such there is a medium confidence in this conclusion (Collins *et al.* 2019). The AMOC is presently in a weakened state, and there is broad agreement that it has weakened since the mid-2000s, and that this is likely part of a multi-decadal cycle superimposed on a long-term trajectory related to climate change (see summary in McCarthy *et al.* 2020, also see Good *et al.* 2018).

Anthropogenically augmented climate change is likely to have an effect on a number of meteorological (e.g. rainfall and temperature) and oceanographic (e.g. sea-level rise, alteration in wave conditions and circulation) parameters in the coming decades, and it is these projections (e.g. Stocker *et al.* 2013, Palmer *et al.* 2018, Pörtner *et al.* 2019) that are the basis for the carbon emissions reductions and adaptation initiatives discussed in Appendix 2, and the wider consideration of this topic in policy and legislation, including the UK's Net Zero commitment.

The principal greenhouse gas (GHG) of concern is CO_2 as it constitutes the largest proportion of GHGs emitted from combustion sources, for example, 81% (352 million tonnes) of UK provisional GHGs emitted in 2019 were of carbon dioxide (BEIS 2020). Additionally, the longevity of CO_2 in the atmosphere, for which figures vary widely, is significant compared to other (though often more potent) short-lives gas species. Houghton *et al*. (2001) suggest a range of 5-200 years, with a figure of ~1,000 years suggested by Archer (2005), though the author indicates that the "tail" of greenhouse gas emissions from fossil fuel sources may take ~30,000 years to completely dissipate. This compares with ~12 years for methane (CH_4), which is short by comparison, though this gas has a Global Warming Potential (GWP) 84 times that of CO_2 over a 20 year time horizon[4] (see Myhre *et al*. 2013). The residence time of CO_2 therefore means that today's policy implications are further reaching than immediate, decadal scales, but could continue to influence the climate for some time. This is further compounded, for example, by the long response times of the oceans and cryosphere such that these systems will be committed to long-term change even if emissions and related radiative forcing are stabilised (Pörtner *et al.* 2019).

The *Climate Change Act 2008* makes provisions for the reduction of carbon dioxide equivalent emissions (i.e. includes other notable greenhouse gases including CH_4 and N_2O). The UK Government is committed to the reduction of greenhouse gas emissions to "net zero" on 1990 levels by 2050. To ensure that regular progress is made towards this long-term target, the Act also established a system of five-yearly carbon budgets. The six carbon budgets, leading to 2035, have been set in law, as has the UK's commitment to reach net zero GHG emissions by 2050. The UK is currently in the third carbon budget period (2018-22). Subsequent budgets have been set at:

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[4] GWP is a value relative to that of carbon dioxide, indicating the radiative forcing effect of a given greenhouse gas over a given "time horizon". Note that there is no scientific argument for the choice of a particular time horizon to use. The 100 year time horizon was adopted by the United Nations Framework Convention on Climate Change (UNFCCC) and used in the Kyoto protocol (Myhre *et al*. 2013), and is therefore also used nationally for the calculation of carbon dioxide equivalent emissions (Shine 2009). Methane has a global warming potential of 34 over 100 years.

- Fourth carbon budget (2023-27); 50% on 1990 levels (1,950 million tCO_2eq)
- Fifth carbon budget (2028-32); 57% on 1990 levels (1,725 million tCO_2eq.) (note that the UK's Nationally Determined Contribution under the Paris Agreement indicates a commitment to reduce GHGs by at least 68% on 1990 levels by 2030).
- Sixth carbon budget (2033-37); 78% on 1990 levels (965 million tCO_2eq.)

The UK met both its first and second carbon budgets and is currently on track to meet its third budget (2018-2022) (CCC 2020). Ahead of the COP26 meeting in November 2021, the UK Government released its Net Zero Strategy: Build Back Greener in October 2021, which sets out a delivery pathway for Net Zero emissions showing indicative emissions reductions across sectors to meet the targets up to the UK's sixth carbon budget. At an international scale, an updated synthesis of 2030 NDCs and sectoral pledges following COP26 indicates that the measures would be expected to reduce warming to 2.4°C by the end of the century (CCC 2021). However, policies are not yet in place to deliver on these targets, and based on current policies a temperature rise of around 2.7°C could be expected by the end of the century (CCC 2021). In addition to the NDCs, which are legally binding short-term targets, Net Zero is being widely adopted as the standard long-term goal and in some cases has been set into national legislation. Estimates of the effect the Net Zero targets would have on global warming, in addition to the 2030 NDCs indicates that if these ambitions are delivered global warming could be limited to just below the 2°C scenario (CCC 2021).

UKCP18 details climate change projections based on a set of scenarios were developed for the IPCC fifth assessment report (see van Vuuren *et al.* 2011, Cubasch *et al*. 2013) termed Representative Concentration Pathways (RCPs). Based on factors which drive anthropogenic GHG emissions (e.g. population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy), these RCPs describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use to inform long-term and near-term modelling. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5) – note that numbers against each RCP relate to the radiative forcing targets for 2,100 in Wm^2. RCP2.6 is representative of a scenario that aims to keep global warming likely below 2°C above pre-industrial temperatures. Where described below, RCP4.5 is similar to SRES B1 (low emissions in UKCP09), RCP6.0 is similar to SRES B2 (between low and medium) and RCP8.5 is similar to SRES A1F1 (high emissions).

The most recent UK climate projections (UKCP18[5]) detail:

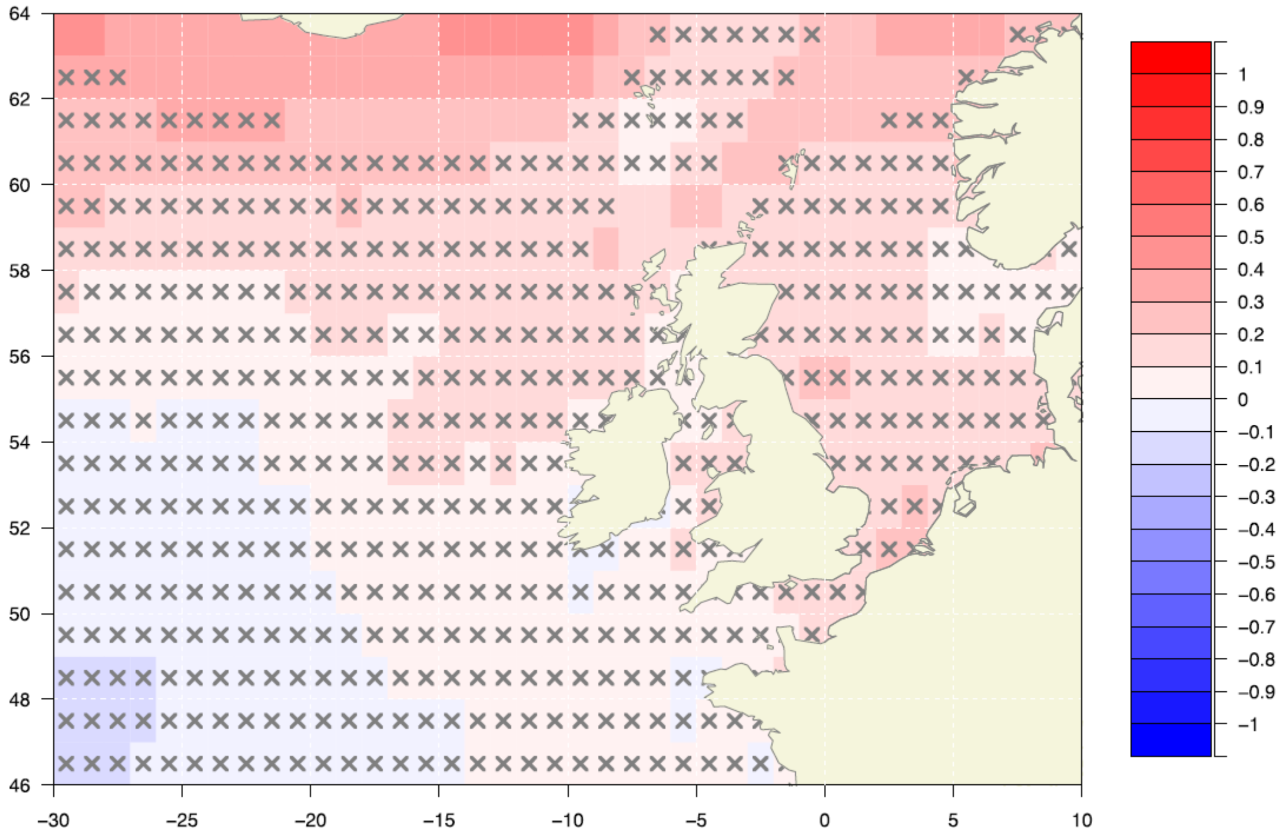
- Terrestrial modelled climate projections (e.g. air temperature, precipitation) – see Murphy *et al.* (2018)
- Marine projections (e.g. coastal sea level including extreme levels related to storm surge and waves) – see Palmer *et al.* (2018). Note that these projections are discussed in Appendix 1b.

The marine report (Palmer *et al.* 2018) for UKCP18 did not provide updated projections for marine air temperature or precipitation, however these are summarised in Tinker & Howes (2020). A 30 year (1988-2017) in marine air temperature estimated from ERA-Interim analysis

[5] https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index

covering the North East Atlantic is shown in Figure A1f.6 (see Tinker & Howes 2020, also see Dee *et al.* 2011). Temperature changes across most of the modelled grid are not significant, other than an area to the north of Scotland (covering much of Regional Sea 8). There is a reasonable level of correspondence in the ERA-Interim data with other long-term temperature datasets including CET and SST anomalies (Tinker & Howes 2020); recent changes and projections for changes in SSTs are described in Appendix A1d.

A1f.6: 30 year (1988-2017) trend in annual average ERA-Interim air temperature at 2m (°C/decade)



Notes: Crosses indicate where the trends are not significant at the 95% confidence level using the Cochrane-Orcutt method to account for autoregression in the time-series data. Source: Tinker & Howes (2020).

The scientific basis of our current understanding of the effects of climate change to date, along with projections based on a revised set of scenarios called, Shared Socioeconomic Pathways (SPPs)[6], is being updated by the IPCC for its Sixth Assessment Report (AR6). A draft of the Working Group I report (IPCC 2021) has been published, with the full report expected in 2022.

[6] AR4 used Representative Concentration Pathways (RCPs). SSPs differ in that they include socioeconomic narratives that are considered to represent major socioeconomic, demographic, technological, lifestyle, policy, institutional and other trends (O'Neill *et al.* 2017, Riahi *et al.* 2017), matched with mitigation targets representing the radiative forcings (Wm^{-2}) in 2100.

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