APPENDIX 3f - CLIMATE AND METEOROLOGY

A3f.1 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 is also relatively mild for the latitude because of the presence of the easterly arm of the Gulf Stream, the North Atlantic Drift. These warm waters originate in the Gulf of Mexico and bring with them mild, humid air.

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. The index is most relevant in winter when the pressure gradients are at their strongest (IACMST 2005). 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). The winter NAO is statistically predicted by the Met Office each year (see Met Office website - NAO pages) and by Hurrell (see Hurrell *et al.* 2003) at Climate and Global Dynamics, University Corporation for Atmospheric Research (see UCAR website). Issues relating to climate change are discussed in the Environmental Issues section below.

Meteorological considerations are of strategic importance to offshore renewable energy developers. The DECC Offshore Renewables Energy Atlas provides information relevant to wave, tidal and wind energy. Figure A3f.1 below indicates the annual mean wind power (at 100m) for the UKCS, with each Regional Sea indicated.

Twenty-nine Met Office stations are located around the UK coast and have accompanying available datasets (e.g. precipitation, wind, air temperature, sunlight) presently spanning the years 1971-2000 (Figure A3f.2). Eighteen World Meteorological Organisation stations record similar meteorological data (WMO 1998) which are available in the most recent UKHO Pilot Projects, and these publications also include details of typical offshore conditions. The OSPAR Quality Status Report (OSPAR 2000a, b) provides some basic meteorological observations relating to the UKCS, and more recently the Inter-Agency Committee on Marine Science and Technology (2005) publication, *Charting Progress: An Integrated Assessment of the State of UK Seas*, summarises the meteorology and climate for the UKCS. Information, principally from these sources, has been used to present the average meteorological condition for each Regional Sea in the sections which follow.

Figure A3f.1 – Annual mean wind power (100m) for the UKCS

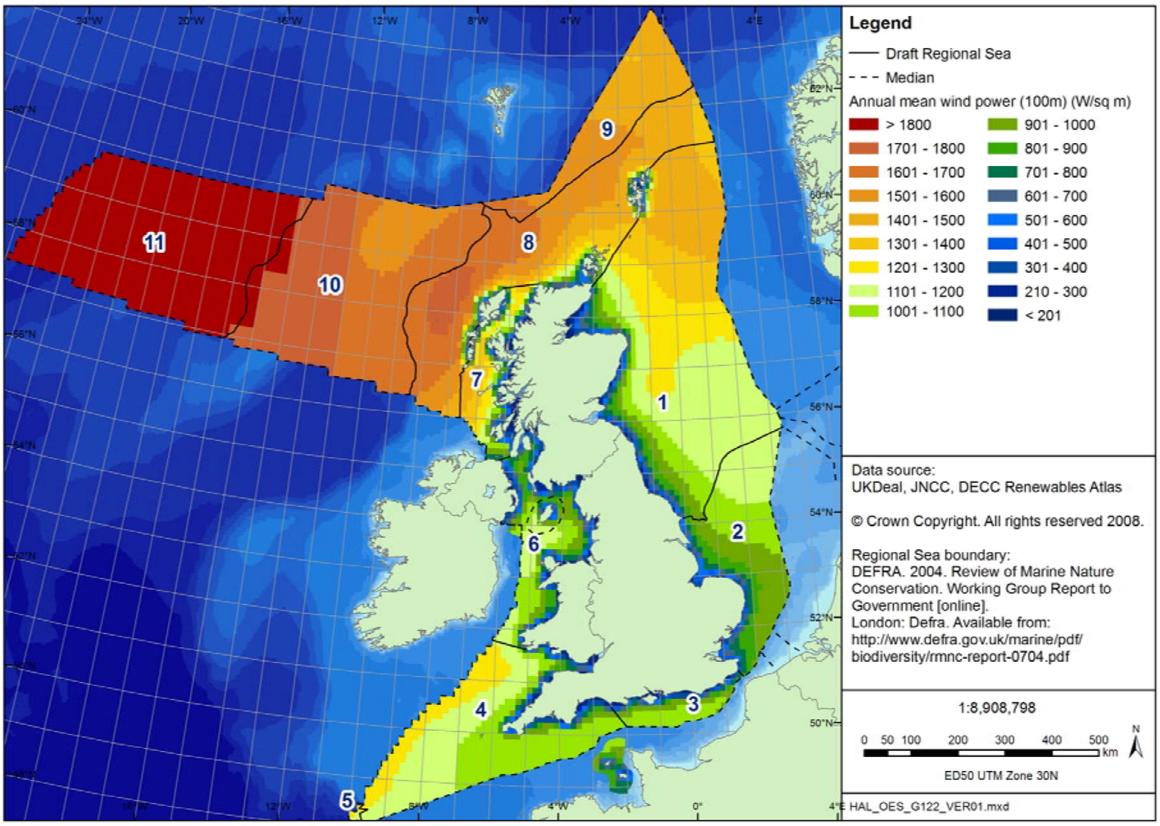
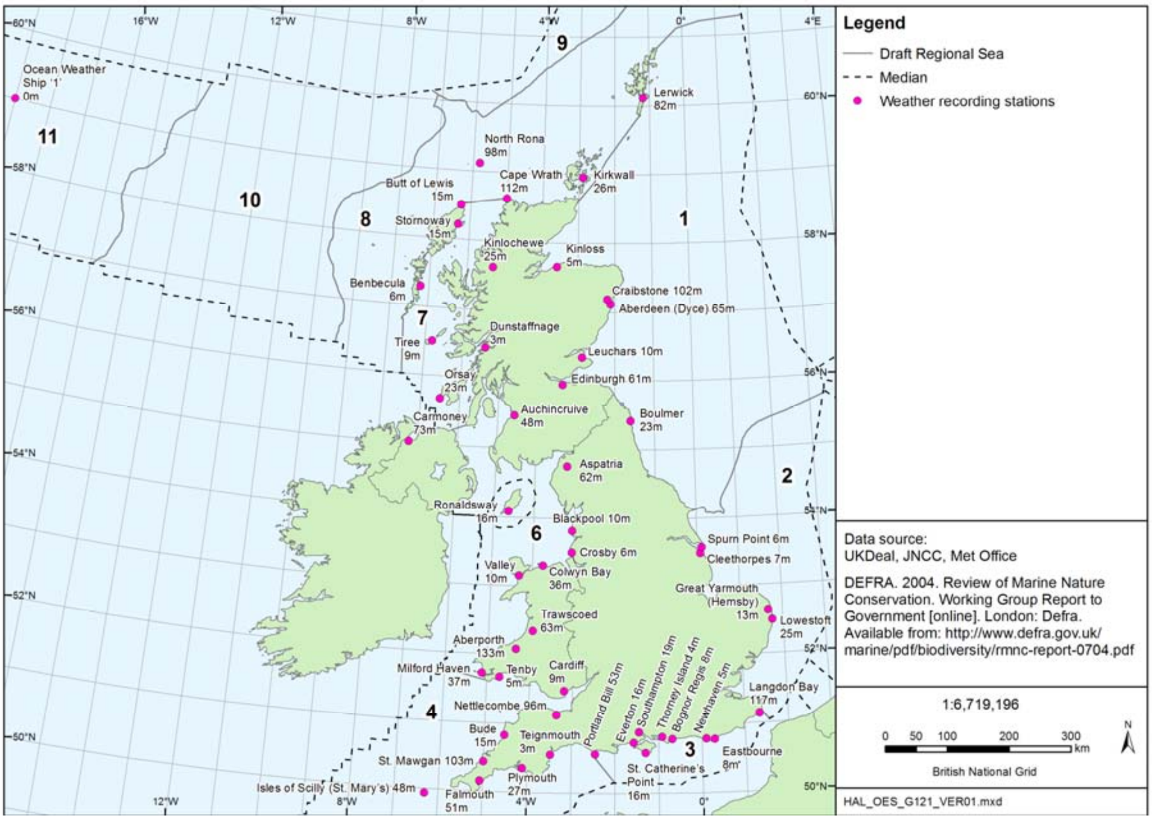


Figure A3f.2 – Coastal Weather Recording Stations



A3f.2 AVERAGE METEOROLOGICAL CONDITIONS

A3f.2.1 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 *ca.* 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 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 2007). The relatively high winter minimum temperatures at the coast are visualised in Figure A3f.3. 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).

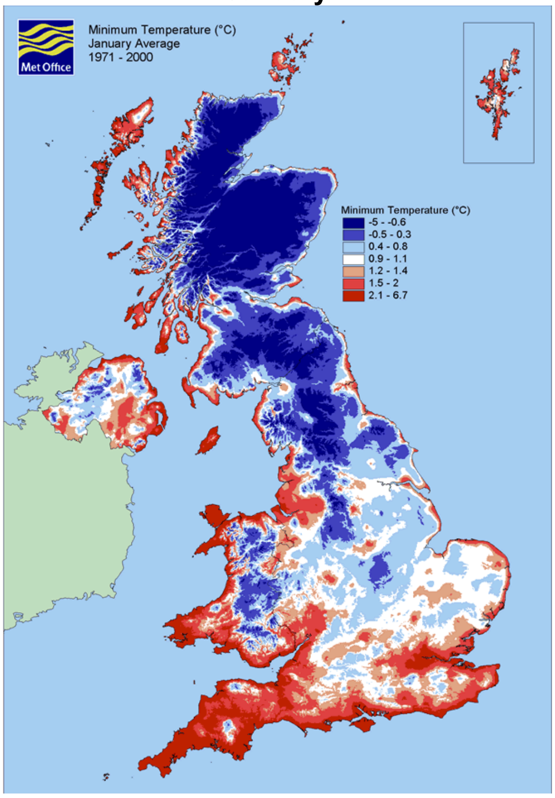
Icing conditions that are known to cause additional structural loading on maritime vessels may also raise engineering (e.g. Frohboese & Anders 2007), public safety (e.g. Morgan *et al.* 1998) and environmental considerations for wind turbines operating offshore. Ice accretion may generate rime or glaze ice through contact with atmospheric water vapour (freezing fog or cloud contact) or precipitation on a wind turbine structure at sub-zero temperatures. The formation of ice on a wind turbine will tend to reduce blade aerodynamic efficiency (Laakso 2005) and by association rotation speed and power output. Concern has been raised about the ability of wind turbines to discharge ice from blades by up to several hundred metres during rotation (Morgan *et al.* 1998). Seifert *et al.* (2002) suggest that a rough throw distance might be calculated as 1.5 times the sum of the hub height and rotor diameter. Practical measures to prevent this from being an issue include de-icing systems (e.g. heated turbine blades). Attention is brought to ISO 12494 which describes the principles of determining ice loads on structures including wind turbines.

MCA guidance (MCA 2000) indicates that for maritime vessels, ice accretion should only be of concern north of 65°N, though this is based on structural loads for vessels which will differ from those acceptable for wind turbines. Durstewitz *et al.* (2004) indicate that icing is more likely in Finland, Norway and Sweden, where arctic conditions can affect turbines inland rather than those areas further south (e.g. UK), and given that the sites being considered are offshore and have a generally southern distribution, there is a low likelihood this phenomenon will cause operational problems. Figure A3f.4 indicates areas where icing may be of concern for developers, though local variations are not well resolved on this map (e.g. topographic variation), as indicated in the accompanying inset for the UK, though coastal areas are notably more mild than those inland.

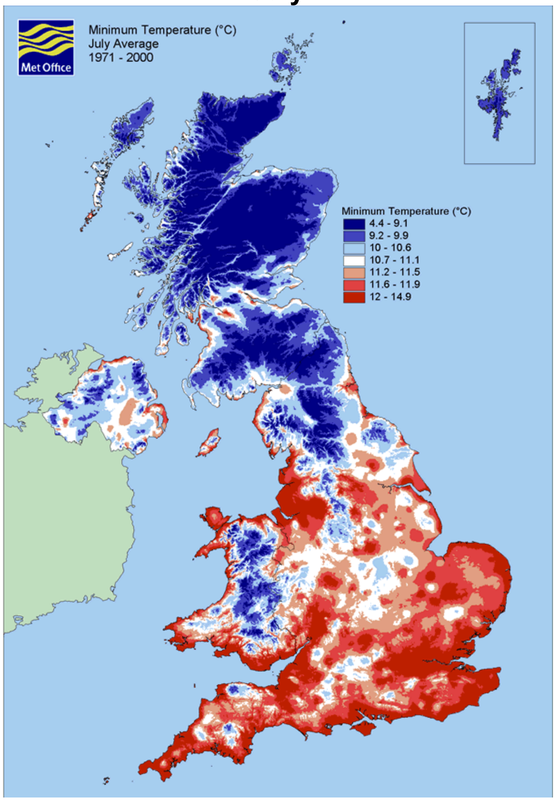
Figure A3f.3 – Average Minimum and Maximum Air Temperatures in January and July (1971-2000)

Minimum air temperature

January

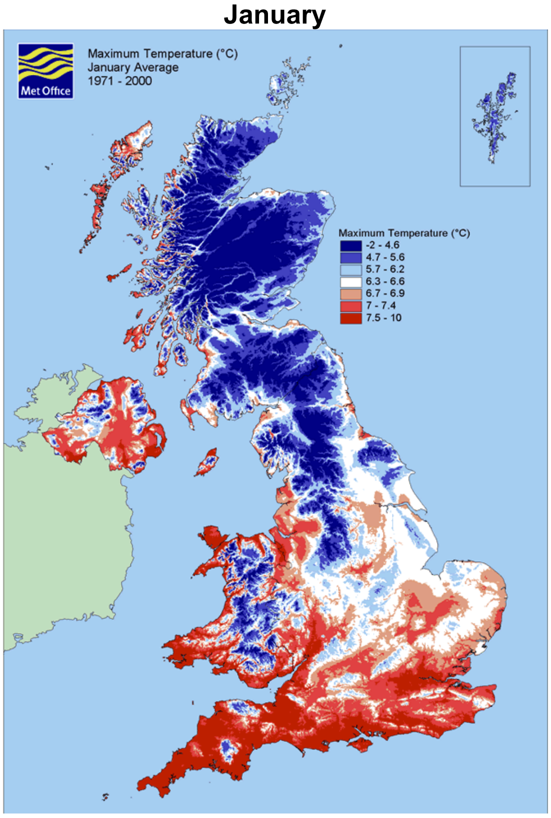


July

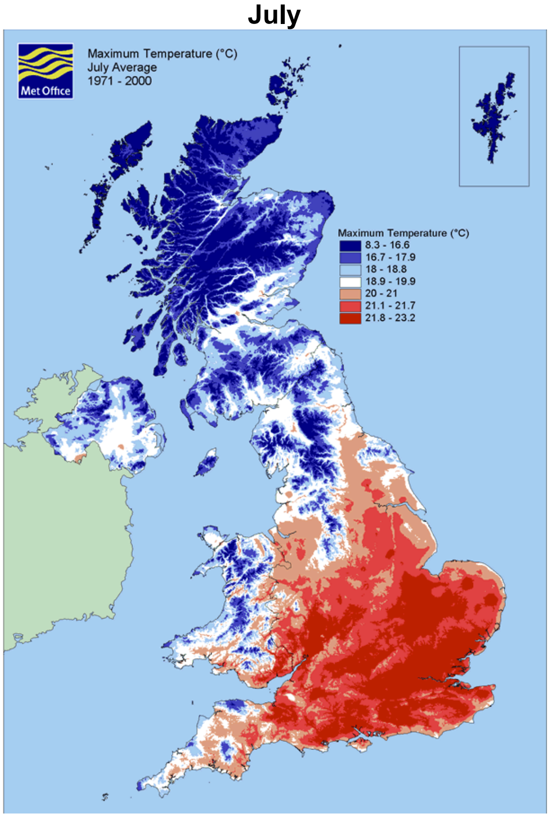


Maximum air temperature

January

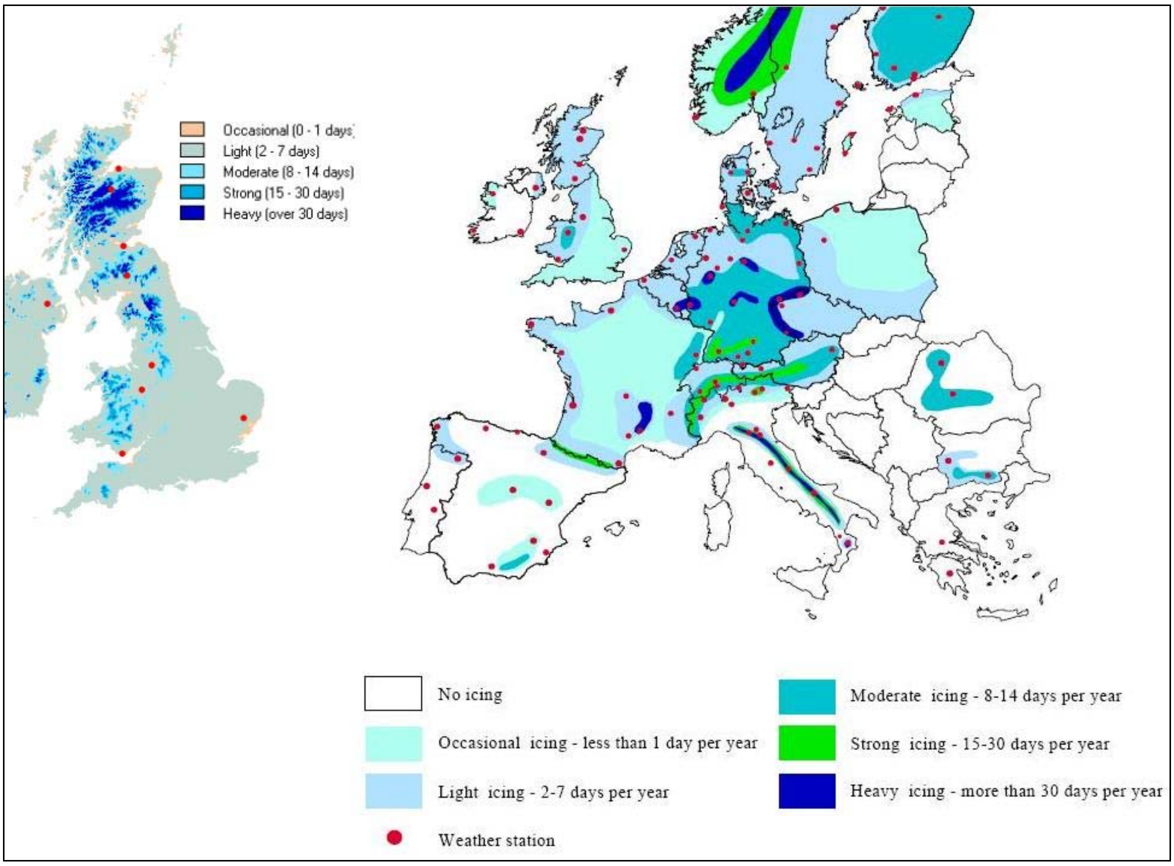


July



Source: Met Office Website

Figure A3f.4 – Icing map of Europe



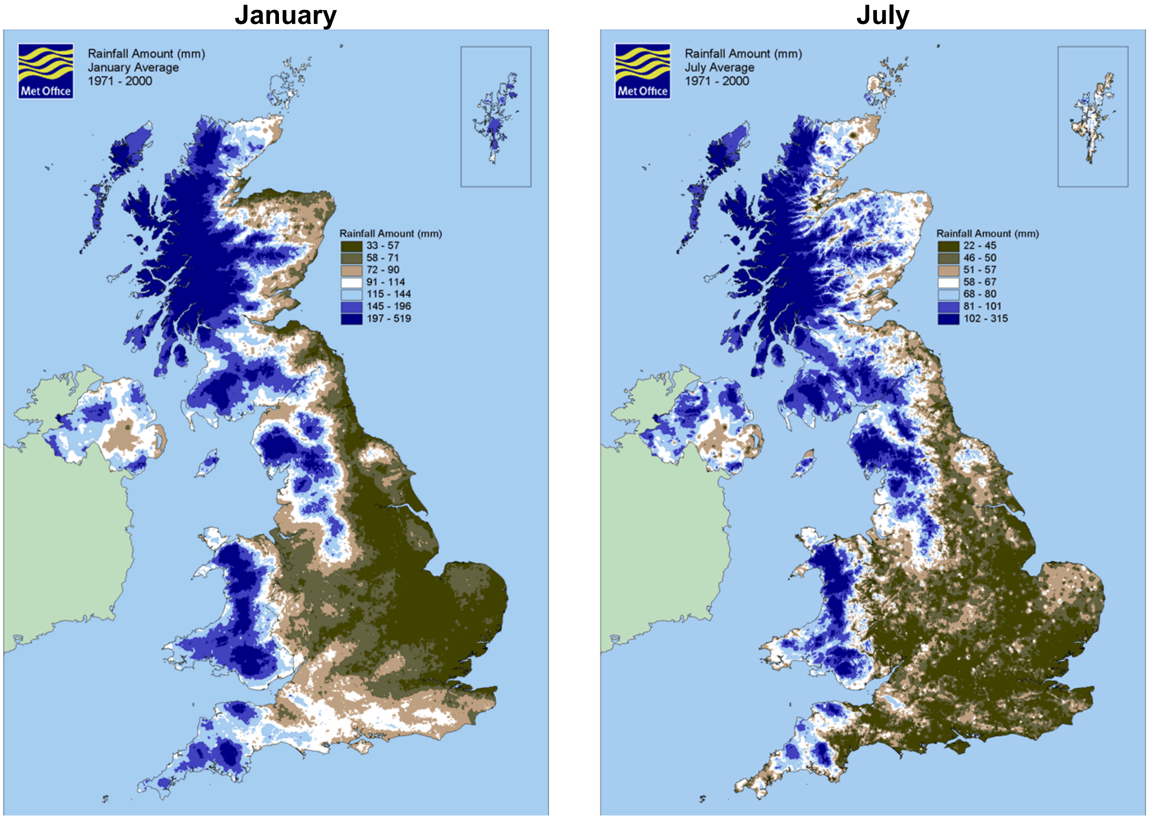
Source: Laakso et al. (2003)

The WMO Handbook of Offshore Forecasting Services (WMO 1998) indicates that icing at sea may be generated by both saline and fresh water, and that conditions under which sea water spray is likely to freeze on structures include: wind greater than Beaufort scale 6, sea surface temperatures less than 2°C, air temperature at below freezing temperatures. To put this in context of the Round 3 sites (Regional Seas 1, 2, 3, 4 and 6), winter mean sea surface temperatures are between 6 and 8°C, mean air temperatures are between 4 and 7°C and winds exceeding Beaufort scale 7 occur only up to 20-25% of the time – it is accepted that these are means and that conditions for icing may be met at some stage, albeit for a short period of time.

A3f.2.2 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 A3f.5) and the orographic effects of mountains areas which have a primarily western distribution.

Figure A3f.5 – Average Rainfall in January and July (1971-2000)

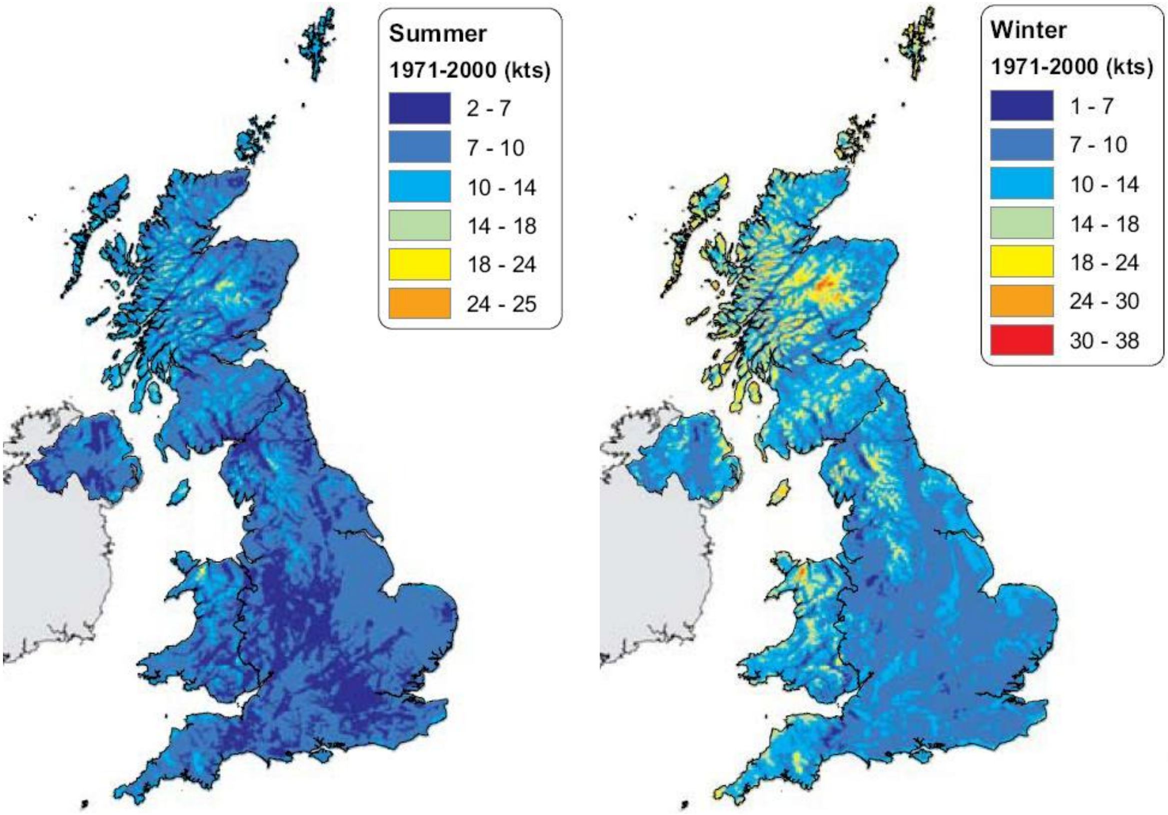


Source: Met Office Website

A3f.2.3 Wind

Like precipitation, a winter maxima for wind speed is expected for most of the UK (Figures A3f.6 and A3f.7). The north and west (Regional Seas 4, 6, 7 and 8) 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, and to the south of 1) with mean winter wind speeds not exceeding 15 knots 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 1997a).

Figure A3f.6 – Average UK Windspeed

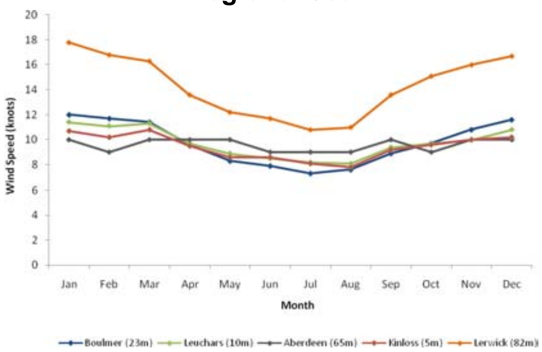


Source: Jenkins et al. (2007)

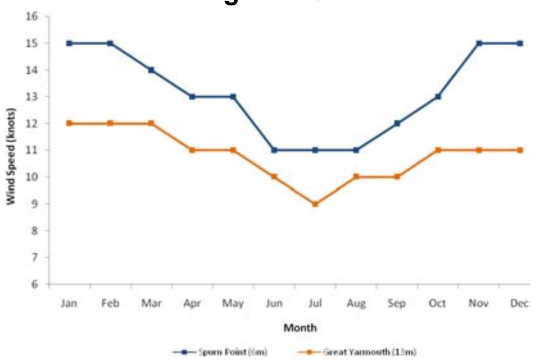
Wind at the coast is largely controlled by air pressure gradients, though local topographic conditions can also provide a considerable influence; for instance, winds may strengthen when channelled down narrow inlets or weaken over waters in sheltered areas (UKHO 1997b). Areas where funnelling effects are associated with significant increases in wind strength (particularly estuaries) are listed by the UKHO (1996, 1999) for a numer of locations in Regional Seas 4 and 6 (Table A3f.1). In 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 1997a).

Figure A3f.7 – Average Monthly Wind Speed (1971-2000) for recording stations in each Regional Sea

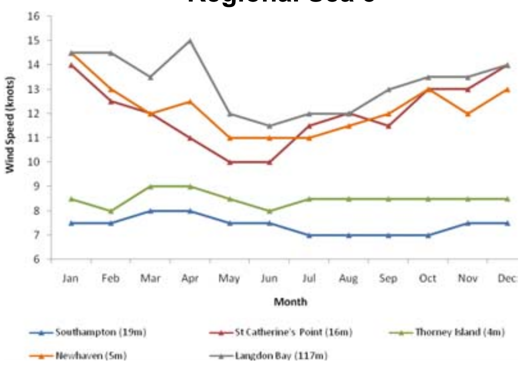
Regional Sea 1



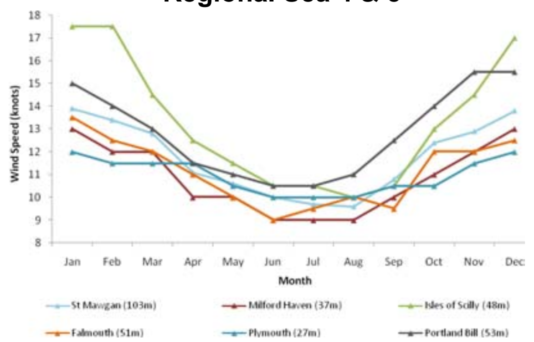
Regional Sea 2



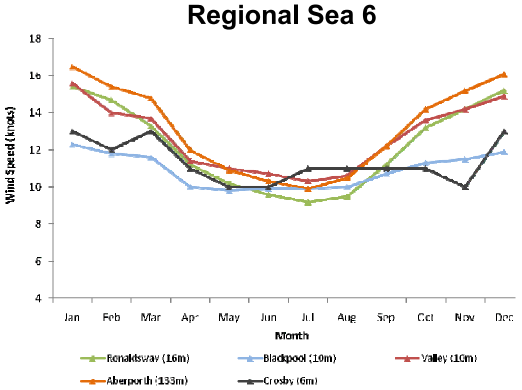
Regional Sea 3



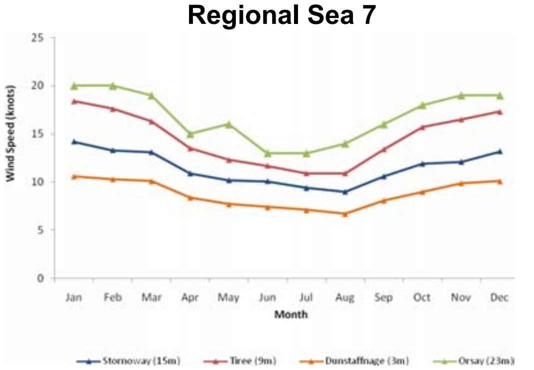
Regional Sea 4 & 5



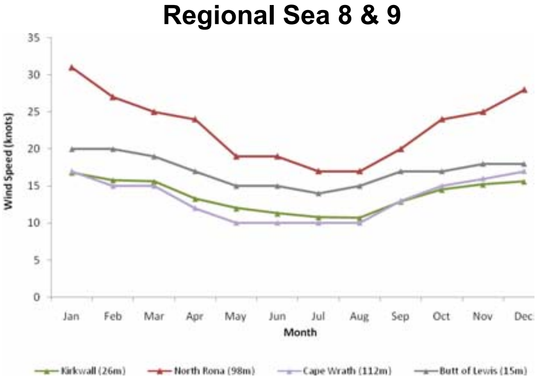
Regional Sea 6



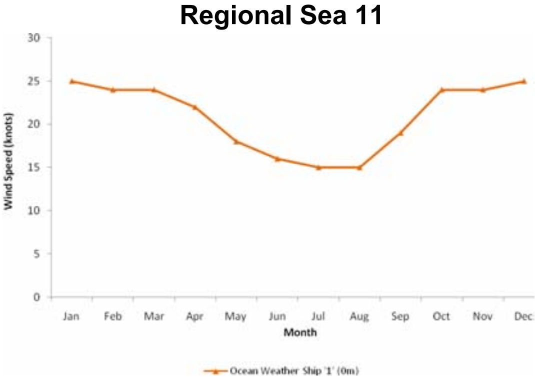
Regional Sea 7



Regional Sea 8 & 9



Regional Sea 11



Source: Met office website, UKHO (1996, 1997a, b, c, 1999, 2004)

Table A3f.1 – Areas influenced by marked increases in wind strength

RSA	Location	Wind Direction
4	Bristol Channel: East	W
	Bristol Channel: West	SW
	Milford Haven	S to W & N
	St George's Channel	S
6	Holyhead	NW
	River Dee Estuary	NE or SE
	River Mersey Estuary	NW or SE
	Morecambe Bay	SW to W
	Solway Firth	SW
	Isle of Man to North Channel	NW

Source: UKHO (1996, 1999)

A3f.3 CONDITIONS AT SEA

A3f.3.1 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. In Regional Sea 1, 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 2000a). Rainfall follows a seasonal trend analogous to that observed onshore, with the percentage chance of rainfall being 13 and 18% in the SE and NW 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 1997a). 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 1997a, b).

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 1997a). The frequency of gales exceeding force 7 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 there (UKHO 1997b). Wind strengths in winter are typically in the range of Beaufort scale 4-6, with higher winds of force 8-12 being much less frequent. Winds of force 5 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 1997b). 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 1997a).

A3f.3.2 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 in Regional Sea 2 decreases in a south-north direction. To the north of the Dover Strait an annual rainfall of between 601-1000mm is expected, reducing to 401-600mm in the outer Thames Estuary and as far north 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 1997a).

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 in the summer months with a greater proportion of strong to gale force winds of Beaufort scale 7-12 in winter (UKHO 1997a). In January, 20% of winds can be expected to exceed Beaufort scale 7, 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 at less than 1km 3-4% of the time, and is associated with winds between 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 (UKHO 1997a). Visibilty in excess of 5 miles is experienced in January on about 55% of occasions, increasing to *ca.* 80% in summer (UKHO 1997a).

A3f.3.3 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 1997c). 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 1500mm (OSPAR 2000a).

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 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 Beaufort scale 7 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 1997c). 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 (UKHO 1997c).

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 5 miles ranges is expected 75% to 55% of the time in the south-west and north-east respectively in January, and 80% of the time for the whole area in summer (UKHO 1997c).

A3f.3.4 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 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 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 Beaufort scale 7 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).

A3f.3.5 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 Beaufort scale 7 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 5 miles for 80-85% of the year.

A3f.3.6 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 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).

A3f.3.7 Regional Seas 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 1997b). Quantity and duration of rainfall is highly variable.

Winds are principally from the west to south-west. In winter months, winds of force 5 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 1997b, 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 south-west. Fog may be experienced around 3-5% of the time in summer and less than 2% of the time in winter (UKHO 2004).

A3f.3.8 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. Ocean Weather Ship ‘1’ in Regional Sea 11 recorded rain of more than 1mm on an average of 25 days a month between 1950 and 1960. 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 or more occur on 70% of occasions in winter and 15% in summer. Winds exceeding Beaufort force 7 occur 30-35% of the time in winter and 5% or more in summer. Ocean

Weather Ship '1' in Regional Sea 11 recorded an average wind speed of 21 knots, ranging from 25 knots in the winter to 15 in the summer (1950-1960)

Visibility tends to be good or very good throughout most of the year, exceeding 5 miles on about 79-84% of occasions in winter and 77-82% in summer. In Regional Sea 11, Ocean Weather Ship '1' recorded an average of 17 days fog per year between 1950 and 1960, with a maximum of 3 days in July (1950-1960).

A3f.4 EVOLUTION OF THE BASELINE

Climate (or weather) data relating to rainfall and temperature are available for the UK from a comprehensive range of monitoring stations dating back to 1914 (Perry 2006). A smaller range of stations also record wind speed, and data are available from these for between 1961 and 1991, and 1971 to 2000. Trends within these datasets have been described by Perry & Hollis (2004), Perry (2006) and Jenkins *et al.* (2007). The longest instrumental record in the UK is the Central England Temperature (CET) which extends back to 1659, coinciding with the advent of the thermometer and a general advance in science (Bell & Walker 2005). Time series data from this source show recent warming witnessed also in global temperature datasets (see discussion below).

Proxy data sources can be used to reconstruct past climatic conditions at a range of spatial and temporal scales and with varying degrees of accuracy. Perhaps one of the most valuable sources of information relating to long-term climate change is data obtained from Ice Cores (e.g. Greenland Ice Core Project, Greenland Ice Sheet Project, EPICA Antarctica project) which may extend current knowledge of atmospheric trace gases (e.g. CO_2), dust and volcanic aerosols back to 800ka (Bell & Walker 2005). Knowledge of short-term and long-term climatic change has been built up through the study of multiple proxy records which has an important application in generating a baseline for the study of recent climatic change which may be associated with human activity.

A3f.5 ENVIRONMENTAL ISSUES

Climate change, particularly that which may be anthropogenically augmented, is the motivation for the UK government CO_2 reduction targets which should in part be addressed by a promotion of renewable energies via Round 3, and subsequent rounds of offshore wind leasing. In recent years, anthropogenic and natural drivers of climatic change have become an increasing focus of study due to concern over the potential impacts of any undesirable climatic deterioration. The input of greenhouse gasses (e.g. CO_2, CH_4, N_2O, O_3) resulting from fossil fuel usage, agriculture and other land use, is of particular concern as these have been linked with atmospheric warming. Ice core records indicate that industrial increases in CO_2 (the major contributor to the 'greenhouse effect') and CH_4 have resulted in atmospheric concentrations not surpassed in at least the last 650 ka (IPCC 2007a). Conversely, negative radiative forcing (i.e. cooling) is associated with aerosols (small particles/droplets) which may be produced naturally (e.g. volcanic eruptions, dust storms), or anthropogenically (e.g. sulphate aerosols, soot, biomass-burning aerosols), and these may have offset some greenhouse related warming (Bell & Walker 2005), though some of the processes associated with atmospheric aerosols are still not well understood (IPCC 2007b).

The IPCC Fourth Assessment Report, Working Group I, entitled, 'The Physical Science Basis' (IPCC 2007a) presents current scientific knowledge on climatic change, associated processes and the potential future climatic trajectory. The principal findings of the report are:

- Global atmospheric CO_2, CH_4 and N_2O has increased since 1750. CO_2 has primarily increased as a result of anthropogenic fossil fuel usage, and current levels have not been surpassed for *ca.* 650,000 years. It is *very likely*[1] (>90%) that CH_4 and N_20 concentrations have increased from agriculture and fossil fuel use.
- The combined increased concentrations of these 'greenhouse gases' has led to a positive radiative forcing of $2Wm^{-2}$ – forcing for CO_2 increased by 20% from 1995 to 2005. Ozone-forming chemicals (nitrogen oxides, carbon monoxide, hydrocarbons), changes in surface albedo due to land cover change and deposition of black aerosol on snow have also attributed to a net positive radiative forcing. Aerosol concentrations have produced a cooling effect.
- Direct observation of recent climate change indicates an increase in global average air and ocean temperatures, widespread melting of snow and ice and rising global sea-levels. The average temperate of the ocean has increased down to 3,000m since 1961, generating seawater expansion associated with rising sea-levels. Global average sea-levels have increased by *ca.* 1.8mm per year (1961-2003), though figures for 1993-2003 show an increased rate of 3.1mm per year. There is high confidence that sea-level rise increased from the 19^{th} to 20^{th} centuries.
- At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and a corresponding reduction in ice cover, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones.
- Some climatic features do not show any statistically significant change. Antarctic sea ice extent remains within an acceptable range of interannual variability. Diurnal temperature range has not changed from 1979 to 2004. There is presently insufficient evidence to suggest that there has been any change in meridional overturning circulation of the global ocean, or small-scale phenomenon such as tornados, hail, lightening and dust storms.
- Most of the observed increase in globally averaged temperatures since the mid-20^{th} century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations. This is an advance since the Third Assessment Report (TAR) conclusion that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in greenhouse gas concentrations". Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns.
- For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES (Special Report on Emissions Scenarios) emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected.
- Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21^{st} century that would *very likely* be larger than those observed during the 20^{th} century.

The UK Climate Impacts Programme (UKCIP) has published an updated report (Jenkins *et al.* 2007) detailing recent trends in climatic variables (e.g. precipitation, air temperature). Met Office data spanning the periods 1961-1900 and 1971-2000 have been used to calculate the annual and seasonal arithmetic difference for each variable between the two datasets and are presented as a series of maps. A longer term dataset

1 From the Summary for Policymakers, the following terms have been used to indicate the assessed likelihood, using expert judgement, of an outcome or a result: Virtually certain >99% probability of occurrence, Extremely likely >95%, Very likely >90%, Likely >66%, More likely than not >50%, Unlikely <33%, Very unlikely <10%, Extremely unlikely <5% (IPCC 2007).

(1915-2006) has also utilised to display the change in each variable based on a linear trend. The principle findings of this research have been:

- Central England Temperature (CET) has risen by *ca.* 1°C since the 1970s, likely influenced by anthropogenic activity
- Scottish and Northern Irish temperatures have risen by *ca.* 0.8°C since 1980. These changes cannot necessarily be attributed to anthropogenic activity
- Overall, change in annual precipitation has been negligible in the east, with a 2-10% increase in the west, particularly in Scotland, Wales and the south-west peninsula. Seasonally, summer precipitation has decreased by up to 10% in north and east Scotland and northern England, whereas in winter, values have increased by up to 10% in Wales and the south west and by up to 30% in north-west Scotland, the Hebrides and Northern Isles.

Revised future projections and climate scenarios for the UK are to be published by UKCIP in early 2009 as an update to the earlier UKCIP report by Hulme *et al.* (2002).

Resulting impacts of enhanced atmospheric greenhouse gas concentrations include increased warming and drought, rising sea-levels due to net polar ice cap and terrestrial glacier retreat and the thermal expansion of the ocean. More changeable and extreme weather is also a possible outcome, though this has been contested for the British Isles (Balling *et al.* 1991) and future changes in Northern European windiness cannot be projected with confidence, though it is surmised it might increase (IPCC 2007a). Indeed, other stochastic influences such as volcanic eruptions may have a significant influence on deviations from average climatic conditions including windiness (Dawson *et al.* 1997), and there is an increasing body of literature suggesting that solar variability has generated climatic changes during the Holocene (Blaauw *et al.* 2004).