Implications of the EU Climate Protection Target for Ireland

Environmental Research Centre Report

Prepared for the Environmental Protection Agency

by

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Executive Summary

The European Union has adopted a long-term climate protection target to limit global mean temperatures to not more than 2°C above pre-industrial levels. This is in response to the United Nations Framework Convention on Climate Change (UNFCCC) Article 2 objective which is to stabilise "*greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*".

Scientific analysis suggests that atmospheric greenhouse gas concentrations would need to be stabilised at levels close to 450 ppm CO_2 equivalent to ensure that the 2°C target is not breached. However, there is still considerable uncertainty surrounding this stabilisation level.

Defining what is "*dangerous*" requires an analysis of the various impacts of climate change and the temperature change at which they occur. For Ireland, the 2°C target represents an appropriate 'guard rail' for avoiding dangerous climate change in relation to major climate impacts. Exceeding this target, the melting of the West Antarctic Ice Sheet and the Greenland Ice Sheet and subsequent sea level rise, as well as a reduction of the Thermohaline Circulation, are among the most important 'high-impact, low-probability' events which would have substantial impacts for Ireland.

Ireland will also experience significant climate change impacts below 2°C, many of which are now unavoidable. Adaptation actions will be required to reduce adverse impacts of these changes. Vulnerable sectors which will be impacted upon as a result of increasing global mean temperatures include:

- water resources – reduced soil moisture, increased frequency and magnitude of flooding, changes in water quality
- ecosystems and biodiversity – change in distribution of plants and animals, for example a possible decline and extinction of Arctic species
- agriculture and food production – increased demand for irrigation, potential for new crops
- sea level rise – loss of coastal habitats, increased erosion, increased incidence of coastal flooding
- the marine environment – impacts upon fish stocks sensitive to small changes in temperature such as phytoplankton, northward movement of cold water species.

The EU climate protection target can only be reached through international co-operation in combating climate change. Further, effective mitigation and adaptation strategies are needed to prevent dangerous anthropogenic interference with the climate system. Ireland should therefore promote this target at the EU and wider international levels. Further research is required to reduce uncertainty in relation to the impacts of increasing greenhouse gas concentrations in the atmosphere.

1 Introduction

The objective of Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) is to achieve "*stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*". The Convention also states that "*Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure food production is not threatened and to enable economic development to proceed in a sustainable manner*" (UNFCCC, 1992). The Second Assessment Report by the Intergovernmental Panel on Climate Change (IPCC, 1996) indicated that severe climate change impacts would increase significantly if global temperatures increase by more than 2°C above pre-industrial times. Based on this assessment, the EU considered that international action on climate change should aim to ensure that this temperature limit is not exceeded (1939th Council meeting, Luxembourg, 25 June 1996). This climate protection target was reaffirmed at EU Environment Council meetings in December 2004 and March 2005 in the run-up to negotiation on future international actions on climate change. This position was informed by the IPCC Third Assessment Report (TAR) (2001).

2 Scope and Contents of Document

The aim of this report is to provide an assessment of what the EU 2°C target may mean for Ireland. It reviews the situation with regard to recent climate change, and the implications of a projected increase in mean temperature. A number of key issues are considered, including: what is meant by "*dangerous anthropogenic interference*", key vulnerabilities, risks and uncertainties for Ireland. It also identifies sectoral impacts which can be expected up to, and beyond, a 2°C temperature increase.

The EU 2°C target is considered in relation to greenhouse gas (GHG) emissions and stabilisation concentrations. There are many uncertainties in relation to concentration stabilisation levels, with different rates of warming considered 'likely' at different stabilisation levels and on different timescales. Risks and vulnerabilities in the climate system are reviewed, with attention focusing on high-impact, low-probability events. Possible large climate changes that could occur abruptly and lead to more adverse impacts are especially important beyond 2°C. Following from this, the implications of climate change beyond 2°C are reviewed for sectors within Ireland including water resources, agriculture, biodiversity and the marine environment. Recommendations for development of adaptation planning and future research are offered.

3 Article 2 of the United Nations Framework Convention on Climate Change

Article 2 of the UNFCCC establishes as its main objective the stabilisation of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system. It also defines this in specific terms, within a time frame to allow ecosystems to adapt naturally to climatic change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner (UNFCCC, 1992). These components establish stabilisation of atmospheric greenhouse gas levels as the key objective, and also establish constraints with respect to adaptation of ecosystems, food production and sustainable economic development.

However, the definition of what is “*dangerous*” and the way to stabilise concentration levels or a specific time frame to do it in are not specified by the Convention and therefore subject to interpretation. The focus on concentration of greenhouse gases rather than climate change itself is also open to some interpretation, as there are many uncertainties surrounding the impacts of specific concentrations upon the climate system.

4 Why an EU 2°C Temperature Target?

In 1996, the European Council first established the position that a temperature target of 2°C should not be exceeded if "*dangerous anthropogenic interference*" was to be avoided. This interpretation of dangerous climate change is defined in terms of global mean temperature. Evidence from the IPCC Second Assessment Report suggested that the risk of severe climate change impacts would increase markedly with a temperature increase of 2°C above pre-industrial levels.

More recent research indicates that ecosystems and water resources may already experience significant impacts with a temperature increase of 1–2°C. However, these would increase significantly, with a greater probability of abrupt impacts beyond 2°C. According to the German Advisory Council on Global Change (WBGU, 2003), in order to avert dangerous climate change, a maximum warming of 2°C should be adopted as a 'climate guard rail'.

Other options to a temperature target could include a greenhouse gas emissions level target, an atmospheric greenhouse gas concentration level, a combined target of a change in mean global temperature with sea level rise, changes in regional climate variables or changes in the intensity and frequency of extreme events (IPCC, 2001). However, global mean temperature was selected as it allows impacts to be directly related to changes in temperature, and also it is more feasible to relate changes in global mean temperature to greenhouse gas concentrations than, for example, to changes in sea level, or local and regional temperature changes (IPCC, 2001; WBGU, 2003). A temperature target is also understandable by the general public.

Scientific analyses also suggest that the rate of temperature increase may be as important as the absolute change. The current rate of global temperature increase of 0.2–0.3°C per decade is already greater than has been experienced over the past 10,000 years. The WBGU analysis suggests that ecosystems find difficulty in adapting to temperature increases of 0.2°C or greater per decade. A high rate of change can increase the risk of high-impact events. Therefore, a rapid rate of warming may in itself threaten achievement of the objective of the UNFCCC.

5 What Level of Greenhouse Gas Emissions Corresponds to a 2°C Temperature Target?

Evidence from the 420,000-year ice core in the Antarctic reveals that carbon dioxide levels in the atmosphere are now higher than at any time in the past 420,000 years (Petit *et al*., 1999). Since the industrial revolution, CO_2 concentrations have risen from 280 parts per million to around 380 parts per million by volume (ppmv) today (Fig. 5.1). The IPCC TAR suggests that the recent warming of about 0.6°C above pre-industrial times is linked to the enhanced greenhouse gas levels.

In order to assess future climate conditions, the IPCC developed a series of Emissions Scenarios based on different economy development pathways. These were published in a Special Report on Emissions Scenarios (SRES) and were used as input to global climate models (GCMs).

Figure 5.2 shows projected changes in global temperature based on these scenarios. A number of features are apparent from this figure. The global temperature will continue to increase under all scenarios. The best-case scenario shows a commitment to approximately 1.3°C global temperature increase over this century. This is because certain components of the climate system, such as the oceans, react quite slowly to the warming impacts of greenhouse gases. This inertia means that, even if greenhouse gas concentrations were stabilised at today's levels, temperatures would continue to increase over the coming decades.

In a separate analysis, Hansen (2004) suggests that at current GHG levels the earth's surface is committed to warming of 0.4 to 0.7°C. This would mean that there is already a commitment to a warming of 1.0–1.3°C, i.e. greater than half of the EU 2°C climate protection target. Unless significant mitigation action takes place in the next 20 years, this target will be breached (Tirpak *et al*., 2005).

5.1 Climate Sensitivity

Climate sensitivity refers to the increase in global mean surface temperature following a doubling of atmospheric CO_2 concentrations above pre-industrial levels, i.e. a concentration of approximately 550 ppm CO_2 equivalent. The first estimate of climate sensitivity was provided by John Tyndall from Co. Carlow who discovered the radiative impacts of greenhouse gases such as CO_2.

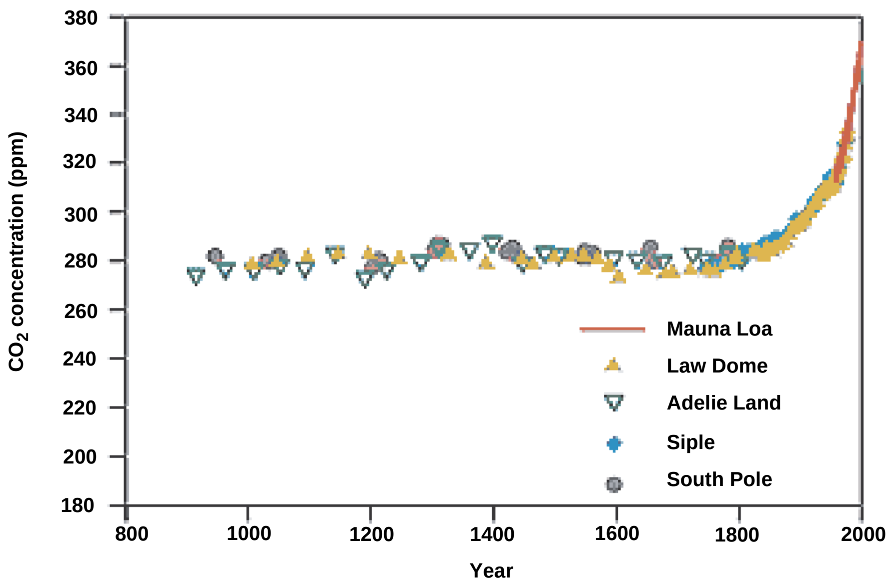

Figure 5.1. Variations in atmospheric CO_2 concentrations in Antarctic ice cores for the past millennium. The Mauna Loa concentration is also shown. Source: IPCC WG1, Chapter 3, 2001.

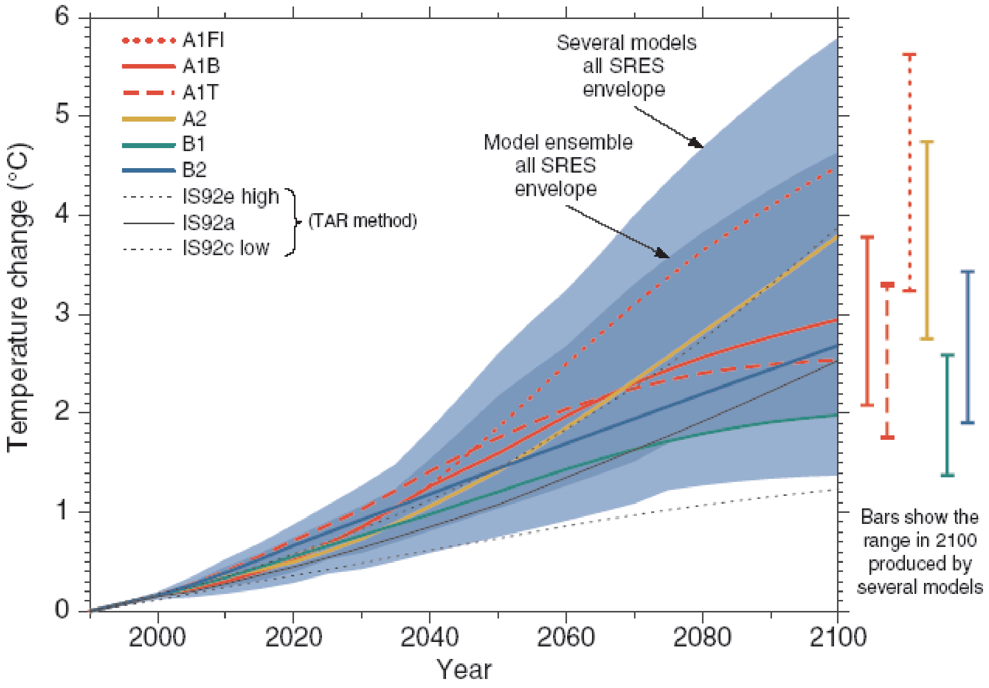

Figure 5.2. Projected global mean temperature change for the six greenhouse gas emissions scenarios assessed by the IPCC. Source: IPCC WG II, Chapter 9, 2001.

Current analysis of climate sensitivity is based on climate models and advanced climatological analysis. This provides a climate sensitivity range of 1.5–4.5°C. This means that the 2°C limit may be reached at varying levels of CO_2 equivalent concentrations depending on the actual climate sensitivity. For example, with high climate sensitivity, CO_2 equivalent would need to be stabilised at levels closer to 400 ppm in order to ensure that the 2°C is not breached, while with low sensitivity, concentrations could be allowed stabilise at high levels and still allow temperature rise to be limited to 2°C.

It is expected that this uncertainty on the climate sensitivity will narrow as scientific understanding increases and models develop. Probabilistic analysis is increasingly being utilised in climate change studies to provide limits in relation to impact assessments and quantification of risk.

5.2 Probabilistic Analysis

Probabilistic analysis is a method used to ascribe probabilities or 'betting' odds to the chances of the occurrence of specific climate events. At current atmospheric greenhouse gas concentrations there is a 2 in 3 chance (an average 73% chance) of staying within the 2°C target (Meinshausen, 2005). At a concentration of 550 ppmv CO_2 equivalent, there is only a 1 in 6 chance of meeting the target, while at 650 ppmv CO_2 equivalent, there is only a 1 in 16 chance of staying within the target (CEC, 2005). Therefore, to be reasonably confident that the global temperature increase will be limited to 2°C would require CO_2 concentrations to be stabilised at levels much less than 550 ppmv CO_2 equivalent. With a high degree of certainty, CO_2 concentrations will have to be stabilised at levels closer to 400 ppmv CO_2 equivalent. Also, delaying action to stabilise CO_2 concentration levels means that greater action would be required in the future to meet a temperature target of 2°C.

The 2°C target level represents the current understanding of the climate system. The target may be revised in light of new scientific findings. However, it is unlikely to be revised upwards as evidence of the impacts of current climate emerges which shows significant climate impacts already occurring below 2°C.

6 Climate Change: The Irish Context

Palaeoclimate records show that the climate in Ireland has remained relatively stable over the past 10,000 years (the Holocene). However, scientific evidence of high-impact, abrupt changes in Irish past climate does exist.

Pollen analysis undertaken in NUI, Galway Palaeoenvironmental Research Unit reveals that climate change may have had an influential role during periods of tree expansion and dominance. Lake sediments from Inis Oirr on the West Coast provide evidence of late glacial and Holocene climate change in Atlantic Europe. Other projects investigate long-term environmental change in Lough Corrib, with stable isotope (^{18}O and ^{13}C) analysis tracking temperature changes and limnic productivity in the past 10,000 years.

Palaeoenvironmental analysis carried out on peat profiles from Achill Island reveals evidence for an extreme climatic event, a storm or series of storms, which deposited a silt layer, around 5200–5100 BP. This event occurred towards the end of a warm dry period, and following it these conditions returned for a number of tree generations before changing to modern climate conditions (Caseldine *et al*., 2005). This extreme climatic event possibly precipitated the human abandonment of the area, comparable to what has been observed at the nearby Ceide Fields. The general trend in this region would appear to be that peat formation replaced agriculture about 5000 years ago.

6.1 Palaeoclimatic Evidence for Abrupt Climate Change in Ireland

With increased quantities and more reliable palaeoclimate records becoming available, new evidence is being presented of the occurrence of abrupt events in the past. A number of climate records provide evidence that abrupt changes, on the scale of decades, occurred in previous glacial and interglacial periods. Ice cores, deep ocean cores, terrestrial and lake sediments from around the world are adding to this knowledge. The evidence shows that rapid events have occurred several times in the past and the climate has an ability to shift abruptly between them.

Probably the most documented event of the present interglacial is the Younger Dryas event, which occurred ~11,500 years ago. It is considered to have occurred due to the catastrophic freshening of the North Atlantic and a subsequent slowdown of the North Atlantic Deep Water (NADW) current (Ruhlemann *et al*., 1999). It occurred within a few decades, lasted approximately a millennium, and ended as abruptly as it started.

The 8,200-year cooling period also provides evidence that the sudden influx of fresh water has the ability to change ocean circulation dramatically. This occurred following the drainage of two glacial lakes into the Hudson Strait. The subsequent reduction in sea surface salinity altered the ocean circulation and what followed was the most abrupt and widespread cooling event of the past 10,000 years (Barber *et al*., 1999). The fact that this event only lasted about 200 years before the circulation was re-established adds to the theory that this abrupt shift occurred within decades.

The major impacts of this event on vegetation in Ireland can be seen from the pollen records in the Corrib basin where there has been a rapid reduction in the percentages of *Corylus* (Hazel) and increases in *Betula* (Birch) and *Pinus* (Pine) for that short period, before return to normal levels (Fig. 6.1). This is also shown in the context of temperature records from the Greenland GISP2 ice core and temperature records from oxygen isotope measurements from southern Germany (Fig. 6.2). This dramatic event is large both in its magnitude (a temperature change of the order of 5°C at Greenland) and in geographical extent (as reflected by the close correlation of the signal in these two locations) (PAGES, 2003).

6.2 Current Climate Research in Ireland

Current Irish climate research includes the development of a set of climate change indicators, in line with European and global studies. The meteorological indicators are being updated and further developed to include more secondary indices such as wet and dry spell persistence, simple daily intensity indices and heat wave duration.

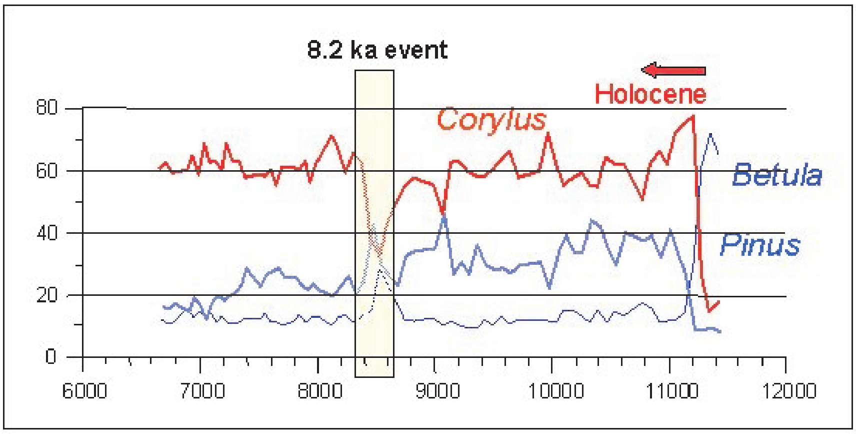

Figure 6.1. Pollen records from Lough Corrib revealing the dramatic change around the year 8200 BP. Source: Bingham, 2004.

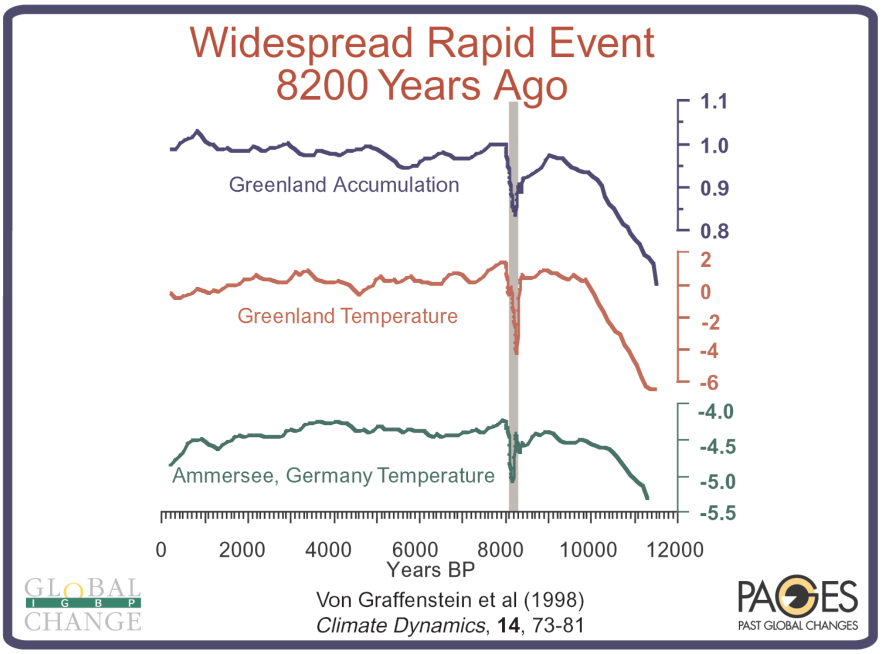

Figure 6.2. The widespread rapid event 8200 years ago. Source: Von Grafenstein *et al.*, 1998. http://www.pages-igbp.org/cgi-bin/WebObjects/products.woa/wa/product?id=41

Statistical downscaling for the 2050s and 2080s has been carried out by Irish Climate Analysis and Research Units (ICARUS) at National University of Ireland Maynooth, and is at present being refined to downscale to the daily scale.

The Community Climate Change Consortium for Ireland (C4I), based at Met Éireann, employ a Regional Climate Model to downscale for the same future time periods. It is notable that, while different techniques and source models are being used, the future scenarios for Irish climate are broadly similar for these analyses.

Other climate research in Ireland includes that by the Coastal and Marine Resources Centre (CMRC), at University College Cork, on the trends and impacts of climate on coastal areas. The Marine Institute also conducts research on the implications for Ireland's marine environment and resources arising from climate change. The results from some of these research projects are presented in later sections. See Appendix 2 for details of research centres currently working on climate research in Ireland.

7 Determining “*Dangerous Anthropogenic Interference*”

Understanding what constitutes dangerous climate change is important for scientific analysis and policy debate (Schneider, 2001, 2002; Dessai *et al.*, 2003).

A number of reasons for concern have been highlighted in the IPCC TAR, including risk to unique and threatened systems, risk from extreme climate events, distribution of impacts, aggregation of impacts and risk from future large-scale discontinuities (IPCC, 2001). These are summarised in Fig. 7.1.

“*Dangerous anthropogenic interference*“ with the climate system, as used in UNFCCC Article 2, is related to both the impacts of climate change and the enhanced level of greenhouse gas concentrations which are responsible for climate change. However, Article 2 leaves the definition of “*dangerous*” flexible and this still remains open to debate. The European Climate Forum (ECF) symposium in 2004 identified three concepts of danger:

1. determinative danger – circumstances that lead to global and unprecedented consequences;
2. early warning danger – dangers which are already present in certain areas that are likely to spread or worsen over time with increased warming, such as Arctic ice sheet retreat or increased frequency of drought; and,
3. regional danger – dangers confined to a single (large) region most likely related to water resources, ecosystems or infrastructure (Hare *et al.*, 2004).

Nonetheless, what is “*dangerous*” is a value judgement for decision and policy makers. Dangerous will be perceived differently due to location and assessment of vulnerabilities (Schneider and Lane, 2005). Parry *et al.* (2001) outlined the impacts in key areas of risks for the 2050s and 2080s. The key areas include hunger, water shortage, exposure to malaria transmission and coastal flooding. From Fig. 7.2, it is clear that there are increasing impacts upon millions of people worldwide with increasing climate change. Economic damage and disruption will increase as will the human costs.

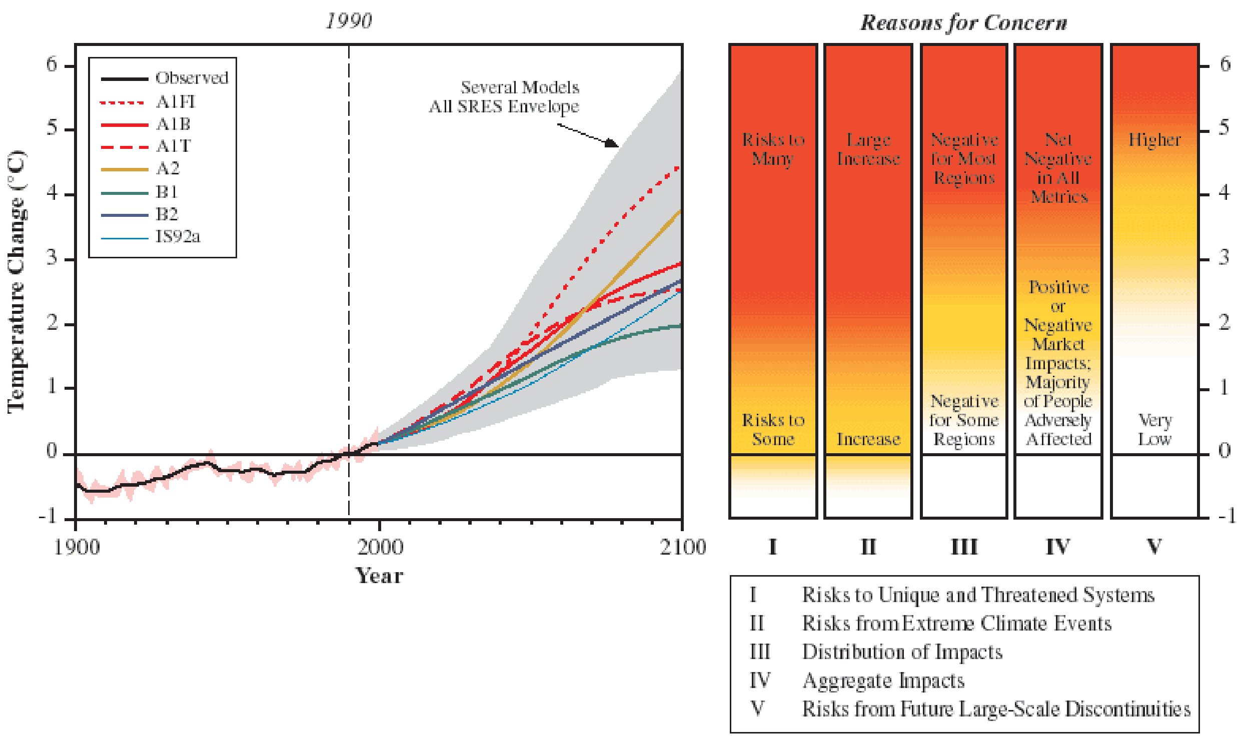

Figure 7.1. Reasons for concern about projected climate change impacts. Source: IPCC, WG II, 2001.

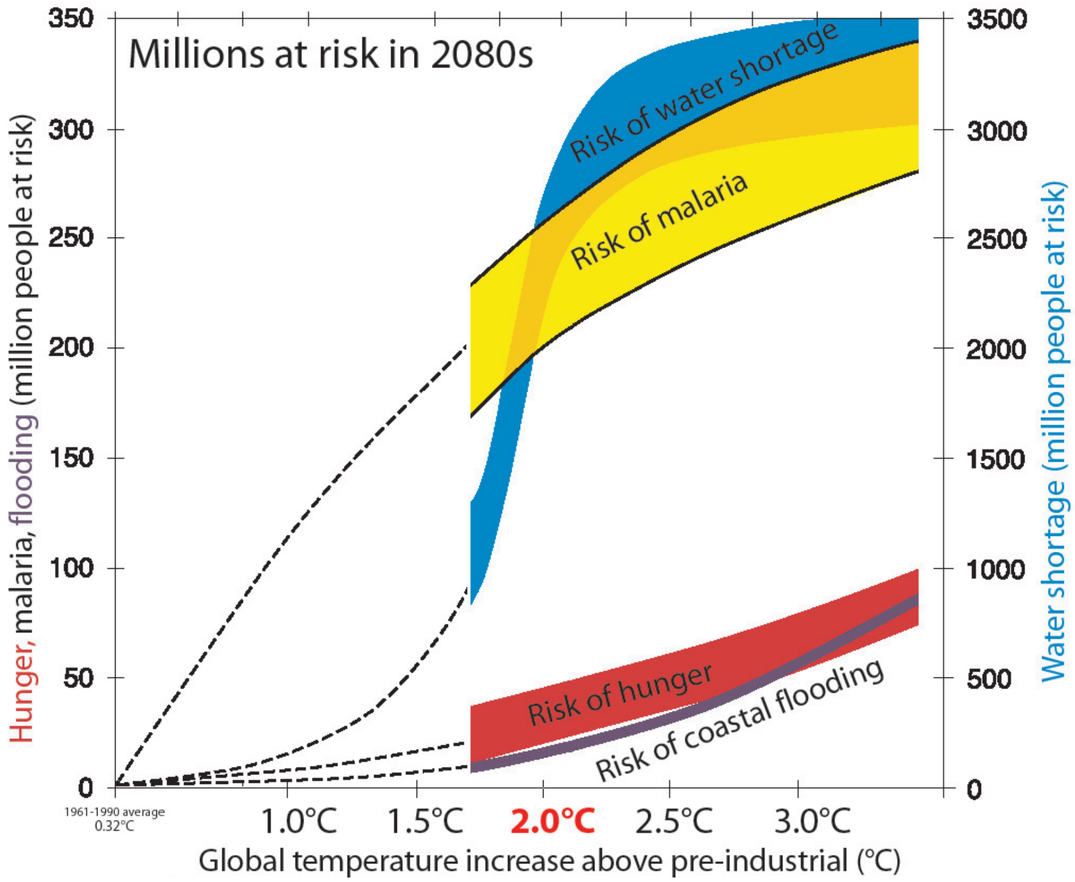

Figure 7.2. Millions at risk in the 2080s. Source: Parry *et al*., 2001; Meinshausen, 2004.

In determining whether a certain impact should be defined as dangerous, the adaptive capacity of natural and social systems has to be taken into account. Adaptive capacity varies greatly between regions and systems and also depends on the speed of change. Economic and social development are good indicators for adaptive capacity. However, these must be coupled to analysis of vulnerabilities and implementation of plans to address these. The 2005 Hurricane Katrina teaches us lessons with regard to the need for integrated planning, coupled with the capacity to manage the impacts of extreme climate events.

8 Key Vulnerabilities and Risks

Impacts can be broadly classified in two ways. Linear or smooth changes are reached gradually and provide humans and ecosystems with time to adapt. These are relatively predictable and allow impact studies to be carried out with greater certainty. Abrupt, high-impact changes occur quickly, with possibly irreversible changes occurring. These events currently have a low probability of occurring. Such events have a number of factors in common:

- the scope of impact (local effects that scale up to global consequences);
- the magnitude of impact (potentially devastating for large regions);
- the persistence of impact (for the ice sheets, at least millennia, perhaps indefinitely) (Oppenheimer, 2005).

In the context of preventing dangerous climate change, high-impact, low-probability events may have more relevance to the discussion on target setting than assessment of the impacts from more gradual changes and adaptation options. However, both are relevant, as unchecked they can have dangerous impacts. To date, most research has been on scenarios with gradual change. It is more difficult to generate realistic scenarios of abrupt climate change that are useful for impact assessments (Alley *et al*., 2003).

8.1 Risk Associated with Gradual Climate Change

The global mean temperature has increased by 0.6°C above pre-industrial levels in the last 100 years (IPCC, 2001). The impacts of this can already be seen, with increased frequency of extreme events such as droughts, intense precipitation and retreat of mountain glaciers. GCMs predict that warming will be in the range of 1.4–5.8°C over the period 1990–2100, based on 35 SRES scenarios and a number of climate models. The Third Assessment Report also indicated that nearly all land areas will warm more rapidly than the global average, particularly at northern high latitudes in the winter season (IPCC, 2001).

Increases in precipitation are projected over the northern mid- to high latitudes, with larger year-to-year variations very likely. Changes in extreme weather are also projected. It is considered very likely that there will be higher maximum and minimum temperatures with more hot days and fewer cold days. Global mean sea level was projected to rise by 0.09–0.88 m between 1990 and 2100 for the full range of scenarios (IPCC, 2001). This is primarily due to thermal expansion and melting of mountain glaciers. What is important is the rate of change, with more gradual change allowing time for human and ecological systems to adapt while rapid change does not.

In Ireland, impacts of climate change based on statistical downscaling from an ensemble of three GCM projections for the end of the present century reveal an increase in mean annual temperatures of 2°C. Temperatures in the autumn period account for the greatest warming, with an increase of 2.7°C. Summer temperatures could increase by 2.5°C, but may be as high as 3°C. Increases of 11–17% in precipitation are predicted for the winter months, while there are reductions in summer precipitation of between 14 and 25%. The largest percentage increases in winter are expected to occur in the midlands, while the greatest reductions in summer are expected along the south and east coasts (Fealy and Sweeney, 2006).

Regional Climate Model projections for the Irish climate for the period 2021–2060 also show a general warming, with increases of 1.25°C in January temperatures and increases of 1.5°C in July temperatures. The largest increases are in the south-east and east of the country. Precipitation increases in all months except March, June, July and August, with increases in December precipitation of between 10% (in the south-east) and 25% (in the north-west) (McGrath *et al*., 2004). A refinement of the impacts for Ireland, using both statistical downscaling and regional climate models, is currently being undertaken with greater emphasis on changes in daily and extreme climate events.

8.2 Risk of Large-Scale Singular Events Triggered by Climate Change

Abrupt high-impact events are largely non-linear and therefore difficult to model and predict. Examples include the collapse of the West Antarctic Ice Sheet or the Greenland Ice Sheet, the destabilising of the Thermohaline circulation, the release of methane clathrates or an alteration of El Niño Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) events. These events would have global and regional effects and potentially irreversible impacts (Patwardhan *et al*., 2003). Current climate change assessments rarely consider these high-impact, low-probability events but research in this area is increasing. A significant global warming, i.e. a 2°C or greater increase above pre-industrial temperatures, could trigger these high-impact, low-probability events which would cause major climate disruption.

As discussed in Section 6, palaeoevidence suggests that large-scale singular events have occurred in the past, occurring in time spans of years to decades, and model studies indicate that rapid transitions in the future climate are possible. High-impact events could also trigger climate feedbacks that strongly accelerate climate change and cause irreversible changes to the climate system.

It is not currently possible to accurately predict the timing or onset of these abrupt events, or when critical thresholds may be reached or passed. The TAR indicated that they are not expected to occur in the period up to 2100 (IPCC, 2001). More recent studies have indicated that rapid changes are already occurring in the Arctic region and Greenland (ACIA, 2004). The scientific consensus is that above 2°C warming there is a significantly increased risk of occurrence of a range of severe large-scale events. Examples of these are discussed in more detail in the following sections.

8.2.1 Thermohaline circulation (THC) collapse or weakening

The thermohaline circulation is a global ocean circulation pattern that distributes water and heat both vertically and horizontally around the globe. It is best known in Ireland from warming associated with the Gulf Stream. Temperature and salinity patterns in the Atlantic create the density differences that drive the THC. Palaeoclimatic evidence suggests that there are multiple equilibria for the THC in the North Atlantic Ocean, ranging from a warm interglacial mode with deep water forming (which we are in at present), a cold glacial mode and an off-state with a complete collapse of circulation (Rahmstorf, 2000). Switching between the main modes occurs as a result of temperature or freshwater forcing (Schneider, 2003). Thus, if changes in global mean temperature cause increases in precipitation, a melting of glaciers or unequal warming of high latitudes relative to low latitudes, the THC could be modified (IPCC, 2001).

The impact of the THC is seen by artificially shutting it down in a complex GCM. A number of climate modellers have simulated this by injecting fresh water into the North Atlantic (e.g. Manabe and Stouffer, 1995; Schiller *et al*., 1997; Vellinga and Wood, 2001; Wood *et al*., 2003). Vellinga and Wood (2001) activated an influx of fresh water into a large part of the North Atlantic, reducing the density of the water column and reducing the rate of North Atlantic Deep Water (NADW) formation (Wood *et al*., 2003). Over Ireland, the mean cooling is in the region of 3–5°C below current average temperatures in the first decade, but this is reduced by the third decade to 2–3°C. This cooling would be uniform among the seasons, and would possibly outweigh global warming in the north-east Atlantic region (Fig. 8.1) (Wood *et al*., 2003).

There are also impacts on precipitation, with a reduction in both surface evaporation and precipitation in response to the cooling. The total amount of precipitation in Europe is reduced by about 0–0.2 m per year, while some of the high ground (in Scotland, Norway or the Alps) receives significantly more snowfall, with snowfall lasting 1–2 months longer in the first decade after THC collapse (Vellinga and Wood, 2001).

A reduced THC has implications for the oceanic uptake of carbon. In the North Atlantic, cold dense waters sinking to the bottom of the ocean are rich in carbon dioxide and this transfer of carbon from the atmosphere to the ocean is a valuable greenhouse gas sink. Visbeck *et al.* (1999) indicated that the Atlantic Ocean is the largest oceanic sink of atmospheric CO_2. A weakening of the THC could diminish the effectiveness of this sink which would mean that there would be greater levels of CO_2 in the atmosphere, and thus enhanced warming. Sarmeinto and LeQuere (1996) found that the oceanic uptake of atmospheric carbon dioxide in modelled scenarios was reduced primarily due to a weakening or collapse of the THC.

Complete shutdown of the THC has not been projected in GCM simulations (Wood *et al*., 2006), although most show a weakening of the circulation. Models show a decline of the overturning of the Atlantic by 20–50% by the end of the 21st century (Rahmstorf, 1999). However,

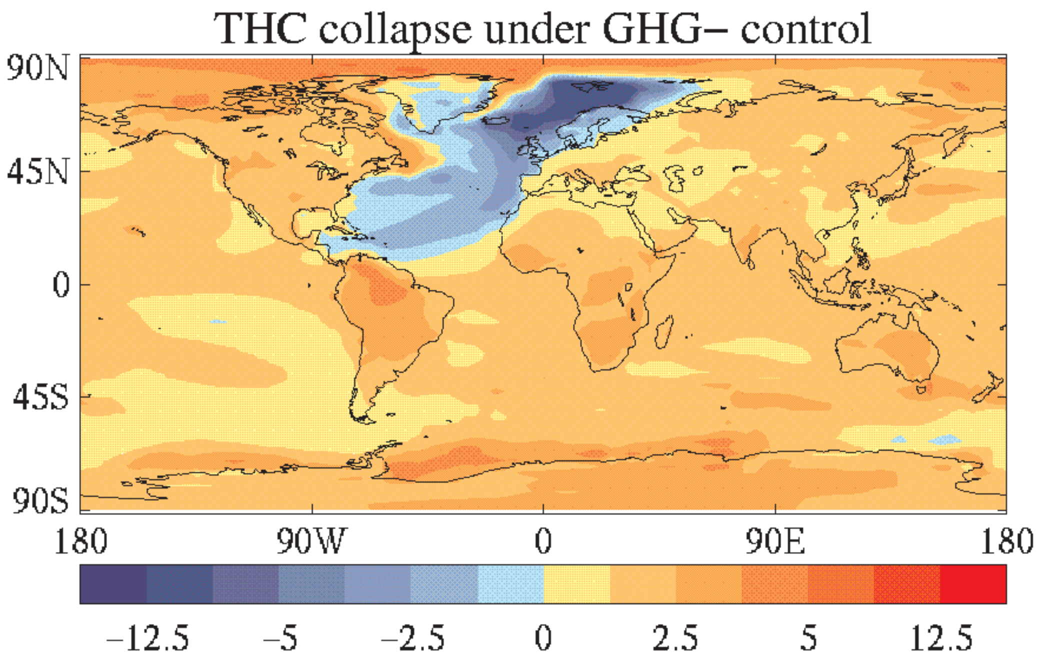

Figure 8.1. Artificially induced thermohaline circulation shutdown in the year 2049 following global warming. Source: Wood *et al.*, 2003.

observational data show that there has been sustained and widespread freshening of the North Atlantic over the past four decades (Dickson *et al.*, 2002). A rapid and dramatic 'flip' in the THC is currently considered a low-probability, high-impact event.

8.2.2 Disintegration of the West Antarctic Ice Sheet

The West Antarctic Ice Sheet (WAIS) is a marine grounded ice sheet, which means that it is partly situated on rock below sea level. The IPCC TAR considered the possibility of the collapse of the WAIS as very unlikely before 2100. However, current analysis suggests there is now uncertainty surrounding the stability of the WAIS and also, to a lesser degree, the East Antarctic Ice Sheet (EAIS).

The surrounding ice shelves may also destabilise the ice sheets. These ice shelves have been disintegrating for about 35 years, starting at the northernmost tip of the Antarctic Peninsula (Alley and Oppenheimer, 2004). The most dramatic ice shelf loss in recent time in the Antarctic was the collapse of the Larsen B shelf, which was ~220 m thick. In a time period of just over 1 month (starting at the end of January 2002), 3250 km^2 of shelf area disintegrated with a volume of over 500 billion tonnes of ice (NSIDC, 2002). The glaciers that fed this ice shelf have thus accelerated and thinned since the collapse. Other major glaciers in the region, around the Amundsen Sea, have also shown rapid thinning in recent years (Rapley, 2005).

Disintegration of the WAIS could raise global mean sea level by as much as 5–6 m. This sea level rise would be rapid and exceed the adaptive capacity of most coastal margins and ecosystems (IPCC, 2001).

Model studies have not yet reproduced the behaviour of the ice streams or the behaviour of the glaciers on the Peninsula (Alley and Oppenheimer, 2004). Oppenheimer (2005) asserts that the WAIS may in fact be more sensitive to warming than suggested by current models. According to a number of authors, the threshold beyond which the ice shelves are vulnerable to collapse could be passed in this century (IPCC, 2001; Wild *et al.*, 2003).

Although there is still much uncertainty, global warming of 2–4°C is likely to destabilise the WAIS (Oppenheimer and Alley, 2004, 2005).

8.2.3 Melting of the Greenland Ice Sheet

Arctic temperatures have increased by nearly twice as much as the mean global average over the last 50 years, with some parts experiencing even greater increases (ACIA, 2004). Climate models project that local warming in Greenland will exceed 3°C at a global mean temperature of ~1.5°C during this century. This could pass the critical threshold for the long-term melting of the Greenland Ice Sheet (GIS) (ACIA, 2004). The maximum surface-melt area on the Greenland Ice Sheet has increased on average by 16% from 1979 to 2002, with melting in 2002 breaking all previous records for total surface melt area (see Fig. 8.2) (ACIA, 2004).

The Greenland Ice Sheet is losing mass at its periphery faster than expected. Oppenheimer and Alley (2005) confirm this view, with models in one case not producing a stable ice sheet above local warming of 3°C. With climate models projecting this temperature to be exceeded by 2100, the threshold for long-term disintegration of the Greenland Ice Sheet could be passed this century. With the fast processes currently identified in the Greenland Ice Sheet and the commitment to future warming already under way, it may be too late to prevent a catastrophic sea level rise (Oppenheimer and Alley, 2005). A complete melting of the ice sheet would result in a 7-m sea level rise over a number of centuries. There is already thinning in some regions of Greenland, but it is not clear whether this is a response to recent warming or an ongoing response to longer-term changes in the region (DEFRA, 2004).

8.2.4 Methane clathrates

With warming temperatures in the Arctic and warming ocean temperatures, the potential for large releases of methane and carbon dioxide to the atmosphere is possible. Currently, carbon is trapped in land and marine biosphere reservoirs, for example organic matter in permafrost in the Arctic, while methane is trapped in clathrates in the cold dense ocean. Buffett and Archer (2004) predicted a global methane inventory of approximately 5000 Gt carbon. A substantial decrease in the clathrates inventory is expected in the future as temperatures exceed those experienced in the past few million years. Using plausible changes in the deep ocean (such as changes in temperature, sea level, O_2 level and change in rate of carbon deposition), Buffett and Archer (2004) found that a warming of 3°C reduces the clathrate inventory to 15% of its present value. The climate impact of a large, rapid and probably uncontrollable methane release to the atmosphere could be intense. However, depending on the mechanism of clathrate release, much of the methane may be oxidised to CO_2 within the ocean

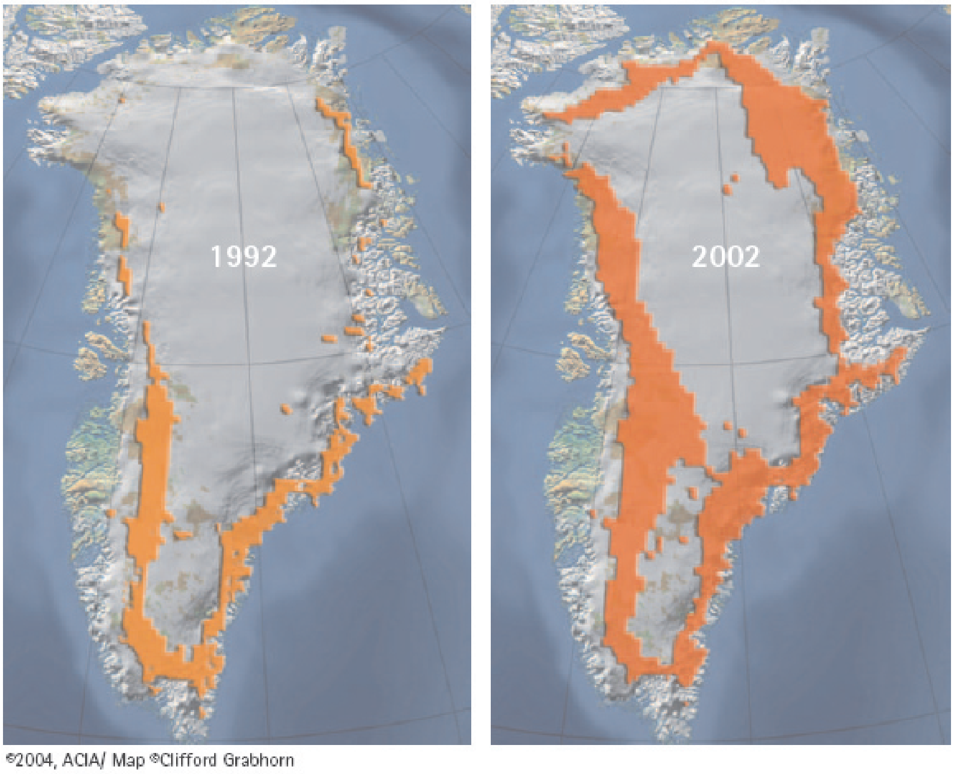

Figure 8.2. Greenland Ice Sheet seasonal surface melt extent, summer 1992 and 2002. Source: ACIA, 2004.

rather than reaching the atmosphere (Buffett and Archer, 2004). This subject is currently under investigation. It takes much longer for the deep ocean to warm (thousands of years) so a thermal perturbation of the methane hydrates could be millennia away (Buffett and Archer, 2004). However, the impacts of a methane release could be significant as methane has a global warming potential (GWP) 23 times that of CO_2.

8.3 Temperatures in Previous Glacial and Interglacial Periods

Temperatures in previous glacial and interglacial periods are preserved in ice cores such as the Vostok Antarctic 420,000-year record (Petit *et al.*, 1999). To put present temperatures in context, the Antarctic temperature during the peak of the interglacial we are currently in (the Holocene) was about 1°C warmer than it was in the mid-20th century. During the previous interglacial (the Eemian) polar temperatures were about 2°C greater than at present (see Fig. 8.3) (Hansen, 2003). However, the rate of polar temperature change is typically a factor of two greater than global mean temperature change. Therefore, the 20th century warming of 0.6°C produces a similar global temperature as that during the Holocene peak (Hansen, 2003). The Eemian period, which was slightly warmer than the present, can therefore be used as an analogue, and is often used to predict changes and the possibility of sudden climate variability (Adams *et al.*, 1999; Cuffey, 2004). The fact that abrupt changes have occurred in the past raises the possibility that they could occur in the future, especially with the addition of greenhouse gas forcing. Instability during the Eemian, with cold and warm periods shifting within short periods, along with possible cooling and freshening of the North Atlantic in the middle of the Eemian period in the Nordic Seas and to the west of Ireland, have furthered the uncertainty (Cortijo *et al.*, 1994; Fronval and Jansen, 1996). Another cause for concern is that sea level during the Eemian is estimated to have been 5–6 m higher than it is today (Hansen, 2003).

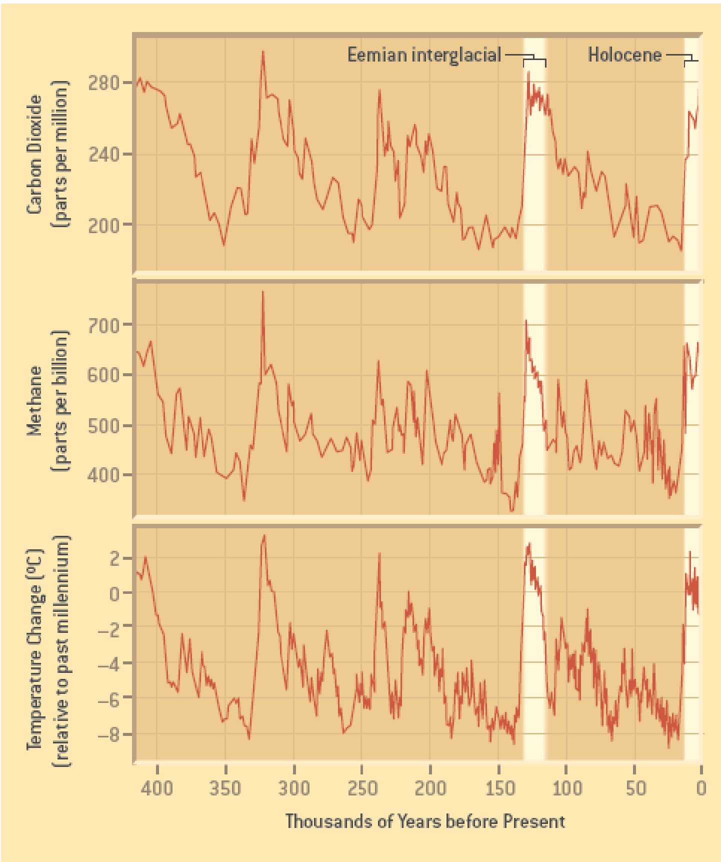

Figure 8.3. Antarctic Ice Core temperature record showing last interglacial period temperatures in the region of 1–2°C greater than today. Source: Hansen, 2004; Petit *et al.*, 1999.

9 Sectoral Impacts of Climate Change for Ireland

If climate changes are linear and smooth, thus relatively predictable, and society has time to adapt, impacts may be lessened and may be manageable. However, if the change is abrupt, occurring over timescales from years to decades, with little warning of when this might occur, there will be reduced adaptability, increased damages and possible irreversibility (Higgins *et al.*, 2002). Downscaling of the impacts from large, abrupt climate changes, such as a shutdown of the THC, from global models to local scale has not yet been widely performed, and model estimates vary widely. There is sufficient evidence though that the impacts would be substantial (Wood *et al.*, 2006). Link and Tol (2004) assessed the economic impacts for Western Europe as a whole, but recognised that the impacts for Ireland could be much more severe than those experienced elsewhere in Europe. In the following sections, the impacts of both gradual and abrupt climate changes are outlined for a number of sectors. These are water resources, agriculture and food production, ecosystems and biodiversity and the marine environment, sea level rise and sea surface temperatures.

9.1 Impacts of Climate Change upon Water Resources

Water supply and quality are highly sensitive to climate variability and change. Future changes in climate are likely to have major impacts on water resources in Ireland. Recent research by Murphy and Charlton (2006) outlines spatial changes in run-off for Ireland in future downscaled scenarios. The results highlight the importance of individual catchment characteristics in controlling response to climate change. The authors find a widespread reduction in soil moisture storage, especially in summer and autumn, which will have serious implications for the agricultural sector. Reductions in groundwater storage and recharge will increase the risk of drought in some areas. The likelihood and magnitude of flood events are also likely to increase, which has important implications for infrastructure and development on affected flood plains. Also, there will be impacts upon the reliability of existing flood defences, and, in the future, increased insurance costs. Water quality is another area for concern as in certain areas it may be impacted by the contamination of coastal aquifers from saline intrusion. Growing population density will also increase resource demands during low flow periods (Murphy and Charlton, 2006). Increased water shortages will have an impact on human health in terms of consumption and hygiene. Regional shortages are already evident at certain times of the year. Future climate change will entail longer dry spells which will mean that supply systems will need to be designed to address these factors.

9.2 Impacts of Climate Change upon Agriculture and Food Production

Changes in temperature, rainfall and increased atmospheric carbon dioxide levels will affect ecological and physiological processes, alter growing season length, biomass production, competition between species, and alter species distribution and behaviour.

In Ireland, increases in temperature and CO_2 levels could bring the potential for increased production of existing cereal and grass crops. However, these may also be hampered by decreases in summer rainfall. Warm-weather crops such as maize and soybean could become viable. Maize could become a major crop while soybean, which is not currently grown in Ireland, could become established in some regions. Potato crops, which are an important crop for Ireland, could be vulnerable and suffer from water stress. Despite the decrease in summer water receipt, total grass production is still expected to increase irrespective of soil type or use of irrigation (Holden *et al.*, 2006). Soil moisture deficits in the summer may require irrigation systems to be used, while in areas where rainfall rates will be maintained, it may be possible to reduce nitrogen application rates (Holden *et al.*, 2006). Increases in temperature in the short term could be beneficial for agricultural yield for example, but temperature increases of more than a few tenths of a degree Celsius could reduce crop yields, depending on the species.

9.3 Impacts of Climate Change upon Ecosystems and Biodiversity

Climate change is likely to lead to both positive and negative effects on ecosystems and biodiversity. In Ireland, the most threatened species are those unable to adapt fast enough to rapid change (change in mean temperature of 1–2°C within decades). The responses of most plants and animals are highly variable with some declining and others expanding their ranges. For example, there will be a decline, and possible extinction, of some Arctic species, while there may be an extension of Boreal-temperate species and other species that favour warmer temperatures. Slower changes in climate will allow a response with less disruption to both ecosystems and economies (Alley *et al*., 2003). Some species have a favourable response to moderate climate changes, but with severe climate change of greater than 2°C they begin to have a negative response. Other impacts include an increase in migrant species of birds and insects, changes in the distribution of plants and animals, earlier breeding and arrival of birds, and changes in bud burst, germination and leaf emergence of plants. The growing season length is already showing signs of increasing with some trees at Valentia Island recording earlier beginning of growing season and later leaf fall (Sweeney *et al*., 2002).

9.4 Impacts of Climate Change upon Sea Level Rise, Sea Surface Temperatures and Ocean Circulation

The IPCC estimates a global sea level rise of between 10 and 90 cm in the period 1990–2100 from the full range of emissions scenarios. Their calculated sea level change is due mainly to thermal expansion of ocean water, melting of glaciers and ice caps, with little change in ice sheet volume (Hansen, 2003). Over the longer term, beyond 2100, much larger changes in sea level are expected, due to melting ice sheets, even if temperature and CO_2 levels are stabilised at double pre-industrial levels. The consequences of sea level rise are severe and long-lasting, with serious implications for coastal communities, loss of land and coastal erosion.

Rahmstorf and Jaeger (2004) argue that a global warming of 3°C, if sustained, is likely to cause a sea level rise of 2.7–5.1 m. Slow response of sea level at present means that policy decisions now will affect sea level for many centuries to come (Rahmstorf and Jaeger, 2004). Gradual sea level rise, of a few centimetres per century, allows for a greater adaptive opportunity, while a rapid change of a few metres per century will most likely exceed the adaptive capacity of a large number of coastal communities. This will result in difficult decisions between abandonment of land or investment in expensive coastal defence mechanisms.

In Ireland, the impacts of sea level rise will be most apparent in the major coastal cities of Cork, Dublin, Galway and Limerick. Counties in the south-east will be most affected, having sandy and mud cliff coastlines. Other low-lying areas such as Louth and North Dublin may be affected as they have little or no protection. The major effects will be a loss of land due to inundation and increased erosion (Titus, 1993 – cited in Fealy, 2003) and increased risk of flooding both at the coast and along major rivers during storm surge events (Fealy, 2003).

Fealy (2003) considers the probability of coastal inundation from a sea level rise of 0.48 m with a storm surge on the east coast of 2.6 m. A storm surge of 2.6 m is currently a once-in-a-century event on the east coast, but with future global warming is expected every 1–2 years in 2100 (Orford, 1988). This extreme water level would place 300 km^2 of land in the greater than 50% probability of inundation class. Rapid sea level rise from the disintegration of the WAIS would be catastrophic.

Projections for storms, including tropical cyclones, mid-latitude storms, tornados and other severe storms are uncertain. Currently the climate record is too noisy to detect clear evidence of increased hurricane intensities but the theoretical understanding of the driving forces behind hurricanes strongly suggests that peak intensities should be higher in a warmer world with warmer ocean temperatures (Emanuel, 1987; Walsh and Pittock, 1998 – both cited in Schneider, 2003; Schiermeier, 2005; Trenberth, 2005). Schubert *et al.* (1998) analysed the frequency, intensity and direction of North Atlantic storms with 1×, 2× and 3× greenhouse gas concentration levels. They found a shift northwards in the cyclone frequency, with no change in intensity and no change in frequency except for an increase in north-eastward moving cyclones with doubled CO_2 levels.

Research currently under way at C4I (Community Climate Change Consortium for Ireland) considers the impact of increased sea surface temperatures (SSTs) on storm activity in the North Atlantic. McGrath *et al*. (2004) find that the North Atlantic SST does have a clear influence on the number of cyclones, with large increases in the number of intense cyclones. For winter and spring, the frequencies of intense cyclones show strong increases according to ECHAM4 and ECHAM5 (Max Planck Institute Global Climate Models), with some of these appearing further south (McGrath *et al*., 2004).

9.5 Impacts of Climate Change upon the Irish Marine Environment

Warmer SSTs cause phytoplankton and zooplankton to bloom earlier, while colder SSTs cause a decline in plankton stocks. Edwards *et al.* (2001) found that low SSTs in the North Sea correspond with low phytoplankton colour values while high SSTs correspond with high colour values. Changes in the North Atlantic Oscillation Index also alter plankton values. Reid *et al.* (2001) found that since the late 1980s, when the NAO moved into a more positive phase, the North Sea has been more productive, possibly due to an increase of warm oceanic water.

Phytoplankton, the base of the marine food chain, are very sensitive to change in SST. Along with other fish species they show rapid response to alterations in climate. A decline in their stocks could have major effects on fisheries and also the human food supply chain in affected regions (Schmittner, 2005). Schmittner shows that they are particularly sensitive to ocean circulation and the meridional overturning. A disruption in the THC, which brings warm tropical water to the North Atlantic and warms SSTs by approximately 4°C (Levitus, 1982 – cited in Higgins *et al.*, 2002), could lead to a reduction of 50% in the North Atlantic plankton stocks from their original level (Schmittner, 2005). A reduced upwelling of deep nutrient-rich ocean water would be detrimental to plankton biomass, and thus North Atlantic fish stocks and sea birds.

As species have different metabolisms and different physiological processes and behaviours, they are likely to respond to warming temperatures at different rates (Mieszkowska *et al.*, 2005). Northern species such as cod, herring and haddock, which prefer colder North Sea temperatures, may all be limited in their southern distribution by an increase in water temperature. Likewise, southern species such as bass may extend their range northwards. While the marine environment will be warmed as the climate alters, like coastal systems it may be influenced by other knock-on effects of climate change, such as rising sea levels, changes in local and global ocean circulation patterns, the supply of nutrients and sediment from the land and changes in waves and storminess (MONARCH, 2001). The impact of these events on aquaculture also needs to be considered. Future research on the impacts of warming temperatures, warmer sea surface temperatures and possible implications of a change in the THC or a sea level rise on the marine environment is necessary.

9.6 Summary of Potential Impacts and Vulnerabilities for Ireland

The preceding sections have outlined the main impacts of climate change for Ireland by sector. These impacts are both positive and negative, depending on the magnitude, and also the rate, of global temperature change. Table 9.1 summarises the key impacts. It is evident that, while benefits can be achieved if global mean temperatures are limited to a 1°C increase, above this level there are wide-ranging negative effects.

Table 9.1. Summary of potential impacts and vulnerabilities for Ireland.

Up to 1°C	Up to 2°C	Greater than 2°C
Longer growing season	Increased likelihood and magnitude of river flooding	Sea level rise due to thermal expansion of oceans, melting of the GIS, collapse of the WAIS
Potential for new crops, e.g. soybean	Reduced soil moisture and groundwater storage	Loss of coastal habitats due to inundation and increased erosion
Increased production of existing cereal and grass crops	Water shortages in summer in the east which will impact upon reservoirs and soil management	Increased incidence of coastal flooding
Earlier breeding and arrival of birds	Increased demand for irrigation	More intense cyclonic and extreme precipitation events
Heat stress will have an impact on human and animal health	Change in distribution of plants and animals, e.g. decline and possible extinction of cold Arctic species	
Negative impact upon water quality, e.g. reduction in quantity of water to dilute pollution	Fisheries could be affected as fish stocks are sensitive to small changes in temperature	
	Increased frequency of forest fires and pest infection	

10 Summary and Conclusions

This report has outlined the background to the EU 2°C climate protection target. It suggests that for Ireland this target represents an appropriate 'guard rail' for avoiding "*dangerous*" climate change in relation to major climate impacts. This climate protection objective can only be reached through international co-operation in combating climate change. Ireland should therefore promote this target at the EU and wider international levels.

There are a number of uncertainties surrounding the 2°C target, however, both in relation to its impacts and the greenhouse gas concentration stabilisation levels that will prevent this target being breached.

Even below the 2°C temperature target, significant climate change impacts are expected to occur in Ireland during the coming decades. Planning, and especially action, is required to avoid the worst effects of these climate change impacts. It is noted that early action will be more cost-effective and sustainable than delayed reaction. Moreover, with suitable adaptation, there are potential positive impacts of climate change that can be exploited.

10.1 Ireland's Position and Priority Areas for Research

A global mean temperature target of 2°C requires a global effort from all countries to take action to avoid exceeding it. Ireland needs to meet commitments to agreed greenhouse gas emissions in order to maintain solidarity and credibility with the international community in this regard. We need to predict the impacts of climate change at local, regional and national levels in order to enable adaptation strategies to be devised.

The complexity and slow response of the oceans to increasing surface temperature as a result of increasing concentrations of greenhouse gases means that an additional significant sea level rise can no longer be avoided.

Further research on the impact of sea level rise is required to reveal the sensitivity and vulnerability of coastal areas to both gradual and rapid sea level rise. The potential impacts of sea level rise and storminess are varied, and include:

- erosion and inundation of the coastline
- increased flood frequency probabilities and flood risk to people and coastal habitats
- socio–economic impacts such as loss of infrastructure and land, and transport disruption.

Warmer SSTs will initiate more frequent and intense storms. Further research on sea surface temperatures, their relationship with the THC and the North Atlantic Oscillation is needed and may enable the prediction of SSTs up to a number of decades in advance.

There will also be significant impacts on key areas such as agriculture, forestry and fishery, water resources, infrastructure, the environment and transport.

It is necessary to incorporate adaptation into policy and planning decisions at all levels in order to successfully deal with the impacts of climate change over time (Pittock, 2003). The costs of adaptation will be greater if the rate of climate change increases, as adaptation will need to be implemented in a shorter timescale.

In terms of abrupt climate changes, the linked processes such as melting of major ice bodies and the behaviour of the THC are likely to have the most significant impacts on Ireland. The rate of loss of ice in sensitive regions and the impacts of a shutdown of the THC have not been assessed in detail as yet. There is still much work to be done to further understand these phenomena and how they relate to the 2°C target.

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Appendix 1 List of Abbreviations

BP	Before Present
C4I	Community Climate Change Consortium for Ireland
CMRC	Coastal and Marine Resources Centre
EAIS	East Antarctic Ice Sheet
ECF	European Climate Forum
ECHAM4/5	European Centre Hamburg Model (Global Climate Model)
ENSO	El Niño Southern Oscillation
GCM	Global Climate Model
GHG	Greenhouse Gas
GIS	Greenland Ice Sheet
Gt	Gigatonne
GWP	Global Warming Potential
ICARUS	Irish Climate Analysis and Research Units
IPCC	Intergovernmental Panel on Climate Change
NADW	North Atlantic Deep Water
NAO	North Atlantic Oscillation
ppmv	parts per million by volume
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperatures
TAR	Third Assessment Report
THC	Thermohaline Circulation
UNFCCC	United Nations Framework Convention on Climate Change
WAIS	West Antarctic Ice Sheet

Appendix 2 Current Research on Climate Change in Ireland

ICARUS (*Irish Climate Analysis and Research Units*) was formed due to a greater need for research on climate and climate change impacts for Ireland. Such impacts are likely to have significance for key sectors such as water resources, agriculture, health and sea level rise among others. The research unit is based in the Department of Geography, National University of Ireland Maynooth. Current areas of research include contemporary climate analysis and indicators of climate change, statistical downscaling and climate scenario generation, impact modelling, hydrological modelling, sea level rise, extreme event analysis, impact of climate change upon health, climate change in urban regions and storm frequency analysis.

http://geography.nuim.ie/ICARUS/index.html

The *Community Climate Change Consortium for Ireland (C4I)* was established in 2003. It is based at Met Éireann headquarters in Dublin. Its main objective is to consolidate and intensify the national effort in climate change research by building a capability for carrying out regional climate modelling in Ireland and to provide assistance to Irish scientists utilising climate model output for their analyses. C4I uses a regional climate model from the Rossby Centre to investigate the characteristics of the past and future climate of Ireland.

http://www.c4i.ie/index.html

The *Coastal and Marine Research Centre (CMRC)* forms part of the Environmental Research Institute at University College Cork. It carries out research from small inland catchments to the open ocean. Examples of some of the projects carried out are:

- Climate Risk – a current project on the modelling and assessment of climate change impacts for the coastal zone (flooding, catchment changes) and their implication on coastal erosion
- STORMINESS is a completed project which identified trends, determined impacts and developed models which reflect the coastal response to storminess.

http://cmrc.ucc.ie/

The *Centre for the Environment (CENV)* based at Trinity College Dublin combines four college departments: the Department of Botany, the Department of Zoology, the Department of Geology and the Department of Geography. It conducts research and teaching on all areas of the environment, including hydrology, carbon cycling, greenhouse gases, palaeoecology, environmental change and air pollution.

http://www.tcd.ie/Centre_for_the_Environment/

The *Environmental Change Institute (ECI)* based at National University of Ireland Galway was founded in September 2000 with one of its key objectives to develop a fundamental understanding of the processes involved in, and the key indicators of, environmental change. There are seven priority research areas: (1) climate change, (2) biodiversity, (3) marine environment, (4) waste, (5) social and economic impact, (6) human impact, and (7) modelling systems. Within the climate change priority research area, there are a number of projects ongoing including estimation of methane emissions in the Irish environment and the investigation of sources and variability of the natural and perturbed atmospheric aerosol.

http://www.nuigalway.ie/eci/

The *Palaeoenvironmental Research Unit (PRU)* in the Department of Botany, National University of Ireland Galway is a small research group, set up in the 1980s, involved in researching long-term environmental change with particular emphasis on the last 15,000 years (late glacial and post-glacial environments) in western Ireland. The main area of expertise is in pollen analysis. Examples of current projects include Late-Glacial and Holocene Climate Change in Atlantic Europe and Long-Term Environmental Change in the Lower Corrib Basin and its Catchment.

http://www.nuigalway.ie/pru/index.html