# Scientific and technical aspects of climate change, including impacts and adaptation and associated costs

Department for Environment, Food and Rural Affairs

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# SCIENTIFIC AND TECHNICAL ASPECTS OF CLIMATE CHANGE, INCLUDING IMPACTS AND ADAPTATION AND ASSOCIATED COSTS

**Summary: The Earth's climate is undoubtedly changing. Over the past century global temperatures have risen by some 0.6 degrees Celsius (deg C) on average and all the evidence points to the primary cause being an increase in concentrations of greenhouse gases in the atmosphere, due to human activities. Already we can see effects of recent warming eg an increased incidence of heat-waves,. the retreat of mountain glaciers and animals and plants responding in a variety of ways. Without actions to curb emissions, globally averaged temperatures are expected to rise by some 1.4 to 5.8 deg C and sea levels by between 9 and 88 cm during this century with increasingly severe impacts on the natural world and society.**

**In the longer term the risks of major climate disruption become more likely. This includes possible changes to the North Atlantic Ocean Circulation, which gives the UK its mild climate, melting of the Greenland and West Antarctic Ice Sheets, each of which could raise sea levels by several metres and the release of methane from melting of permafrost, which would fuel further warming.**

**Some of the effects of climate change may be diminished by implementing adaptation measures, e.g. improving coastal defences but these will become increasingly expensive and of limited utility. The most effective response is to reduce emissions of greenhouse gases so that the current upward trend in concentrations of greenhouse gases is ultimately halted at a level which avoids the "dangerous" impacts of climate change. The EU has proposed that we should aim to limit temperature rise to 2 deg C to avoid dangerous climate change. This was equated to atmospheric carbon dioxide levels below 550 ppm but the most recent IPCC assessment suggests that a limit closer to 450ppm would be more appropriate.**

This paper reviews the evidence for climate change, its human causes, projections for future climate change, its likely impacts and related adaptation options, and the issues surrounding stabilisation of greenhouse gases in the atmosphere at an acceptable level.

### A. Evidence for climate change and its effects

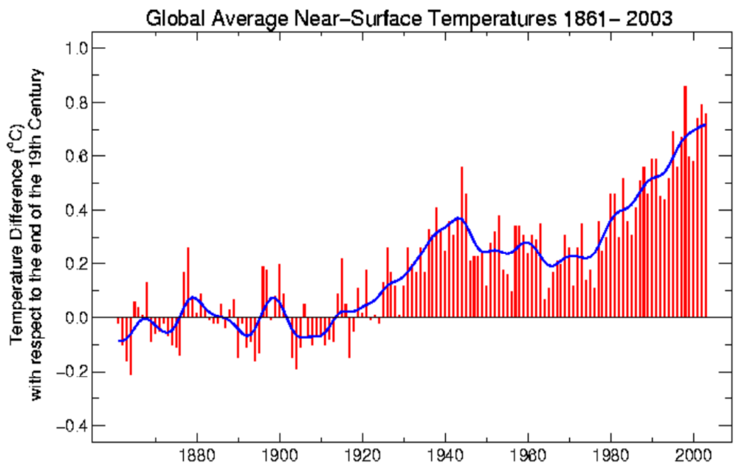
The Earth's climate is undoubtedly changing. Figure 1 shows the observed global temperature record over the last century and a half. The average global temperature has risen by 0.6 degrees Celsius (deg C) since the beginning of the 20th century, with land areas and the polar regions warming more and the oceans a little less. This may not sound like much, but recent warming takes us out of the range of average temperatures experienced in the Northern

Hemisphere over the last 1000 years. (Data for the Southern Hemisphere are sparse, which limits what can be said about the globe as a whole.) During the last ice-age, global temperatures are estimated to have been about 5 deg C lower. The rise in temperatures since the 1970's has been sustained and consistent with model projections.

Globally, all of the 10 warmest years on record have occurred since the beginning of the 1990s, and include each year since 1997. Snow cover has decreased by 10 % since the 1960s and there has been a significant retreat of glaciers and ice sheets. Arctic spring and summer sea-ice extent has decreased by about 10 to 15% since the 1950s.

The locations of plants and animals have shifted pole-wards and upwards. Plant flowering, arrival of migrating birds, the breeding season for birds, and the emergence of insects have all been observed to occur earlier across the northern hemisphere. Coral reef bleaching due to unusually high sea surface temperatures has increased in frequency.

**Figure 1 Observed temperatures for the globe since 1861 (Hadley Centre)**

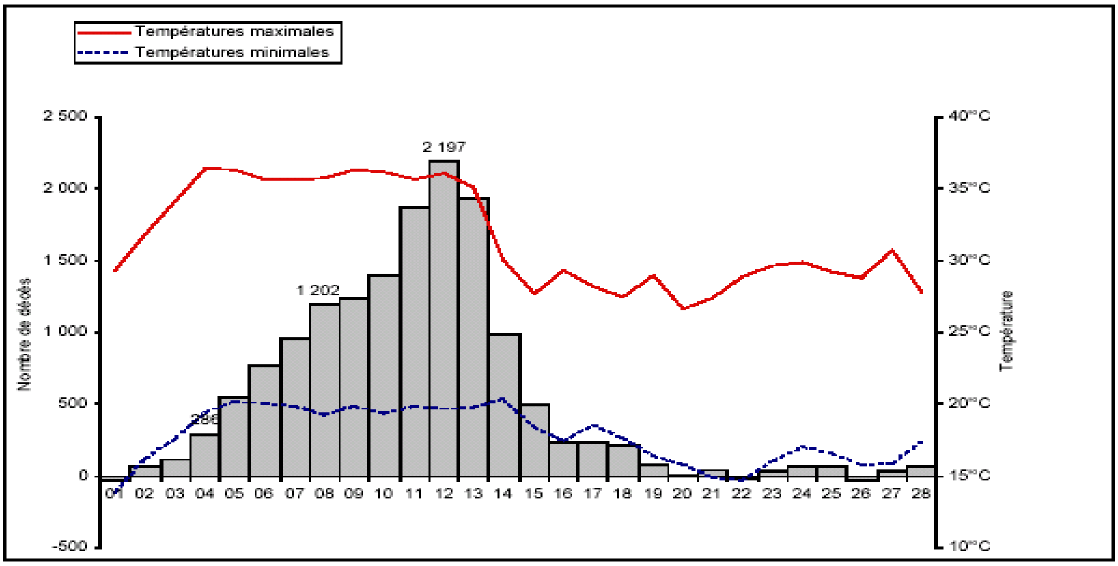



Recent experience in the UK and the rest of Europe shows that extreme events can have significant human and economic costs. In the UK, the hottest day ever recorded in Britain occurred on 10 August 2003, when the temperature reached 38.5 deg Cat Brogdale, near Faversham in Kent. The heat-wave also affected much of Europe and is estimated to have caused some 26,000 premature deaths and had an estimated direct economic cost of $13.5bn. The heat wave was particularly severe in France (Figure 2) leading to some 15,000 premature deaths. There are some initial indications that the increased level of greenhouse gases in the atmosphere was likely to have contributed to the severity of this heat-wave.

More extreme rainfall events are also expected to be a feature of climate change. The impacts of these could be significant. In 2002, the severe floods in Europe caused 37 deaths and had an estimated direct cost of $16bn. A recent report from the Association of British Insurers noted that in 2000 the UK experienced its wettest autumn for almost 300 years, with heavy rainfall leading to damage to 10,000 properties and nearly £1 billion in insurance claims.

Claims for storms and flood damages in the UK have doubled to over £6 billion over the period 1998-2003, compared to the previous five years, with a prospect of a further tripling by 2050. It is too early to link such events unequivocally to climate change but they are an early warning of what we might expect.

**Figure 2 – Temperatures and death-rate during the heat-wave in France, August 2003 (WHO).**

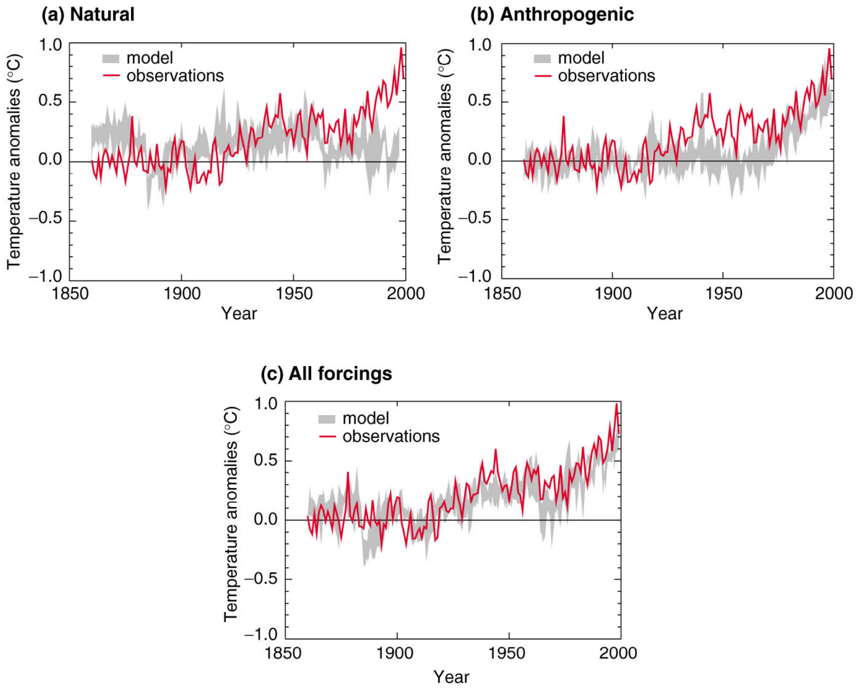



## B. Evidence for Human influence on climate change

It is well recognised that the world is warming. But what are the causes? Since the industrial revolution carbon dioxide levels have risen by over 30 % as have the levels of other greenhouse gases. The warming of the last century is broadly consistent with this increase. But some have speculated that changes in solar activity, cloudiness, or the earth's orbit around the sun are responsible in varying degrees.

Recent work by the Hadley Centre, and others, has provided strong evidence that greenhouse gases are primarily responsible. They used their complex climate model to simulate the general trend in twentieth century temperatures, using various combinations of external influences as input to the calculations. Three experiments were undertaken which are reproduced in Figure 3 below. The first (a) attempts to simulate the observed global temperature (shown in red) of the past hundred and fifty years taking into account only natural changes (solar and volcanic), but keeping anthropogenic influences, i.e. greenhouse gases, constant. The model (shown in grey) reproduced the observed warming in the early part of the century but not the warming in the latter part. They then kept the natural influence constant and including the historic increase in greenhouse gas levels (b). This reproduced recent warming but was a poor fit to the middle of the record. The third experiment (c) combined natural and human influences and showed the best fit over the whole record. Statistical tests have shown that it is impossible to explain the recent warming with natural changes only.

**Figure 3 Comparison of observed and modelled temperature change for different combinations of possible influences on the climate system (Hadley Centre).[1]**




Such work contributed to the conclusions of the Inter-governmental Panel on Climate Change (IPCC) in their 2001 report which noted that there was new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities. In 2002 the US Administration requested the US National Academy of Science to review the science of climate change and this review confirmed the IPCC's findings.

In summary, whilst there appears to have been some contribution to warming from natural sources especially in the first half of the 20th century the dominant cause, particularly in the last few decades, is very likely to be an enhanced greenhouse effect due to human action.

## C. Future Climate change

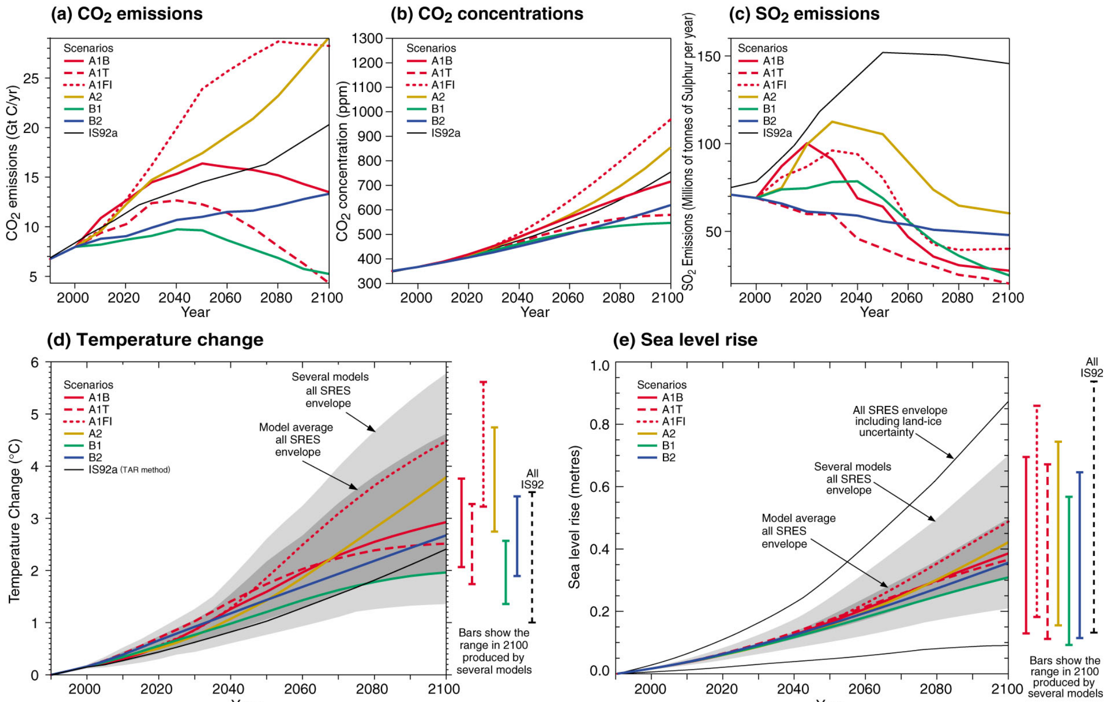
Greenhouse gas emissions and concentrations are continuing to rise. It is clearly of concern to assess what the implications of that might be. The

[1] See also a larger version of this chart at end of annex

possible future course of climate can be assessed through the use of climate models in combination with various future greenhouse gas emission scenarios.

In 2000 the IPCC published a set of 6 emission scenarios for the 21st century based on different scenarios for population growth, economic growth and the uptake of sustainable development policies. These are reproduced in figure 4, part (a) below. As can be seen the emission scenarios vary widely. Models which calculate the uptake of carbon by the ocean, soils and vegetation were used to compute future carbon dioxide concentrations, reproduced in (b). Other pollutants such as sulphur can also affect the climate system by forming aerosols so future scenarios for sulphur dioxide emissions were also prepared (c). Climate models were then used to generate a range of future climate scenarios, taking account of future changes of greenhouse gases and aerosols. These are reproduced in (d). Global warming also affects sea levels by melting land ice and causing the ocean to expand. Other models were used to calculate sea level rise (e).

**Figure 4 – Emission scenarios and projections of temperature change sea level rise (IPCC).** [2]




In summary the IPCC Third Assessment Report noted that by 2100:

- Carbon dioxide concentrations could increase from about 368 parts per million (ppm) in 2000 to between 540 and 970 ppm in the year 2100. We need to go back over 20 million years to find such levels. The pre-industrial level was about 280 ppm.

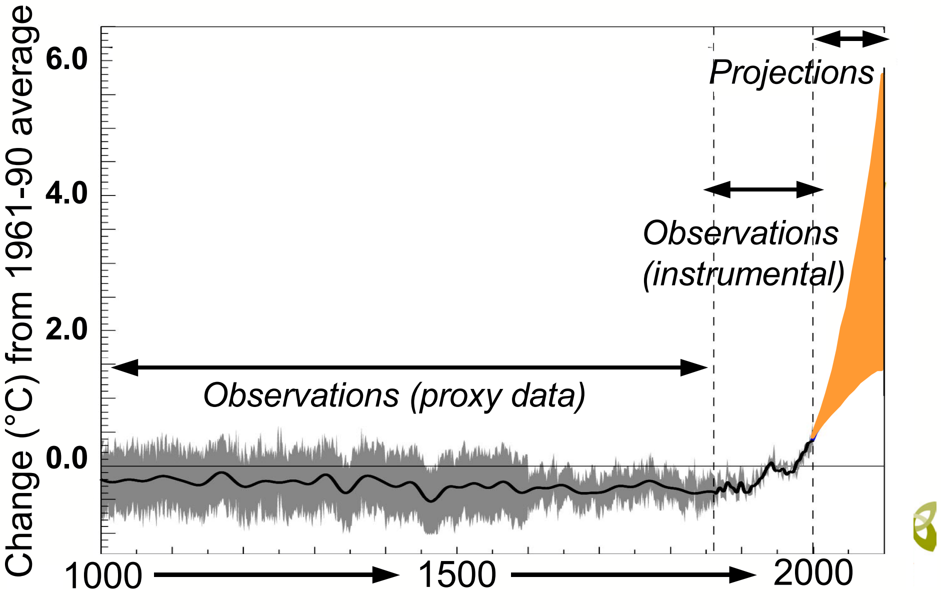
[2] See also larger version of these graphs at end of this annex

- Globally averaged surface temperature could increase by between 1.4 and 5.8C relative to current levels.
- Global mean sea level could increase by between 9 and 88 centimetres.

It noted that carbon dioxide, temperature and sea level would continue to rise long after emissions were reduced. Associated with these changes the frequency, intensity and duration of extreme events, such as more hot days, heat waves, and heavy precipitation events was expected to increase. Such changes can be significant in terms of the effects they have.

There is clearly considerable uncertainty about the level of climate change over the next 100 years due to uncertainty in the future level of emissions and the responsiveness of the climate system to greenhouse gases. Even so all scenarios project levels of warming which are unprecedented in historical times as shown in figure 5.

**Figure 5 Temperature changes over the last 1000 years deduced from bio-physical sources such as tree rings, and projected by models over the next 100 years (IPCC) Proxy data is for N.Hempisphere only, Instrumental observations are global (see IPCC report)**

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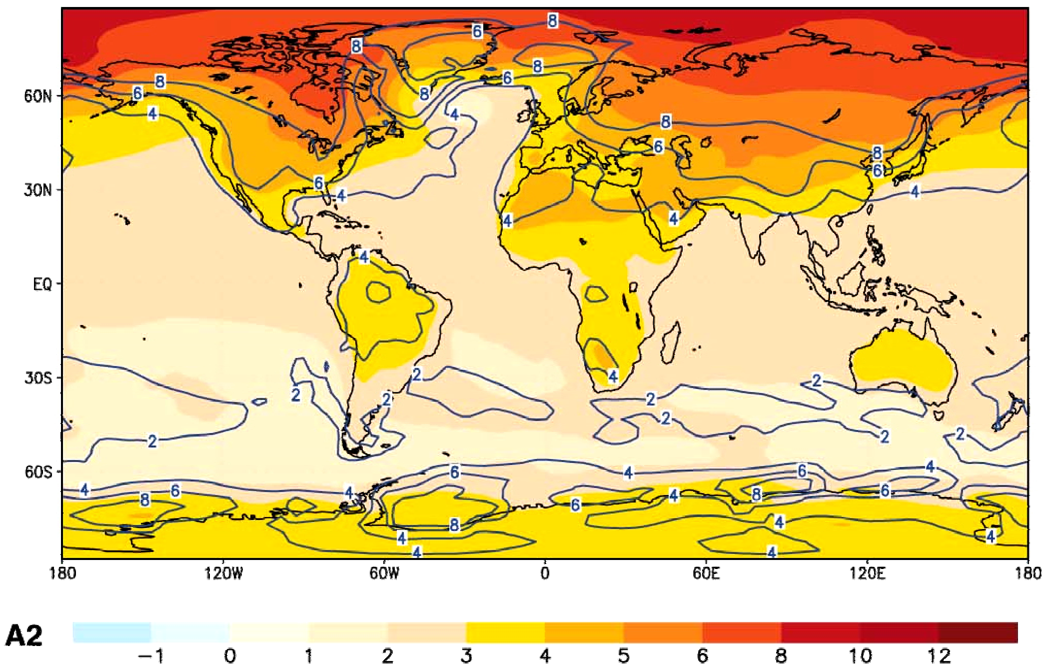
Temperature change will not be uniform across the globe. Continental areas will warm by much more than the average and some of the largest changes will be seen in polar regions where reduction in snow and ice will allow more of the sun's heat to be absorbed. This is shown in figure 6 for one future scenario.

**Figure 6 Annual mean temperature change, 2071 to 2100 for IPCC scenario high growth scenario (A2).**




## D. Abrupt climate change and other high impact, low probability events.

The above results suggest that climate will change smoothly. But in reality there will be considerable year to year and decade to decade variability superimposed on this underlying trend. Furthermore greenhouse gas induced warming this century could potentially set in motion large-scale, high impact, abrupt changes in physical and biological systems, such as changes to ocean circulation and de-stabilisation of the polar ice sheets. Such events are very difficult to predict but we cannot ignore the risk.

For example, most models predict that global warming will result in a weakening of the North Atlantic Circulation (commonly referred to as the Gulf Stream). This would mean that the UK and NW Europe might not warm as much as other areas and current projections take this into account to some extent. Some speculate that the Gulf Stream might shut down completely, plunging the UK and Europe into a new ice-age. Such ideas were behind the recent climate disaster movie "The day after tomorrow." But on the evidence we have so far we think it is unlikely that the gulf stream will shut down altogether (on the timescale of the next 50-100 years), although this cannot be completely ruled out.

If Greenland's temperature passes a threshold of 2.7 deg C, the Greenland Ice Sheet will begin to melt. 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. If the Greenland

Ice Sheet were to melt completely, global sea levels would increase by a further 6 to 7m over about 1000 years. It is likely that there will be enough greenhouse gases in the atmosphere by the middle of this century to cause the temperature in Greenland to exceed this threshold.

The West Antarctic Ice Sheet is also deemed to be at risk from climate change but the situation is more complicated and less certain. The general view is that significant changes are unlikely this century. In the longer term however its stability is in question and it could also add a further 5 metres to sea levels.

A warming of the ocean and melting of permafrost could result in the release of large stores of trapped methane into the atmosphere, which could cause acceleration of global temperature increases. This subject is currently under investigation (for instance by the Hadley Centre) as it is not clear at what temperature increase such processes might occur.

By the second half of the century, increasing temperatures could reduce the ability of grasslands, forests and soils to absorb carbon dioxide from the atmosphere and begin to release carbon back into the atmosphere. There are also indications that eventually the Amazon rainforest would begin to die back due to reduced rainfall. Such changes would significantly exacerbate climate change. This may mean that current projections of climate change underestimate future temperature rise.

## E. Potential impacts of climate change

### Global

The predicted changes in global temperatures and sea level summarised above will have a wide range of impacts worldwide on the natural environment, ecosystems and human health and society.

As noted in *section A* land ice is declining and vegetation and animal behaviour is already showing signs of responding to current climate changes. Changes in snowmelt, permafrost and rainfall will change the volume and timing of river flows and groundwater recharge.

Vegetation is affected by changes in temperature, rainfall, and directly by increased atmospheric carbon dioxide levels. This will affect ecological and physiological processes, alter growing season length, biomass production, competition between species, and lead to shifts in species ranges and possible extinctions. Climate change is likely to lead to irreversible and accelerated losses of biodiversity, with some recent research suggesting that between 16 and 37 % of the land species in the areas studied could be committed to extinction by 2050, under mid-range climate change scenarios. It is not only natural ecosystems that will be affected, crop and animal production will also face changes.

Coastal wetlands comprising of salt-marshes, mangroves and associated un-vegetated inter-tidal areas, could experience substantial changes and losses due to sea-level rise. It is estimated that the potential loss of the world's coastal wetlands could be up to 20%. Coral reefs will also be affected by rising ocean temperatures and $CO_2$ which may cause chronic stress and disease epidemics, mass coral bleaching and the inhibition of calcification.

Such changes, together with direct climate effects, will affect human society, putting increased pressure on food and water resources and energy supplies. In turn (and in combination with other factors) this may contribute to the causes of migration, instability and conflict. It is estimated that 1/3 of the world's population are presently living in water stressed countries. Depending on the emission scenarios, climate scenarios and population change, it is estimated that up to 2/3 of the world's population will be living in water-stressed countries by 2050 as a result of climate change.

Rising sea levels combined with population increases and other socio-economic changes could mean additional tens of millions of people flooded per year in coastal regions. A recent research programme (*Fast-track*) supported by Defra concluded that by the 2080's the annual number of people at risk from coastal flooding due to surges could increase from about 10 million to as many as 80 million worldwide, with around half of the increase likely to be in the poorest parts of Asia.

*Fast-track* also used Hadley Centre projections of climate change for the IPCC scenarios together with a global model of malaria transmission to provide a 'broad brush' global overview of human health impacts. While warmer temperatures tend to increase the season and distribution of malaria, decreases in rainfall tend to decrease its distribution. For those countries that currently have limited capacity to control malaria, the model estimated that an additional 90 million to 200 million people could be *at risk* by the 2080s. This includes some increases due to population growth in new risk areas in Eurasia and Africa.

The IPCC concluded that a 2.5 deg C rise in global temperature might cost 1.5–2.0 % of global GDP in terms of damage in the future. Swiss Re, the world's second largest insurer, has recently said that the economic costs of global warming is threatened to double to $150 billion per year in 10 years, hitting insurers with $30-40 billion in claims, annually.

## Regional impacts of climate change.

### *The United Kingdom*

Climate change scenarios for the UK, published by Defra in April 2002, show that:

- Annual temperatures averaged across the UK may rise by between 2 and 3.5 deg C by the 2080s, depending on the future scale of global emissions

of greenhouse gases. Warming will generally be greatest in parts of the southeast, where temperatures may rise by up to 5 deg C in summer by the 2080s. High summer temperatures will become more frequent and cold winters will become increasingly rare.
- Winters will become wetter and summers may become drier across all of the UK. The largest relative changes will be in the south and east where summer precipitation may decline by up to 50% by the 2080s. Heavy winter precipitation will become more frequent, but the amount of snow may decline by 60% or more in parts of Scotland and up to 90% elsewhere by the 2080s.
- Sea-levels are expected to continue to rise around the UK, in line with global changes but with local variations due to land movement. In southeast England sea-levels could rise by between 26 and 86 cm by the 2080s. This means that, at some east coast locations, extreme sea-levels that currently have a 2% chance of occurring in any given year, could occur between 10 and 20 times more frequently by the 2080s. No contribution from the melting of Greenland or Antarctic ice is assumed on this timescale.
- Storminess may increase during the winter.

Such changes in the UK will affect many areas of public and private sector life. Table 1 (below) shows some examples of climate change impacts in the UK.

### *Adaptation to Climate Change in the UK*

More attention is now being given to adaptation but technically the subject is in its infancy. The Government and devolved administrations are taking a lead in preparing to adapt to climate change. Strategic decisions that are made now have long lifetimes: to reduce risks, minimise damages and take advantage of potential benefits, adaptation must be factored in at an early stage. The more excessive regional temperature increases and precipitation changes may only be felt in a few decades time, but many investment and infrastructure decisions are designed to last this long. Adaptation to cope with more frequent weather extremes and to plan for the longer term changes needs to begin now.

**Table 1: Examples of climate change impacts in the UK**

| Sector | Examples of impacts |
|---|---|
| *Business* | Increased weather variability and flooding could affect UK business, with the possibility of damage to premises, transport disruption and problems with construction. |
| *Transport* | Increased flooding during winter will affect all modes of transport. Some coastal railways (and roads) may be at risk of inundation by the sea during periods of particularly high winds / high tides (e.g, Wales, SW England). |
| *Tourism* | Warmer, drier and sunnier summers could benefit domestic summer tourism, while significant changes in snowfall could have negative effects on some aspects of winter tourism. Conservation of heritage sites (both built and archaeological) will be increasingly challenging in the changing climate, especially at coastal sites. |
| *Health* | Hotter summers are likely to lead to an increase in heat-related summer deaths and a significant increase in cases of food poisoning. Cases of skin cancer are also likely to increase. Severe winter gales and coastal flooding will lead to an increased risk of major disasters, but cold-related winter deaths are likely to decline substantially. Increases in vector-borne and water-borne diseases may present local problems but their overall impact is likely to be small. |
| *Insurance* | The industry could face higher pay-outs due to greater incidence of subsidence following extended dry periods, or of damage to properties in flood-plain and coastal areas. |
| *Poorest communities* | The impacts of climate change may be felt disproportionately by the poorest people in the UK, for example, through lack of climate resilience in the lowest quality housing, through uninsured losses from severe weather damage to property and through potential increases to water bills. |
| *Flood defence* | Increased flooding risk in many lowland areas, due to more frequent river flooding and more severe storm surges. |
| *Water supply* | Increased water demand and more droughts could create worsening water supply problem in parts of England. |
| *Agriculture* | There is likely to be a mixture of effects on crop production – some beneficial (such as reduced frost damage, and accelerated growth as a result of warmer temperatures), others detrimental (such as spread of crop diseases, and increased water stress reducing crop yields). |
| *Wildlife* | Climate change presents threats for some species and opportunities for others. The range and distribution of plants and animals is likely to change. |

The Government set up the UK Climate Impacts Programme (UKCIP) in 1997 to encourage private and public sector organisations to assess their vulnerability to climate change so that they can plan their own adaptation strategies. UKCIP has developed a toolkit, including a risk-assessment framework and a method for costing impacts of climate change, to assist organisations in this task. All regions of the UK have carried out scoping studies to look at the impacts of climate change on the sectors that are particularly important to them. And more detailed research into potential adaptation responses is beginning. A guide on preparing for climate change has been issued to local authorities in the UK as part of an emerging work-stream on adaptation.

Government departments have carried out studies to look at the implications of climate change for their policy responsibilities. A number of Departments are engaged in research to improve understanding and awareness of the implications of climate change impacts in their policy areas. Meanwhile, adaptation to climate change is already being drawn into a range of policy areas including building regulations, health, forestry, conservation, and international development. Table 2 shows some other specific examples.

**Table 2. Some examples of adaptation responses in the UK**

| Sector | Example of adaptation |
|---|---|
| *Transport* | • Network Rail, highways authorities and London Underground each have major programmes of work in progress to improve the way in which they respond to today's weather.<br>• The Highways Agency and Network Rail have maps of flood hotspots which are used to predict where trouble will occur and target maintenance and contingency plans. |
| *Health* | • Awareness-raising of summer health problems and advice on sun- and heat-related ill health prevention strategies through a variety of initiatives.<br>• Specific advice to the public on the handling, cooking and storing of food during the warmer summer months.<br>• The findings of the report "Health Effects of Climate Change in the UK" (2001) are valuable in health protection policy development. They will also be used to inform future public health messages and decisions on future research priorities. |
| *Financial Sector* | • The *Institutional Investors Group on Climate Change* (www.iigcc.org) is working to promote awareness of the risks and opportunities presented by climate change to the financial sector. |
| *Land-use planning* | • Revisions to the planning system are taking into account the impacts of climate change. For example, planning guidance on development in areas at risk of flooding has been made more robust to advise a precautionary and risk-based approach.<br>• Planning guidance in Scotland continues to be based on avoiding development where there is significant risk of flooding and managing the threat in areas where it is less acute. |
| *Flood and coastal defence* | • Government guidance on flood defence in England and Wales includes allowances for sea level rise and higher river flows as a result of climate change. *Foresight Future Flooding* report (http://www.foresight.gov.uk/fcd.html )has contributed new evidence to inform the revisions of strategies.<br>• Investment into improving flood warning services, improving flood and coastal defence infrastructure, and increasing public awareness of flood risk is aimed at reducing long term risk.<br>• There are already a number of examples of adaptive coastal defence around the country, including managed retreat. |
| *Water resources* | • Climate change projections are taken into account in strategies and plans for water resource management, catchment abstraction management, and maintenance of supplies in drought conditions.<br>• There are a number of initiatives to reduce demand for water. These range from sector-specific programmes such as *Envirowise*, to influencing customer behaviour, to setting minimum standards for water efficiency through regulation. |
| *Agriculture* | • A substantial amount of research on climate change impacts on |

| | |
|---|---|
| | agriculture has already been funded, and indicates that UK agriculture should be highly adaptable to changing socio-economic and environmental scenarios. |

### *Developing countries*

The impacts of climate change are likely to be significant in both developed and developing countries but the latter will have less capacity to respond proactively, resulting in the exacerbation of existing inequalities in health status, access to adequate food, clean water, and other essential resources.

A 2 deg C average global temperature rise (which is possible by the middle of the century) could mean as much as 4 deg C in the middle of large continents like Africa. For Africa, there is a wide consensus that climate change will worsen food security, accelerate irreversible losses of biodiversity and have negative impacts on human health.

Increases in sea-level and the intensity of tropical cyclones will displace many millions of people in low-lying coastal areas of temperate and tropical Asia – e.g. for Bangladesh, a 1 metre rise in sea-level would result in the loss of one-fifth of the viable land area, affecting 15 million people.

Sea-level rise of the magnitude currently projected is expected to have disproportionately large effects on the economic and social development of many small island states. In extreme circumstances, sea-level rise and its associated consequences (e.g., land loss, salinity intrusion to freshwater supplies) could trigger abandonment and significant "off-island migration" at great economic and social costs.

In China, by the end of the 21$^{st}$ century, average temperature increase may be between 3-4 deg C, crop yields (rice, maize and wheat) could fall by up to 37%, and large scale shrinkage of permafrost in northeast China is likely to occur leading to ground subsidence and loss of ecosystems/biodiversity.

In India, changes to the climate will affect a wide variety of ecosystems and socio-economic sectors with corresponding impacts on water resources, agriculture, forestry and other sectors. According to recent research, annual river runoff may decline up to 70 % and cereal yields may decline up to 20%, and it is also expected that a sea-level rise of 1 metre could displace 7 million people.

### *The Arctic*

Recent indications from the Arctic Climate Impacts Assessment are that average Arctic temperatures have risen by nearly twice as much as the global average over the last 50 years causing increases in surface and oceanic temperatures, increases in precipitation, reductions in sea ice and glacial volumes, increases in river runoff and sea level, decaying permafrost and shifts in the ranges of plant and animal species.

Thawing ground and receding permafrost will affect engineering, transport, infrastructure and agriculture, as well as for biodiversity and indigenous communities. Indigenous people are already reporting that thinning and depletion of sea ice will push some key marine mammals towards extinction including the polar bear, walrus and some seal species that are hunted by the Inuit.

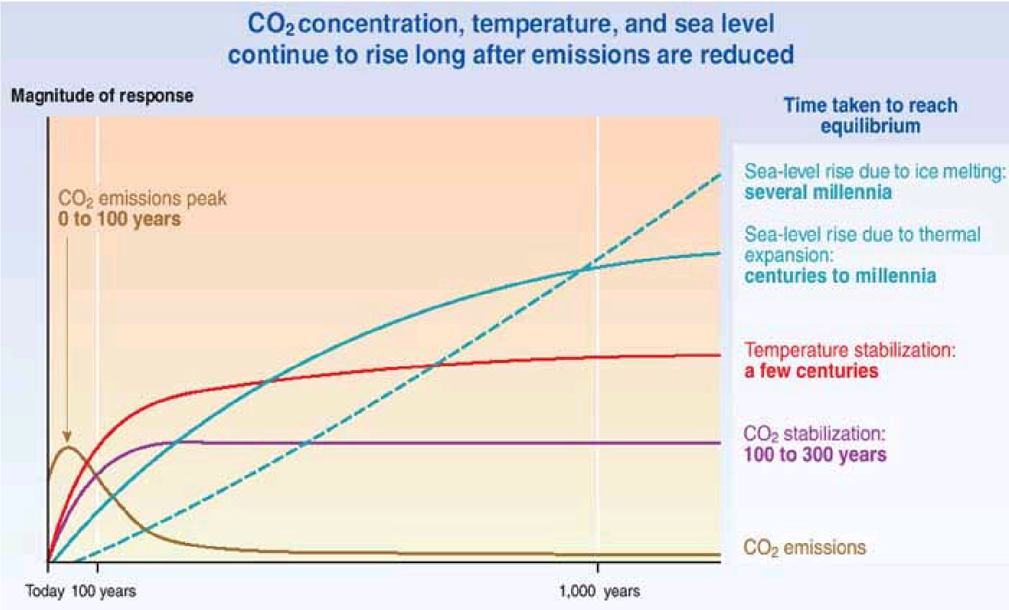
**F. Limiting climate change and its effects**

There are two main policy responses to climate change – a) adaptation to ameliorate its effects and b) mitigation by reduction in emissions.

Both responses are essential – mitigation to limit the overall scale of climate change and adaptation to deal with climate change which is now unavoidable. International efforts so far have concentrated on the short term prospects for mitigation through the Kyoto Protocol. But there is an increasing need to consider the long-term implications of climate change, to consider how much climate change we can cope with and how much emissions need to be reduced to avoid a level of climate change that would lead to an unacceptable level of damage, both in the UK and elsewhere. Implicit in this is a recognition that adaptation becomes more difficult the greater the change and may not be possible above certain levels.

At some point in the future the international community needs to move towards identifying initially some climate and / or greenhouse gas stabilisation options. The EU has already stated that we should aim to keep temperatures from rising by more than 2 deg C above pre-industrial levels. One of the challenges of stabilisation is the need to recognise that the world needs to act well ahead of any target it sets as the climate system responds relatively slowly to any actions taken. This is demonstrated in figure 7. Carbon dioxide levels may possibly be stabilised within a century but temperatures would still rise for a few centuries after and sea levels for millennia. This means that if we are to avoid significant changes say to the major ice sheets we need to act now.

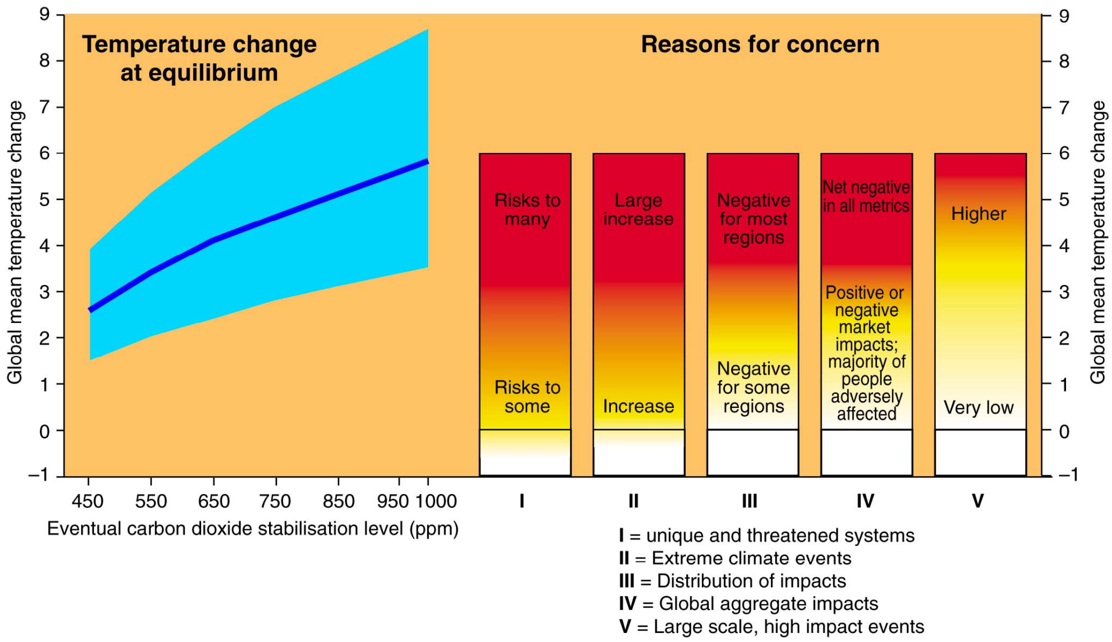
**Figure 7 Timescales for Stabilisation (IPCC)**




The current atmospheric concentration of carbon dioxide is 372 parts per million (ppm), rising at a rate of 1-2 ppm / year. Thus at present rates of increase, concentrations are likely to reach 450 ppm in 50 years, causing temperatures to rise by about 2C in 2100. However, global emissions are projected to rise more rapidly than this, and concentrations to continue increasing beyond 450 ppm. IPCC has stated that concentrations could reach 540 to 970 ppm in 2100. Thus if no additional international restrictions are agreed, the dates at which 450 ppm concentration or a 2 deg C temperature rise will be brought forward.

A global mean temperature rise of 2 deg C means a significantly greater risk to unique and threatened ecosystems, a noticeable increase in extreme weather events, with serious impacts in terms of flooding, health, water availability and food production. The risk of conflict linked to water availability and population displacement is likely to increase. Large scale high impact events, such as a collapse of major ice sheets or disruption of the ocean circulation, will become more likely, though the risk is considered to be small at this level of climate change. But above 2 deg C such events cannot be discounted. As noted before a local warming of 2.7 deg C will initiate melting of the Greenland ice cap. The Intergovernmental Panel on Climate Change summarises the risks associated with different temperature changes in Figure 8. On the right hand side, red (dark) represents severe impacts.

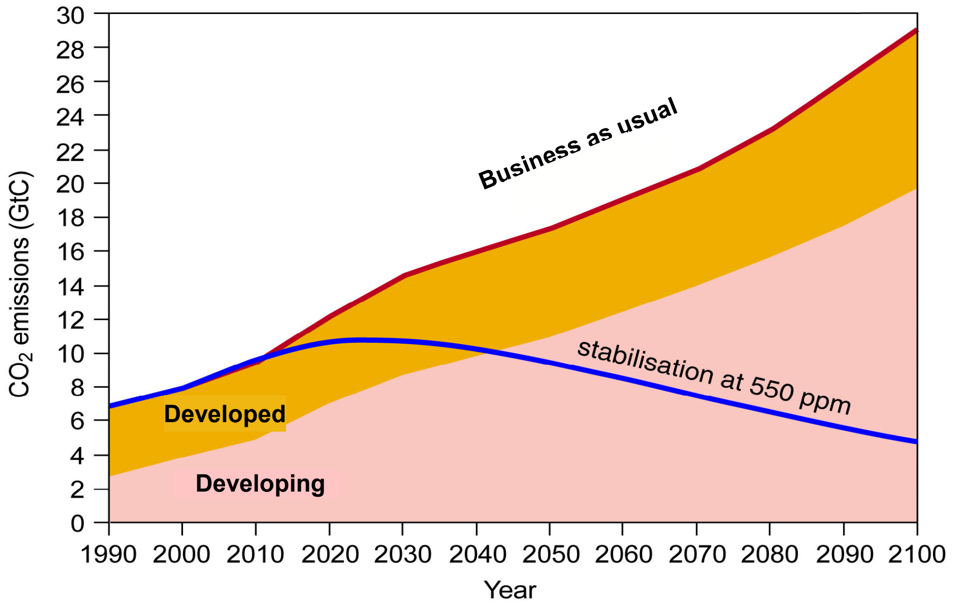
**Figure 8 Temperature at stabilisation (left) and risk of severe impacts (right)**




The EU has proposed that we should aim to limit temperature rise to below 2 deg C to avoid dangerous climate change. The IPCC conclusions suggest that this is a good working target. Earlier EU work linked a 2 deg C rise to atmospheric carbon dioxide at 550 ppm, and this was the assumption made for our Energy White Paper. But the more recent IPCC conclusions suggest that a concentration limit of about 450ppm would be more appropriate. Defra has work in hand to better define the risks associated with different carbon dioxide concentration levels.

The IPCC notes that to stabilise carbon dioxide concentrations at 450 ppm requires emissions to peak and begin to fall in the next 10-30 years. Yet emissions are unlikely to do so without concerted action. Figure 9 demonstrates the divergence between what is effectively a business-as-usual scenario and a stabilisation scenario at 550 ppm. Exxon Mobil estimates that by 2020 the world will need 40% more energy than today and that 80% of that extra demand will come from developing countries.

**Figure 9 Comparison of Business as Usual and stabilisation scenarios**




The Kyoto Protocol has spurred countries to adopt policies and measures to tackle emissions and significantly raised the profile of climate change. The direct effects of these policies could reduce global emissions by 1% in 2010 compared to what they would be in the absence of the protocol (this is less than expected because US emissions are rising so strongly). But this falls far short of the much deeper cuts which will be needed to avoid dangerous climate change.

## G. Confidence and Uncertainty

Climate change inevitably attracts scientific controversy. It is a complex subject and there are significant economic issues at stake for countries and industries.

The UK has a good science base for tackling climate change and some well recognised world class institutes, such as the Hadley Centre at the Met Office and the Tyndall Centre at a number of British Universities. The Government is well served through these and other institutes, but the international debate needs to draw on the best scientific thinking from around the world. In 1988 the Intergovernmental Panel on Climate change was set up to assess the scientific, technical and socio-economic aspects of climate change and since then has produced three major assessment reports and several special assessments. The IPCC draws on the work of thousands of scientists worldwide and has well designed procedures to ensure full review of its assessments.

From such assessments and the views of our own scientists we can be confident that we have a good understanding of climate change. The basic thesis that climate is changing, that human activities are responsible and that if unchecked such activities will lead to significant climate change and associated damages is accepted by the majority of scientists. It is also recognised that there are significant areas of uncertainty which we have reflected in this paper, particularly with respect to abrupt climate change.

**Figure 3 Comparison of observed and modelled temperature change for different combinations of possible influences on the climate system (Hadley Centre)**

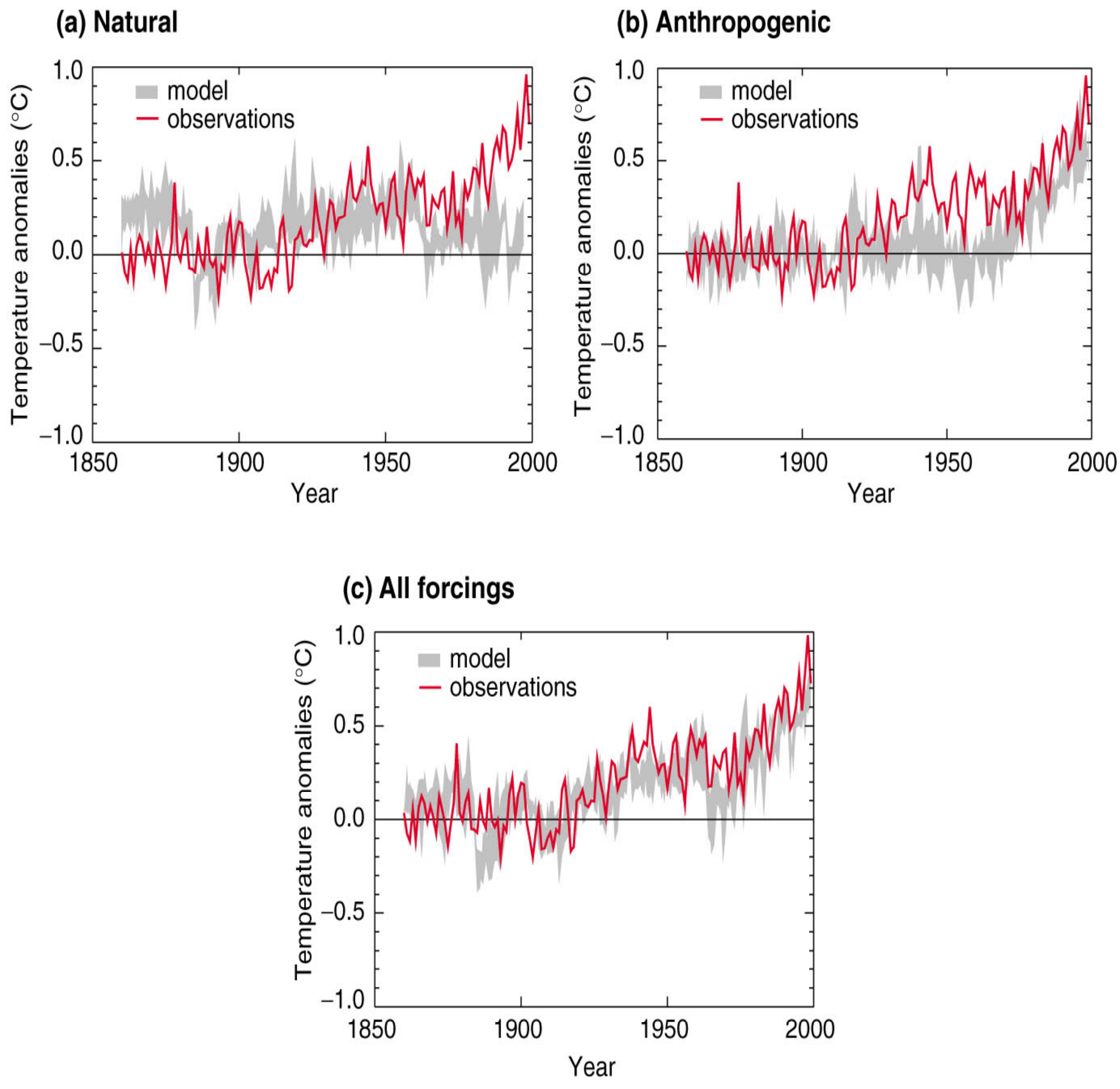


**Figure 4 – Emission scenarios and projections of temperature change sea level rise (IPCC).**