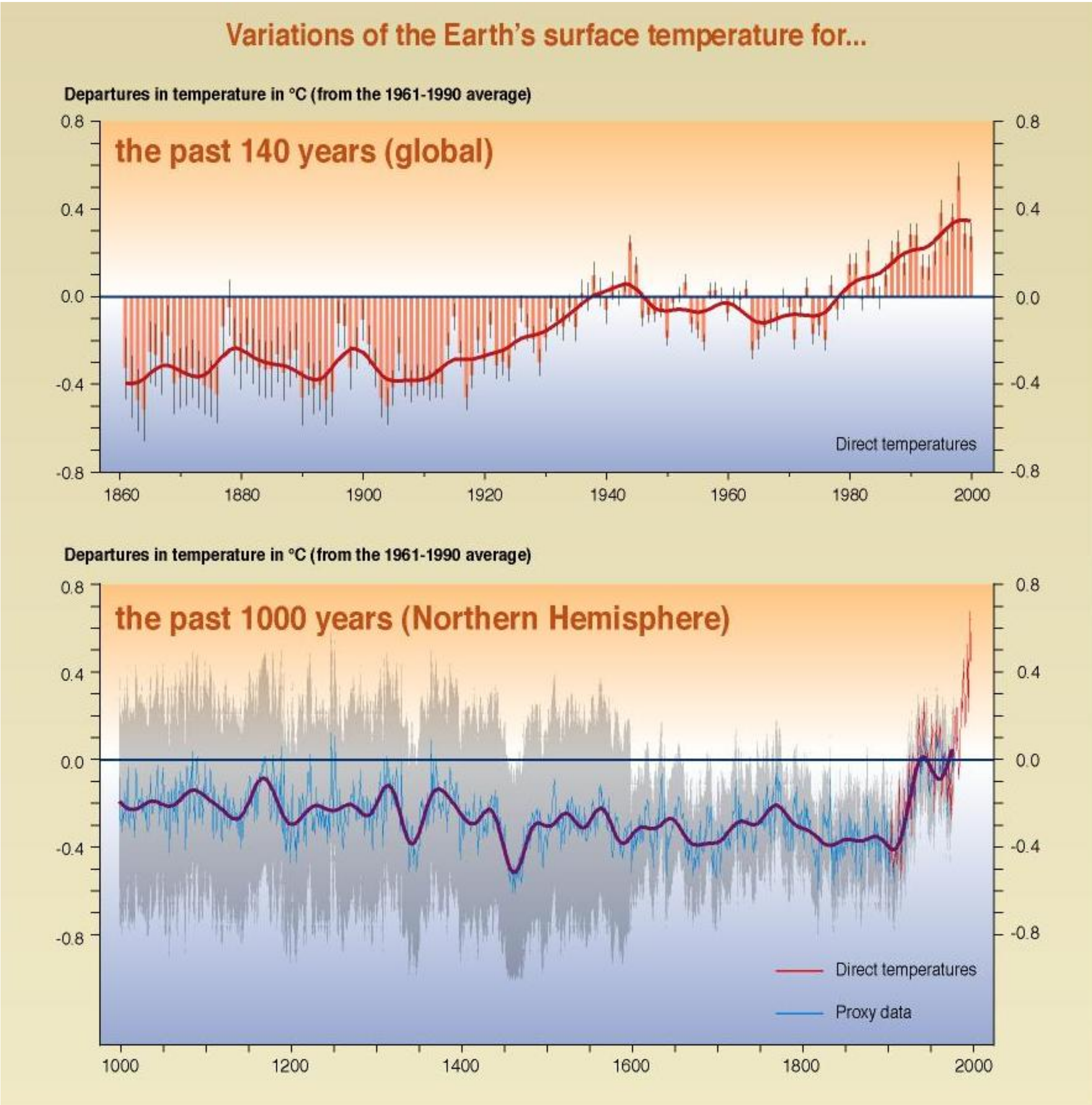
A SHORT INTRODUCTION TO CLIMATE CHANGE

1. Introduction

1.1 This note is intended to give a very brief overview of some of the central aspects of climate change. More detailed information on any aspect is available on request.

2. The Earth's climate changes continuously but recently temperature has increased much more quickly than expected

2.1 Climate change has always occurred. At different times during our planet's history it is possible that one could have grown trees at the North Pole and gone ice climbing where Paris now stands.



[1]

2.2 The cycles of global warming and cooling have been studied extensively, and currently accepted models suggest that we are in a warm phase between ice ages. However, there has been a period of warming over the last 100-150 years which is not thought to be part

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[1] Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report: Climate Change 2001.

of normal climate fluctuations. Eleven of the last twelve years have been the warmest on record (since 1850) and are 'likely' to have been the warmest in the last 1300 years[2].

3. Evidence of increasing CO_2 levels and temperature

3.1 The most recent evidence comes from direct measurements taken over the last hundred years or so[3]. For periods predating the era of temperature and CO_2 measurements other evidence such as ice cores, pollen distribution, and tree and coral rings have been used. Ice cores are useful because they contain small amounts of trapped air which can be analysed for CO_2 content; in addition, the water in the ice can be analysed for two different forms of oxygen, the relative amounts of which can be used to calculate the air temperature when the ice was formed[4].

4. Evidence of the effects of increasing temperatures

4.1 The Intergovernmental Panel on Climate Change (IPCC) is publishing its Fourth Assessment Report on Climate Change this year. This will constitute the most comprehensive report to date. The summary of Part I of the report (The Physical Science Basis) was published on the 2 February 2007. It states *"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level….*

At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones..."[5]

4.2 The sections of the report covering the effects on nature and humans are not due to be published until later in the year. However, the effects of the recent warming has been highlighted by the plight of the polar bear, the melting of the permafrost, changes to flowering times and species migration.

4.3 The following diagram is also taken from the IPCC's recent summary. It shows recent global temperature rises, sea level increases and the depletion of northern hemisphere snow cover.

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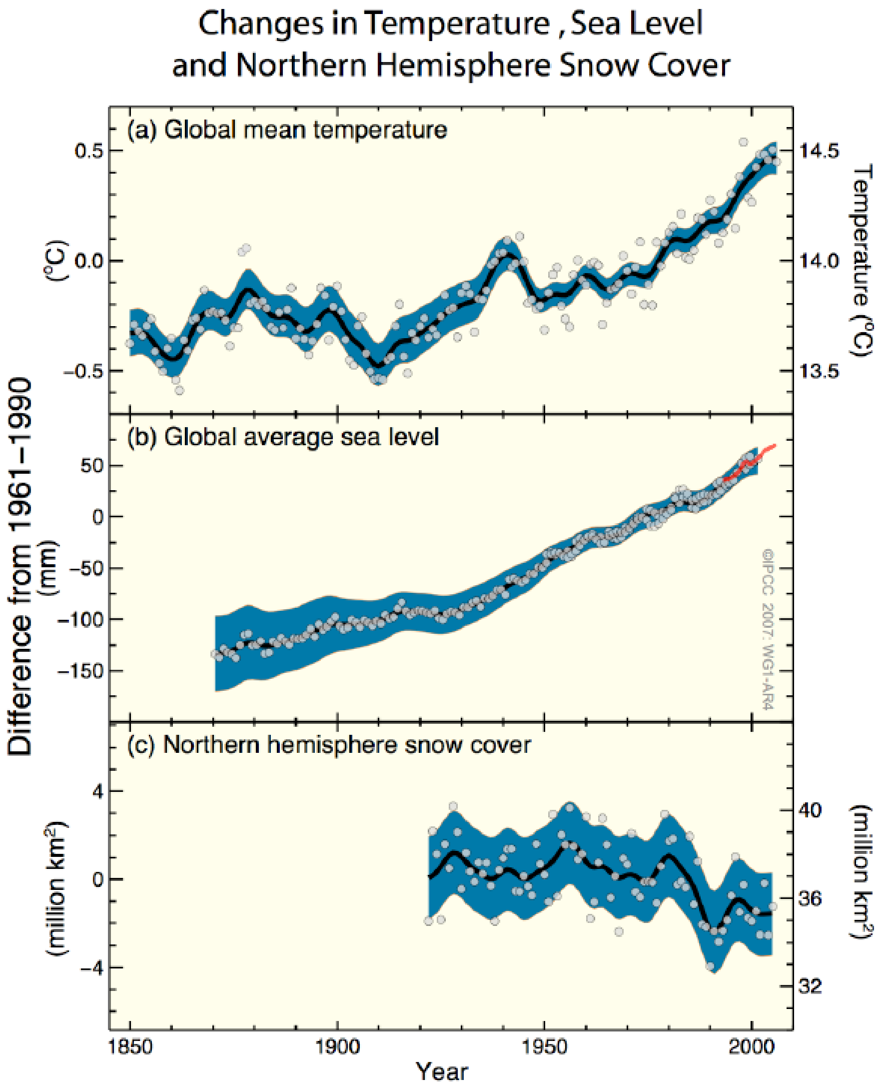
[2] "Climate change 2007: The Physical Science Basis - Summary for Policymakers" Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). p4 & 8.

[3] The most reliable measurements of global CO_2 have been taken since 1958.

[4] Houghton, J (2004) "Global Warming - The Complete Briefing" Cambridge p66-68

[5] "Climate change 2007: The Physical Science Basis - Summary for Policymakers" Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). p4



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5. **Possible explanations for the recent increases**

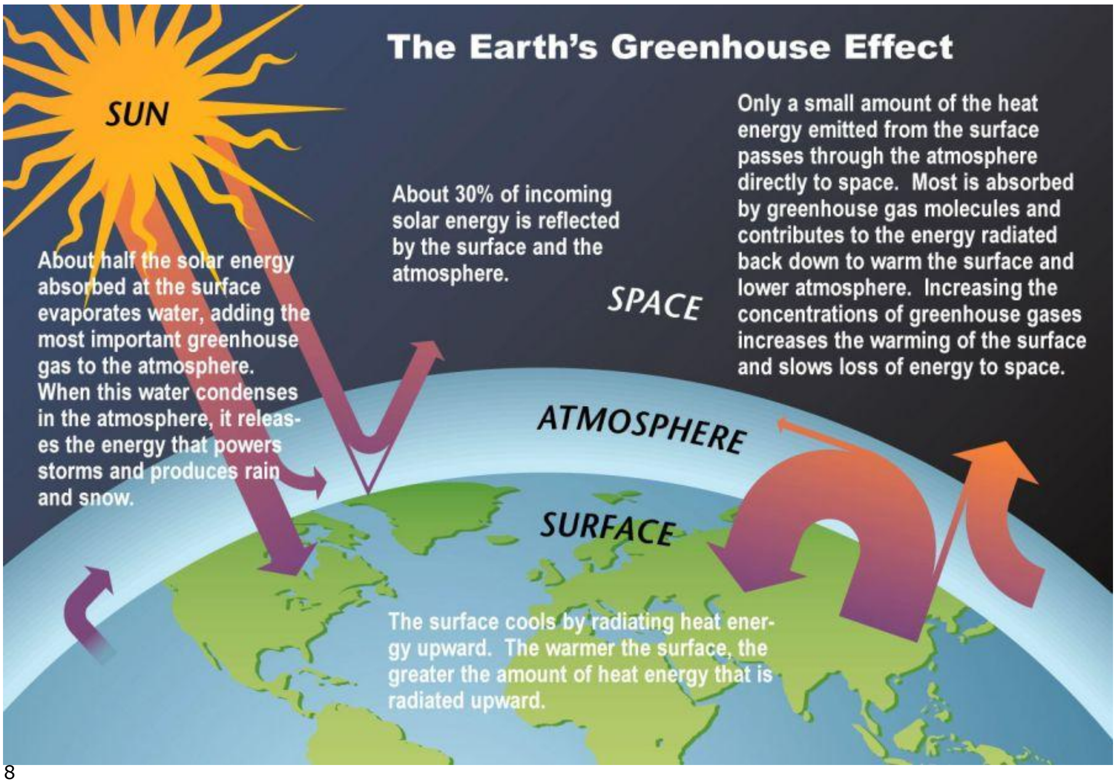
5.1 There are many factors which affect the climate, the majority of which either increase or decrease the amount of solar radiation to which the earth is exposed: output of the sun, the shape of the earth's orbit around the sun, the varying angle of the earth's tilt and events which release large amounts of dust into the atmosphere, such as volcanoes and meteor impacts. These factors have been used to help explain the initiation and termination of past ice ages. However, according to current research, these factors do not explain the recent increases in temperature.

6. **Greenhouse Gas effect**

6.1 The "Greenhouse Effect" was first postulated by Joseph Fourier in 1827, and is the process by which the earth maintains a warm temperature relative to other objects in space. Solar radiation from the sun enters the earth's atmosphere. Some is reflected back into space and some reaches the earth's surface. Much of the radiation reaching

[6] *"Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c)."*

the surface is then reflected back out again. However, the nature of the radiation has changed sufficiently for it to be absorbed by water vapour and gases such as carbon dioxide (CO_2) and methane. The radiation is then re-emitted into the atmosphere as heat. Without this effect, the Earth's surface would be up to 30°C cooler[7].



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6.2 The most noted greenhouse gas (GHG) is carbon dioxide but water vapour, methane, nitrous oxide, chlorofluorocarbons and ozone all have a "greenhouse" effect. Rather than quantify the levels of each different GHG it is common practice to refer to the equivalent amount of the carbon dioxide. Hence the current level of CO_2 in the atmosphere is approximately 380ppm, but the carbon dioxide equivalent (CO_2e) amount is 430ppm. This is thought to be higher now than at any time in at least the past 650,000 years[9]. The amount of CO_2 in the mid 1700s was approximately 280ppm. If GHGs continue to be produced at the current rate then 2050 GHG levels are likely to reach 550 ppm CO_2e. However based on current trends annual emissions are likely to increase rather than continue at the current level and some models predict that it is possible that CO_2 will reach this level by 2035.[10]

7. Modelling of increased CO_2 levels

7.1 The effects of increasing CO_2 levels on global temperature is modelled using computer programs. The basic calculation of how much more heat will be retained by a greater amount of CO_2 is relatively straightforward. The difficulty with climate prediction is the multiple uncertain feedbacks and consequences from heating which need to be incorporated into the models, for example:

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[7] http://earthobservatory.nasa.gov/Laboratory/PlanetEarthScience/GlobalWarming/GW_Movie3.html
[8] http://www.usgcrp.gov/usgcrp/Library/nationalassessment/overviewclimate.htm
[9] "Climate change 2007: The Physical Science Basis - Summary for Policymakers" Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). p2
[10] Stern review Part I (p12)

(a) Water vapour and clouds - As temperatures increase so will the amount of water vapour in the atmosphere. Water vapour acts as a GHG but also contributes to cloud formation which, dependent on the type and height of cloud, can reflect away incoming sunlight (cooling) or trap warmth in the atmosphere (heating).

(b) Ground changes - Ice and snow reflect sunlight back into the atmosphere thus having a cooling effect. As the ice at the poles recedes more heat will be absorbed by the exposed ground (heating).

(c) Methane release - there are large quantities of methane stored in the deep lakes, the ocean and in permafrost. If these stores are released due to heating, for example melting of the permafrost, this will have a significant heating effect (1 molecule of methane has the same GHG effect as approximately 8 molecules of CO_2)[11].

(d) Decreased carbon sinks - As the level of CO_2 in the atmosphere increases so does the amount absorbed by the ocean which changes the pH of the ocean making it more acidic. This is likely to have profound effects on sea life and along with heating will ultimately decrease the CO_2 absorbing capacity of the oceans. Changes in precipitation may lead to water shortages causing various forests to die back which will release large amounts of carbon (heating). Increasing temperatures and rising carbon dioxide levels will increase plant productivity in some areas (cooling) until the temperatures become too hot and then productivity will decrease.

(e) Atlantic Thermohaline Current also known as the Meridional Overturning Current (MOC) - As fresh water is released from the melting Greenland ice cap it may interfere with the current which brings heated water across the Atlantic and up past the UK. This interference may reduce the temperature in regions affected by the current although it is not thought that it will be sufficient to counteract the projected heating effect from GHGs. *"It is very unlikely that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence."*[12]

7.2 All these factors make it very difficult to model the future climate. As the slightest change to the initial data can result in very different results, modellers run their simulations many times making slight changes in the parameters to try to obtain a spread of scenarios. The outcomes most frequently projected by the simulations can be taken to be the most likely outcome.

7.3 A public version of these types of experimental simulations was carried out by Climatepredict.net in association with the BBC where the spare computer capacity on individuals' home PCs was utilised to run thousands of simulations[13].

7.4 Many predictions have now been performed such that a consensus view on the likely effects has emerged. The IPCC summary report indicates that a doubling of CO_2 levels over pre-industrial levels is 'likely'[14] to commit the world to between a 2 and 4.5°C rise with a best estimate of about 3°C.

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[11] Houghton, J (2004) "Global Warming - The Complete Briefing" Cambridge p42

[12] "Climate change 2007: The Physical Science Basis - Summary for Policymakers" Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). p12

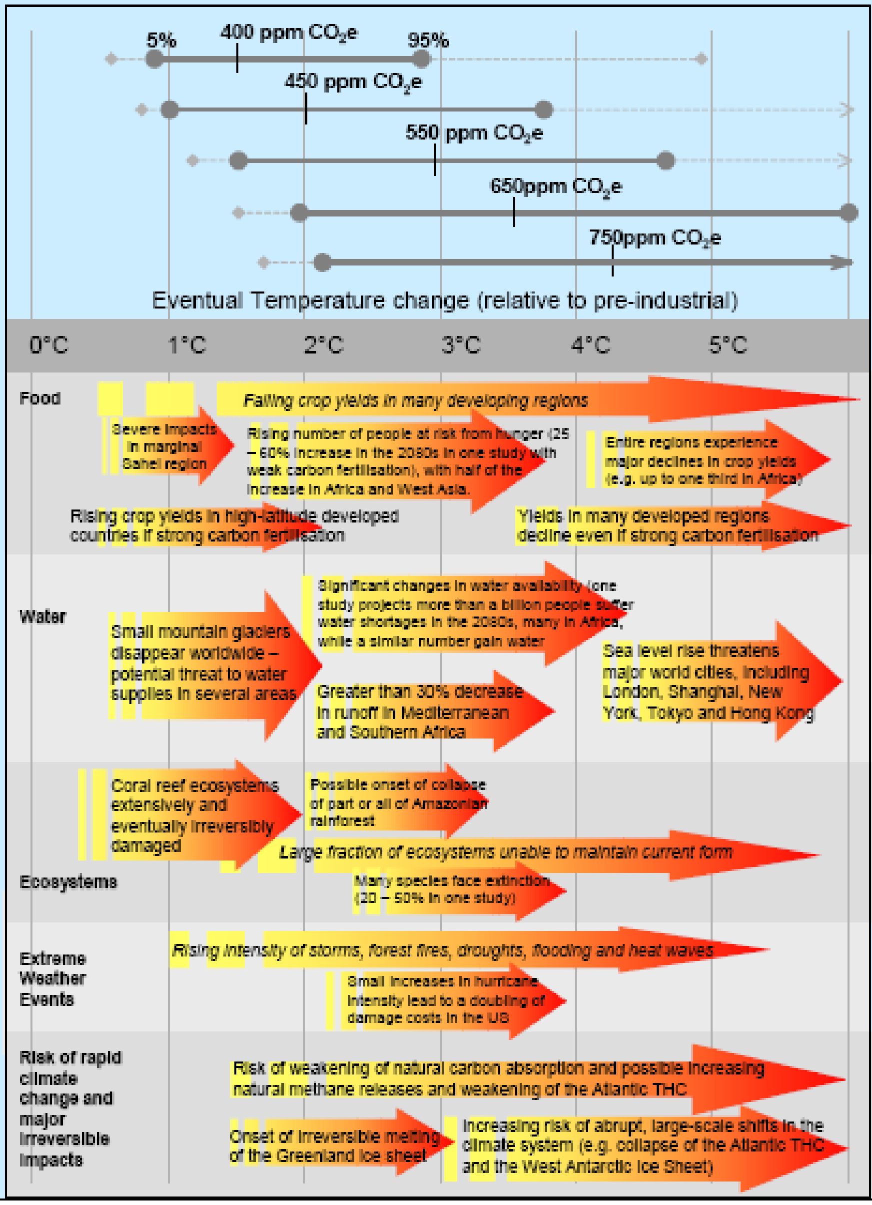
[13] http://www.bbc.co.uk/sn/climateexperiment/theresult/resultsataglance.shtml

[14] In the IPCC Summary *"the following terms have been used to indicate the assessed likelihood, using expert judgement, of an outcome or a result: Virtually certain > 99% probability of occurrence,*

8. Projected effects of increasing CO_2 levels

Figure 2 Stabilisation levels and probability ranges for temperature increases

The figure below illustrates the types of impacts that could be experienced as the world comes into equilibrium with more greenhouse gases. The top panel shows the range of temperatures projected at stabilisation levels between 400ppm and 750ppm CO_2e at equilibrium. The solid horizontal lines indicate the 5 - 95% range based on climate sensitivity estimates from the IPCC 2001[2] and a recent Hadley Centre ensemble study[3]. The vertical line indicates the mean of the 50[th] percentile point. The dashed lines show the 5 - 95% range based on eleven recent studies[4]. The bottom panel illustrates the range of impacts expected at different levels of warming. The relationship between global average temperature changes and regional climate changes is very uncertain, especially with regard to changes in precipitation (see Box 4.2). This figure shows potential changes based on current scientific literature.



8.1 These projections are taken from the Stern Review (2006):

"Warming will have many severe impacts, often mediated through water:

Extremely likely > 95%, Very likely > 90%, Likely > 66%, More likely than not > 50%, Unlikely < 33%, Very unlikely < 10%, Extremely unlikely < 5%."

• Melting glaciers will initially increase flood risk and then strongly reduce water supplies, eventually threatening one-sixth of the world's population, predominantly in the Indian sub-continent, parts of China, and the Andes in South America.

• Declining crop yields, especially in Africa, could leave hundreds of millions without the ability to produce or purchase sufficient food. At mid to high latitudes, crop yields may increase for moderate temperature rises (2 - 3°C), but then decline with greater amounts of warming. At 4°C and above, global food production is likely to be seriously affected.

• In higher latitudes, cold-related deaths will decrease. But climate change will increase worldwide deaths from malnutrition and heat stress. Vector-borne diseases such as malaria and dengue fever could become more widespread if effective control measures are not in place.

• Rising sea levels will result in tens to hundreds of millions more people flooded each year with warming of 3 or 4°C. There will be serious risks and increasing pressures for coastal protection in South East Asia (Bangladesh and Vietnam), small islands in the Caribbean and the Pacific, and large coastal cities, such as Tokyo, New York, Cairo and London. According to one estimate, by the middle of the century, 200 million people may become permanently displaced due to rising sea levels, heavier floods, and more intense droughts.

• Ecosystems will be particularly vulnerable to climate change, with around 15 - 40% of species potentially facing extinction after only 2°C of warming. And ocean acidification, a direct result of rising carbon dioxide levels, will have major effects on marine ecosystems, with possible adverse consequences on fish stocks."

9. Reduction of CO_2 levels

9.1 Various bodies, the EU for example, have adopted 2°C as the threshold temperature beyond which changes occur which it will be not possible to reverse for thousands of years, large rises in sea-level, wide-spread food shortages, and the extinction of many species are a few of the projected consequences. It should be remembered that although the average temperature rise would be 2°C that this would not occur uniformly around the globe. Some areas, such as the poles, will experience a much greater temperature rise and others no rise at all.

9.2 There are many studies which examine different scenarios for reducing CO_2 levels. Some advocate an immediate reduction, others work on the basis of a peak in emissions in the next couple of years followed by decreases in the following years, and others suggest that it would be more realistic to expect levels to peak 10-15 years later followed by dramatic reductions in CO_2.

9.3 There has been considerable debate as to the level to which CO_2e needs to be reduced. Recently a paper by Malte Meinhausen presented at the Scientific Symposium "Avoiding Dangerous Climate Change" organised by the MetOffice in February 2005 stated that it if CO_2e was stabilised at 550ppm it was highly unlikely that global temperatures increases would remain below 2°C.

> "*Drawing from a set of 11 published climate sensitivity uncertainty estimates, the probability of exceeding 2°C equilibrium warming (e.g. European Union target) is found to lie between 63% and 99% for stabilization at 550 ppm CO2 equivalence. Only at levels around 400 ppm CO2 equivalence or below, could the probability of staying below 2°C in equilibrium be termed 'likely' for most of the climate*

sensitivity PDFs. The probability of exceeding 2°C ranges from 8% to 57% in this case."[15]

10. Reducing carbon in the atmosphere

10.1 Carbon dioxide remains in the atmosphere for approximately 200 years. Hence, to reduce the level of CO_2 it is necessary to reduce or stop further emissions and to try and remove some of the CO_2 already present in the atmosphere.

10.2 Huge amounts of carbon are cycled between the land, ocean and air. Plants take up CO_2 to use in photosynthesis. They incorporate carbon into their structure and emit the associated oxygen (O_2). Animals eat the plants and break down their structure whilst breathing in O_2 and breathing out carbon in the form of CO_2. Therefore destroying forests results in a large release of carbon as well as the loss of a system which normally absorbs carbon.

10.3 Most fuels are carbon based and when these are burned the carbon locked up within the fuel is emitted as CO_2. To reduce carbon emission it will be necessary to use less energy, develop non-carbon based energy sources, find ways to capture the carbon emitted from fossil fuels, and reverse deforestation.

11. Mechanisms to tackle the effects of increased carbon dioxide

11.1 There are research initiatives which are investigating other ways to deal with the effects of increased CO_2. One possibility relates to the effects of aerosols and particles such as sulphur in the upper atmosphere. It is known that the dust thrown up by volcanoes has a significant cooling effect on the atmosphere. It has been suggested that it would be possible to inject particles into the upper atmosphere to mimic this effect and therefore initiate a cooling of the climate.

11.2 Another possibility relates to placing structures in space which will be able to deflect or block sunlight.

11.3 The main problem with these ideas as long term solutions is that they do not tackle the non-thermal effects of CO_2 rise, such as ocean acidification, nor do they provide a renewable source of energy to replace depleting oil stocks.

11.4 International strategy

11.5 The Intergovernmental Panel on Climate Change[16] was established in 1988 and produced its first Assessment Report in 1990[17]. Two years later the "Earth Summit" was held in Rio where an agreement called the United Nations Framework Convention on Climate Change (UNFCC) was introduced[18]. Under this agreement governments agree to gather and share information, launch strategies to tackle climate change and to co-operate in

[15] Malte Meinshausen (2006) "What Does a 2°C Target Mean for Greenhouse Gas Concentrations? A Brief Analysis Based on Multi-Gas Emission Pathways and Several Climate Sensitivity Uncertainty Estimates" In "Avoiding Dangerous Climate Change" Ed. Hans Joachim Schellnhuber, Cambridge University Press

[16] The role of the IPCC is to *"assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. The IPCC does not carry out research nor does it monitor climate related data or other relevant parameters. It bases its assessment mainly on peer reviewed and published scientific/technical literature."* (http://www.ipcc.ch/)

[17] Since this time the IPCC has published two further reports and is in the process of publishing their fourth.

[18] It has been signed by over 180 countries to date (http://unfccc.int/2860.php)

preparing for the effects of climate change[19]. In 1997 the Kyoto Protocol was agreed which set individual targets for cuts in GHG emission from Annex I Parties[20] which added up to a *"total cut in greenhouse-gas emissions of at least 5% from 1990 levels in the commitment period 2008-2012."*

11.6 In order to achieve their emissions targets countries should reduce their emissions of CO_2. In the EU this is being facilitated by the EU Emissions Trading Scheme. Different sectors are included in the scheme and companies are assigned a certain number of carbon credits which gives them the right to emit a corresponding number of tons of carbon. If they exceed their quota they have to purchase credits from other companies which have successfully decreased their emissions and therefore have credits to spare.

11.7 If countries are having difficulty meeting their targets they can use other mechanisms which have the bonus of aiding the developing world to reduce its emissions and increase its technological know-how.

(a) Clean Development Mechanism

"The clean development mechanism (CDM) defined in Article 12 provides for Annex I Parties to implement project activities that reduce emissions in non-Annex I Parties [developing countries]*, in return for certified emission reductions (CERs). The CERs generated by such project activities can be used by Annex I Parties to help meet their emissions targets under the Kyoto Protocol. Article 12 also stresses that such project activities are to assist the developing country host Parties in achieving sustainable development and in contributing to the ultimate objective of the Convention. …*

The CDM is expected to generate investment in developing countries, especially from the private sector, and promote the transfer of environmentally-friendly technologies in that direction."[21]

(b) Joint Implementation Strategy

"The basic principles of the mechanism commonly referred to as "Joint Implementation" are defined in Article 6 of the Kyoto Protocol.

"For the purpose of meeting its commitments …, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy", provided that certain (participation) requirements are fulfilled.

In other words, under JI, an Annex I Party (with a commitment inscribed in Annex B of the Kyoto Protocol) may implement an emission-reducing project or a project that enhances removals by sinks in the territory of another Annex I Party (with a commitment inscribed in Annex B of the Kyoto Protocol) and count the resulting

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[19] *"-gather and share information on greenhouse gas emissions, national policies and best practices*
- launch national strategies for addressing greenhouse gas emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries
- cooperate in preparing for adaptation to the impacts of climate change" (http://unfccc.int/essential_background/convention/items/2627.php)

[20] Annex 1 countries are developed countries who have accepted GHG emission reduction obligations and must submit an annual greenhouse gas inventory.

[21] http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php

emission reduction units (ERUs) towards meeting its own Kyoto target. An Annex I Party may also authorize legal entities to participate in JI projects."[22]

12. Future measures

12.1 In order to meet current targets and the future targets covering the post-Kyoto period (2012 onwards), measures such as widespread carbon taxes (e.g. increased Air Passenger Duty), increased regulation (e.g. building regulations), tighter planning control (e.g. floodplains), and individual carbon allowances are likely to be introduced.

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[22] http://unfccc.int/kyoto_protocol/mechanisms/joint_implementation/items/1674.php