Global Warming: Environmental and Economic effects

Research Paper 95/85

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This paper describes some of the predicted environmental consequences of global warming, and in a separate discussion considers whether it is economically worthwhile trying to mitigate these.

This paper is one of a pair and accompanies Library Research Paper 95/86, *Global Warming: Policy Responses*. Both are designed to complement a Note (Number 61) produced by POST in May 1995, *Global Warming: the state of the science,* which discusses climate modelling.

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Summary

A recent POST Briefing Note (*Global Warming - the State of the Science*, May 1995) summarised the scientific evidence that enhanced global warming, due to human activities, is taking place. This paper describes the environmental and economic effects of global warming and a third paper, *Global Warming: Policy Responses*, Library Research Paper 95/86, will describe the response of the international community.

Section I briefly explains the greenhouse effect, and Section II describes the natural variations that occur in the Earth's climate and discusses how far these can account for the recent warming trend. By the middle of the next century it will probably be clear that this trend is no natural variation but due to man's activities. Section III describes the primary climate change effects which are expected. Temperature will increase almost everywhere, by about 0.2°C per decade. Precipitation will increase at mid and high latitudes, with decreased rainfall in the Tropics. Sea level may rise by about 20cm by 2030, but there will be significant regional variations, requiring improved coastal defences in many countries, and threatening disaster to some low-lying nations. Feedback effects may occur, worsening the situation.

Section IV discusses the effects on habitats and wildlife. Initially, global warming may affect organisms at the edge of their geographical distributions, but problems could arise for ecosystems and species unable to shift their distribution or adapt easily. Extinction rates are likely to rise. Section V considers the effect on UK agriculture, forestry and fishing. Even a small rise in sea levels could cause drainage problems in low-lying land. Temperature increases might change the crops which would best be grown in the UK. Carbon dioxide acts as a crop fertiliser, but the effects are complex, and more fertilisers might be needed to derive benefit from this potential. Some pests will increase. For forestry the effects are also mixed. UK trees could be more damaged by storms or forest fires. On the other hand the trees might grow more quickly in the higher temperatures.

Section VI discusses a range of possible health effects. Although only a tiny number of people are expected to die directly from the heat, there could be a spread of tropical diseases such as malaria (possibly even into the UK) with considerable indirect effects. Section VII discusses the insurance industry's fears of severe losses and asks whether these are justified; there is for instance no clear evidence that the frequency of extreme storms will increase.

Sections VIII and IX demonstrate a paradox, in that the estimates of the environmental effects are normally high, but estimates of the economic consequences are extremely low. In other words, economists argue that the world could absorb the climate changes expected over the next 50-100 years with a negligible loss of output. On this basis, there is no economic case for expensive action now to delay global warming. Possible objections to such arguments are discussed.

CONTENTS

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Global warming: Economic effects[2]

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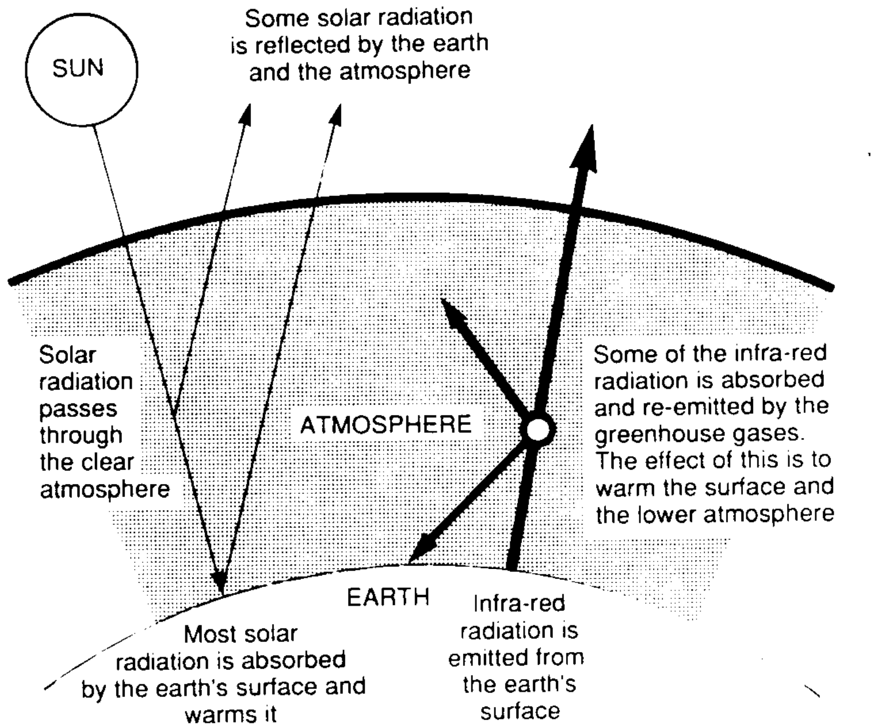
Global warming: Environmental effects

I. Introduction: the Greenhouse effect

The greenhouse effect is essential for life on Earth. Without it, the Earth would be 33°C cooler. It works through 'greenhouse gases' (GHGs) in the atmosphere acting like the glass in a greenhouse.

The glass in a greenhouse allows solar radiation to pass though it. This is then absorbed by the plants and soil, which are warmed and emit longer wavelength thermal radiation, much of which does not pass back out through the glass. Instead, the glass absorbs some of this and then re-emits it, raising the temperature inside the greenhouse. The global greenhouse effect can be represented by a simple diagram[1]:



The main GHGs are water vapour and carbon dioxide, but methane, chlorofluorocarbons (CFCs), nitrous oxide and tropospheric (high level) ozone are also GHGs. Oxygen and nitrogen, the bulk of the air we breathe, do not act as GHGs. Problems arise because mankind's activities are increasing levels of GHGs. It is thought that this might **enhance** the greenhouse effect and lead to increased heat retention or **greenhouse forcing**, with ensuing

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[1]From: *Climate Change 1992* The Supplementary Report to the IPCC Scientific Assessment IPCC WMO/UNEP 1992 p.7

consequences for global climate and sea levels. Further background can be found in Library Research Paper 93/106 and in POST Note 61.

II. Natural climate variation

A. Glacial cycles

The Earth's climate is naturally variable and cyclical, and its recent history has involved a series of 100,000-year glacial/interglacial cycles during which temperature has typically varied by 5-7°C. During the last glacial period, or 'ice-age', massive ice sheets covered much of North America and Scandinavia, and sea levels were about 120m lower than today. The last ice age finished around 10,000 years ago, when we started our present interglacial period, the ice retreated from Britain, and sea levels started to rise. Indeed, Britain was connected to Europe by a land bridge until about 7,000 years ago[2].

It is likely that the glacial cycles are partly driven by changes in the Earth's orbit and rotation, known as Milankovitch effects. (Glacial periods appear associated with times when the Earth's tilt is changing and its orbital path is further away from the sun so that less solar radiation is reaching the Northern hemisphere in summers.)

How do we know about such ancient temperature changes? A record of past climate and atmosphere has been preserved in the ice caps of Antarctica and Greenland. By drilling out cores 2½ kilometres in depth, a record is provided that can extend back 200,000 years. Bubbles of air trapped in the cores are tiny preserved samples of the ancient atmosphere at the time when the ice was deposited. The ratios of different types (isotopes) of oxygen and nitrogen in the ice indicate the surface temperature when the ice was deposited. There has been a strong correlation between temperature and atmospheric carbon dioxide concentration but correlations cannot be used to demonstrate any cause and effect.

On top of the 100,000-year glacial cycles, there have been shorter cooler episodes, such as the so-called 'Little Ice Age' which lasted about 500 years and ended in the 19th century. During this time glaciers advanced in almost all alpine regions worldwide. The climate change associated with such shorter episodes has been less than 1°C.

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[2]Intergovernmental Panel on Climate Change *Climate Change The IPCC Scientific Assessment* WMO/UNEP 1990 pp.201-3

One significant event occurred between 12,000-10,700 years ago and is known as the Younger Dryas event after the spread of an Arctic flower, *Dryas*, which happened at the time. The Earth had been warming up for 6,000 years following its last ice age, when suddenly during the Younger Dryas it swung back into much colder conditions.

At the end of the Younger Dryas it warmed again, and Antarctic ice core records reveal a warming of 7°C in just 50 years, associated with fewer storms and 50% more precipitation. The sudden Younger Dryas event might have been linked to the melting of ice sheets affecting ocean circulation, salinity and surface temperature ('thermohaline' effects).

The Younger Dryas does not seem to have been caused by Milankovitch orbital effects, and its real importance is the possibility that a similar sudden event could occur today, were a change in ocean circulation to be triggered, by perhaps increased precipitation over the North Atlantic during warming caused by GHGs[3]. It is not thought that the present warming will lead to any major outflow of ice in the next century (rather, predicted increases in sea level are expected mostly through thermal expansion of the oceans). Periods of massive iceberg release are known as Heinrich events[4].

Recently, analyses of Greenland ice cores have lead some researchers to conclude that rather than gradual climate transitions, the climate may often have suddenly jumped or 'flipped' from one stable state to another. In such flips average global temperatures may have changed by as much as 7°C in one year. As with the Younger Dryas event, other flips are thought to be linked to changes in ocean circulation[5].

B. Recent warming

Over the past three centuries glaciers have been retreating worldwide, and from about 1910 onwards there has been marked warming (with a lull between 1940 and 1975). Eight of the ten warmest years on record have occurred in the 1980s and 1990s,[6] and 1994 was the 18th consecutive year in which the global mean temperatures at the surface were above the 30-year normal value[7].

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[3]ibid

[4]*Nature* vol 357 25 May 1995 pp 305-8 "Correlation between climate events in the North Atlantic and China during the last glaciation"

[5]*New Scientist* 4 March 1995 p.13 "Arctic Ice shows speed of climate 'flips'"

[6]The Hadley Centre *Modelling climate change 1860-2050* February 1995

[7]World Meterological Office Press Release No. 561 7 March 1995 *WMO issues summary of the state of the global climate during 1994*

Glaciers exist at high altitudes in the Tropics and many have been retreating by many metres a year over the past two decades. At least one (the Meren glacier on Mount Jaya, Indonesia) will probably disappear completely soon. Since the shrinkage of glaciers on Mount Meren does not seem to be linked to a decrease in precipitation or snow, the Australian scientists monitoring the glaciers believe it must be due to an increase in temperature[8].

Scientists have of course considered whether the present warming trend is part of another glacial cycle. For instance, some of the global warming since 1850 could be a recovery from the Little Ice Age[9]. It is difficult to tease apart changes to the greenhouse effect caused by man and those caused by natural climate variations and cycles, and to some extent we will have to wait until the changes due to man-made (anthropogenic) climate change become so large that they unequivocally swamp smaller natural fluctuations. In 1990 the Intergovernmental Panel on Climate Change (IPCC) considered that this would probably not happen for a decade or so[10] (please see section III.B below).

However, the temperature change expected by 2050 is more than double that likely to arise through natural causes[11], and global mean temperatures will be higher by the middle of the next century than they have been in the last 150,000 years[12]; all within 10,000 years of the last glacial period and within a cycle that normally takes 100,000 years.

C. El Niño

El Niño, 'the Christ Child', is so named because it causes a warm sea current to flow along the Peru and Ecuador coasts at Christmas. The phenomenon is far more widespread than this however, and extends along a third of the globe's circumference. El Niño is a cyclical event which occurs every two to six years in the tropical Pacific and is driven by ocean dynamics coupled with atmospheric factors such as trade winds. A large area of warm water is produced extending roughly along the Equator from South America (Chile, Ecuador and Peru coasts) towards Australia. This may persist for a few months or a few years, and there is a cooler counterpart which occurs, known as 'La Niña'.

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[8] *New Scientist* "Meltdown warning as tropical glaciers trickle away" 24 June 1995 p.18
[9] Intergovernmental Panel on Climate Change *Climate Change The IPCC Scientific Assessment* WMO/UNEP 1990 p.203
[10] ibid p.14
[11] The Hadley Centre for Climate Predication and Research *Progress Report 1990-1992*, July 1993 p.4
[12] Intergovernmental Panel on Climate Change *Climate Change The IPCC Scientific Assessment* WMO/UNEP 1990 p.xxviii

The El Niño in 1982-83 was intense, with increased sea surface temperatures of 7°C, causing associated droughts and floods in almost all continents. The El Niño which began in 1990 weakened but increased again in 1993, and floods in central USA, and droughts in Australia and Africa are probably linked to this El Niño. From 1973-1990 maize yield in Zimbabwe fluctuated 'almost exactly' in step with El Niño and the Southern Oscillation (the 'normal' fluctuations in low pressure systems that occur over the Pacific and which cause the monsoons)[13].

Computer models are beginning to be able to model and predict El Niño and associated events. The 1987 El Niño was successfully forecasted, with great benefits to Peruvian agriculture. A good test of computer atmospheric models is to see if they can simulate the climate anomalies caused by El Niño[14].

While it is important to be able to predict El Niño events for their own sake, and they provide useful tests for models, their frequency and intensity are also sometimes quoted as possible indicators of climate change. The current prolonged El Niño has been dominating relative to its cooler counterpart La Niña, with only one La Niña but five El Niños since 1976, including the severe 1982-83 episode. There appears to be little consensus as to whether these changes are indeed real (records are poor) and if so, whether they are due to global warming. Since El Niño itself produces warming, cause and effect are especially difficult to show in this case[15].

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[13] *New Scientist* 4 February 1995 pp 32-5 "El Niño goes critical".
[14] *Global Warming The complete briefing.* John Houghton 1994 p.63
[15] *New Scientist* 4 February 1995 pp 32-5 "El Niño goes critical"

III. Greenhouse forcing

A. The IPCC

The Inter-Governmental Panel on Climate Change or IPCC was established in 1988 under the auspices of the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP). Three working groups were established. Working Group I was to *assess available scientific information on climate change*. The IPCC is widely respected and draws on the expertise of hundreds of scientists worldwide; its reports are scientifically rigorous and can be considered reliable.

In 1990 the Group produced its First Report, *Climate Change The IPCC Scientific Assessment*[16]. This landmark document concluded that temperatures would rise by about 0.3°C per decade (with an uncertainty range of 0.2°C to 0.5°C per decade) based on the assumption that carbon dioxide emissions would continue their current trend (under the "Business As Usual scenario"). This uncertainty range was quite wide but the IPCC makes no apologies for its honesty; in a recent letter to *Nature* the Chairman of the IPCC Sir John Houghton FRS commented that[17]:

> "Regarding contrary opinions, the review process undertaken by IPCC specifically addresses conflicting scientific opinion and ensures that these are properly exposed and represented in the statements of uncertainty..."

The IPCC produced a Supplementary Report in 1992[18]. This "generally confirmed" the 1990 estimates of future warming rates but acknowledged shortcomings in the General Circulation Models (GCMs) or mathematical climate models being used to model climate change. Some of these shortcomings have now been addressed (see below and POST Note 61).

The IPCC produced a Special Report[19] to the first session of the Conference of the Parties to the UN Convention on Climate Change in Berlin, March 1995 (please see the accompanying Library research paper 95/86, *Global Warming: Policy Responses*). This stated that the major

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[16] WMO/UNEP IPCC 1990

[17] "Correspondence: Berlin and global warming policy" *Nature* 18 May 1995 p.176

[18] *Climate Change 1992* The Supplementary Report to the IPCC Scientific Assessment IPCC WMO/UNEP 1992

[19] *Climate Change 1994* Radiative Forcing of Climate Change *and* An Evaluation of the IPCC IS92 Emission Scenarios, IPCC Working Groups I and III, 1995

new findings since 1992 had added to the detail of our knowledge but had not changed "the essential results concerning radiative forcing of climate which appeared in the 1990 or the 1992 IPCC scientific assessments".

The IPCC's next report (its second Full Scientific Assessment) is due out in March/April 1996, by latest estimates[20]. This will be produced by all three Working Groups and will consider, inter alia, the likely impacts of different levels and timetables of GHG stabilisation.

B. Warming

Anthropogenic (man-made) effects on global temperature may be obvious by 2050 but in 1990 the IPCC considered that the unequivocal detection of an enhanced greenhouse effect was not likely for a decade or so[21].

It is worth reiterating often that there is absolutely no doubt that man's activities are increasing the concentrations of greenhouse gases (GHGs) in the atmosphere. For example, human activity has definitely been responsible for the 25% increase in carbon dioxide since the early 19^{th} century[22]. It is also worth noting that the climate change models in use today are increasingly sophisticated and increasingly capable not only of replicating past temperature changes but of predicting future trends.

To summarise, in 1990 the IPCC estimated future warming rates of about 0.3^{o}C per decade (uncertainties ranging from 0.2 to 0.5^{o}C/decade) over the next century, and these estimates were generally confirmed by the IPCC's 1992 reassessment[23]. At the time it was acknowledged that the estimates did not incorporate certain effects, such as those from sulphate aerosols.

'Sulphate aerosols' are simply sulphate particles in the air, produced by sunlight acting on sulphur dioxide. Sulphur dioxide can of course be produced through burning fossil fuels, but it can also be produced by volcanic eruptions. In 1991 Mount Pinatubo ejected 20 million tons of sulphur dioxide, plus huge quantities of dust, into the stratosphere[24]. Sulphate aerosols do not persist for long in the atmosphere because they get washed out by rain when they fall to lower altitudes, and their significance has only recently been fully appreciated. In essence, they stop radiation from the sun reaching the earth, or act as a sunshade. Mount

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[20] *The Newsletter of the Scientific Assessment Working Group of the [IPCC]* No 5 February 1995

[21] Intergovernmental Panel on Climate Change *Climate Change The IPCC Scientific Assessment* WMO/UNEP 1990 pg.14

[22] ibid

[23] IPCC *Climate Change 1992 The supplementary report to The IPCC Scientific Assessment* WMO/UNEP 1992

[24] *Global Warming The complete briefing.* John Houghton 1994 p.15

Pinatubo's eruption produced a cooling of 0.3-0.5°C in the temperature record in 1992[25]. Aerosols, then, have a shading and cooling effect; this includes clouds of dust or smoke produced over industrialised areas acting as parasols.

The most recent model produced early in 1995 by the Bracknell-based Hadley Centre for Climate Predication and Research incorporated aerosol effects and thus produced slightly cooler estimates than previous models. It predicted that average global temperatures would increase at a mean rate of about 0.2°C/decade. The model has been tested using historical data and has successfully reproduced the 0.5°C rise in global average temperatures over the past 130 years (earlier models produced a figure of about 1°C, rather than the 0.5°C actually observed). The Hadley Centre summarises[26]:

> "The experiment was extended to 2050 using a 'non-interventionist' emissions scenario similar to that prepared by the Intergovernmental Panel on Climate Change (IPCC). The model predicts a long-term increase in global temperatures of slightly in excess of 0.2°C/decade, which is probably twice the rate which some of the more sensitive ecosystems can tolerate. When the (cooling) effects of sulphate aerosols are removed, the model predicts a warming of 0.3°C/decade, which is consistent with previous estimates from the IPCC".

Although regional patterns are complex, nearly everywhere is expected to warm.

C. Precipitation

Climate change due to greenhouse forcing is expected to lead to increased precipitation in mid- and high-latitude regions especially in winter, with decreases in precipitation in many parts of the subtropics[27].

A recent study of global rainfall trends over the 20th century used results from 8300 rain gauges in different countries, corrected for uneven distributions of these and patchy records. The study revealed a decline in rainfall in the Northern Hemisphere Tropics, little change in the mid-latitudes (23.4°N-50°N) and an increase in rainfall at high latitudes (above 50°N, which is roughly the latitude of England's south coast). This is roughly in agreement with predictions from climate models, but cannot be taken as proof of these[28].

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[25] *Climate Change 1994* Radiative Forcing of Climate Change *and* An Evaluation of the IPCC IS92 Emission Scenarios, IPCC Working Groups I and III, 1995 p.32
[26] The Hadley Centre *Modelling Climate Change 1860-2050* February 1995
[27] ibid, p.9
[28] *New Scientist* "Rain moves north in the global greenhouse" 4 March 1995 p.18

Consumption of water has risen fourfold in the past 50 years worldwide. Two-thirds of human water use is for irrigation and agriculture. Over 80% of California's agricultural land, for instance, is irrigated. Irrigation can be very wasteful because up to 60% of the water used evapourates and seeps from open irrigation ditches[29]. Another problem is salination; river water can pick up salts from the rocks it passes over and instead of carrying this down to the sea, salt flats can be produced if the water is brought to a standstill and it evaporates. In water logged fields the problem is worse because water does not flush the soils out; salination significantly reduces crop yield in around 30% of the world's irrigated fields, according to UNEP[30].

As temperature rises, more water will evaporate from the Earth's surface. The problem is that this will not be balanced by increased fall-back or precipitation in all areas. Precipitation will increase in some parts of the world and decrease in others, particularly during summers. With more evaporation and less precipitation in some areas, there will be less free surface water or 'run-off'.

Run-off, the water left over after evaporation and take-up by plants, is the main water source readily available for use by humans. As it is, much run-off is used up by man - almost none of the water in the Colorado river, for example, ever reaches the sea. If run-off does not supply adequate water, mankind turns to natural underground water reservoirs (groundwater aquifers). As these get used up faster than they can be replenished the groundwater has to be drawn from deeper and deeper. In Beijing, China, the water table is dropping by 2m a year because groundwater is being pumped out[31].

The National Rivers Authority (NRA)[32] considers that rainfall is its most important climate change parameter. This makes it all the more important that more precise predictions are made for changes in rainfall, particularly on a small (UK) scale (climate models operate on a global, coarse scale of 80,000 km^2 and the land area of the entire UK is only 244,755 km^2). The NRA points out that in general, the more arid a catchment area, the greater will be the effect of changes in rainfall and evaporation on runoff.

Around 40% of the Earth's land surface has low levels of precipitation and when rain does fall it is during brief, erratic, high intensity storms. Over a fifth of the world's population live in such 'drylands'. Already such areas are threatened with desertification through over-intensified use of the soil and natural droughts (the dust bowl years of the USA produced by intensive cotton production provide an example). Around two-thirds of such drylands are in Asia and Africa.

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[29] *Global Warming The complete briefing.* John Houghton 1994 p.100

[30] *The Dammed. Rivers, dams and the coming world water crisis.* Fred Pearce 1992 pp191-4

[31] *Global Warming The complete briefing.* John Houghton 1994 p.100

[32] *The implications of climate change for the National Rivers Authority* Institute of Hydrology R&D Report 12 March 1994 pp22 and 36

As is so often the case when considering global warming, 'feedback effects' may occur. They may be little vegetation in an area because there is little rain, but when an area loses vegetation cover, rainfall may be still further reduced. Such a mechanism was suggested in 1975 by Jules Charney in connection with droughts in the Sahel[33]; an area covered in vegetation absorbs more sunlight and reflects back less: it also produces water vapour through plant 'transpiration' (inside higher plants there is a continual stream of water moving vertically upwards, from uptake at the roots to evaporation at the leaf pores). Finally, land covered with vegetation is rougher (has more ups and downs) than flat, barren land. This roughness in topography, water vapour production and absorption of sunlight energy act together to set up air [convection] currents and to produce rainfall. To summarise, deforestation leads to reduced rainfall; more plant cover means more rainfall.

D. Sea level

Under the IPCC 'Business-As-Usual' scenario, an average rate of global mean sea level rise of around 6cm per decade is estimated over the next century (uncertainty range 3-10cm per decade), mainly due to thermal expansion of the oceans and the melting of some land ice. By 2030 global mean sea level is estimated to rise by about 20cm, with a rise of about 65cm by 2100.

Meltwater contributions from the Greenland and Antarctic ice sheets are expected to be small and it is not likely that there will be any major outflow of ice from Antarctica due to global warming in the next century[34] (recent calving of icebergs from floating peninsular Antarctic ice sheets is considered to be due to a regional warming and has not involved the main land-based ice mass[35]), but the behaviour of the ice sheets does contribute to the uncertainties in calculated sea level rise. For example, the polar ice caps currently reflect much of the incoming solar radiation rather than absorbing it. But were the temperature of the Earth to rise and the ice caps to melt, more solar radiation would be absorbed by the darker-coloured land revealed by the melting ice, creating even more warming. Elsewhere, any thawing of the permafrost, releasing methane, a potent GHG, could lead to a similar increase in the rate of warming. Recent work[36] suggests that methane hydrate is stored in the permafrost much nearer the surface than previously thought, thus increasing the likelihood of thawing. These are further examples of feedback effects.

It is important to note that sea level rise will continue to occur for a while even after GHG concentrations are stabilised; the system has great momentum. For instance, even if we stabilised GHG emissions by 2030 and thus stopped greenhouse forcing, the slowness of ice

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[33] *Global Warming The complete briefing.* John Houghton 1994 p.101
[34] Intergovernmental Panel on Climate Change *Climate Change The IPCC Scientific Assessment* WMO/UNEP 1990 p.xxx
[35] for example, "Scientists keep cool over giant iceberg" *Sunday Telegraph* 26 March 1995 p.19
[36] "Shallow methane could turn on the heat" *New Scientist*, 8 July 1995

mass, ocean and climate responses would mean that sea levels would continue to rise until 2100, by as much again as they had from 1990 to 2030[37].

Another important point is that a 20cm rise by 2030 or 65cm by 2100 would not be spread evenly across the globe. Factors such as surface atmospheric pressure and thermal expansion of the oceans would cause local variations. In addition, continents are independently moving, uplifting, sinking and colliding because of natural geological processes: they are not fixed in position but they can 'drift' and collide with each other.

1. Adjusting for tectonic movements

During the last glacial or 'ice-age', a massive weight of ice pressed down on the north of Britain for longer than it did in the south. With the retreat of the ice at the start of the interglacial (about 10,000 years ago) this weight was removed; natural geological movements mean that Scotland and parts of northern England and Wales are slowly rising in 'rebound' and the south and east of England are correspondingly slowly sinking at a rate of about 1-2mm per year[38].

The estimated global mean sea level rise of about 20cm by 2030, which is broadly applicable to Britain[39], thus has to be adjusted for natural ongoing vertical land movements.

The NRA, MAFF and Welsh Office allow for sea level rise in determining the design of sea defences. By working out net sea level rise estimates after vertical land movements are allowed for, defences can (where cost justified) be designed to be made higher without having to be completely rebuilt[40], if sea level rises do occur in the future.

While around the globe continents are uplifting or sinking, for various geological reasons, on a smaller, local scale, many river deltas are sinking because of reduced sediment deposition and increased erosion (please see next section).

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[37]Intergovernmental Panel on Climate Change *Climate Change The IPCC Scientific Assessment* WMO/UNEP 1990 p.xxx

[38]*Strategy for flood and coastal defence in England and Wales*, MAFF October 1993 deposited paper 9700

[39]*The Potential Effects of Climate Change in the United Kingdom*, UK Climate Change Impacts Review Group first report for the DoE, January 1991

[40] *NRA Sea Defence Survey* p.6 (undated)

2. Coastal defence

Coastal defences in Britain have been erected and strengthened with renewed purpose since the floods along the east coast of Britain claimed over 300 lives in 1953. The economic cost of the 1953 east coast flooding has been estimated at £900m at 1989 prices[41].

Approximately 8000km^2 of land in England and Wales already lies within 5m of present sea level, so Britain already relies to a great effect on sea defence and land drainage. Some of the low-lying areas that are particularly susceptible to sea level rise are the coasts of East Anglia, Lancashire and Yorkshire/Lincolnshire, the Essex mudflats, Sussex coastal towns, the Thames estuary, parts of the North Wales coast, the Clyde/Forth estuaries and Belfast Lough[42].

Many areas at risk are conurbations or high grade agricultural land, and many road, rail and other communications systems run along the coast. All UK oil refineries, and power stations representing around half of the UK's generating capacity, are situated on the sea or in lower estuary areas. With the switch to gas, the need for cooling water is less pronounced in modern plants, so in the future fewer power stations may be situated on rivers or coasts, but oil refineries are likely to stay in such locations[43].

MAFF (the Welsh Office in Wales) has overall responsibility for flood defence and coastal protection in England[44]. The planning, design, construction and maintenance of defences is carried out by the National Rivers Authority (NRA; soon to be included in the Environment Agency), Internal Drainage Boards (IDBs) and local authorities, who, using their local knowledge, identify the need for defences. The NRA deals with designated main rivers and the coasts while the IDBs deal more with inland flooding. MAFF administers grant aid for capital defence schemes. New or improved flood warning schemes and coast/flood defence measures must meet given national criteria; they must be environmentally acceptable, technically sound and economically worthwhile. In 1990/91 MAFF gave out £40m in capital grants and £63m was planned for 1993/4, supporting about 250 new schemes per year[45].

In formulating policy, MAFF places the highest priorities on the saving of lives, so stresses that urban areas should be given high levels of protection, with flood warning systems[46]. However, modern coastal defence practice is moving where possible towards using 'softer'

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[41] *The Potential Effects of Climate Change in the United Kingdom*, UK Climate Change Impacts Review Group first report for the DoE, January 1991 p.49
[42] ibid
[43] *The Potential Effects of Climate Change in the United Kingdom*, UK Climate Change Impacts Review Group first report for the DoE, January 1991 pp. 69 and 49
[44] *Strategy for Flood and Coastal Defence in England and Wales* MAFF, September 1993, deposited paper 9700
[45] ibid p.19
[46] DOE Planning Policy Guidance Note 20 (PPG20), *Coastal Planning*

defences which make use of, rather than always fighting, the natural processes of erosion, transportation, deposition and consolidation occurring on the coast[47].

Coastal defence groups consisting of the NRA, local authorities and other, voluntary, bodies come together regularly in a national Coastal Defence Forum organised by MAFF and the DoE, with the aim of reaching a strategic approach and spreading good practice. In 1992 an Advisory Panel on Flood and Coastal Defence R&D[48] was set up to advise MAFF and the NRA on future R&D in coastal flood and defence priorities[49].

As long ago as 1988 it was reported that Thames Water had decided that the Thames Barrier, which cost £500m to build and which opened in 1984, could be breached as early as the middle of the next century during storm surges (which could increase in frequency with rising sea levels) and might need to be modified[50]; the need for ongoing assessment and review of the viability of the Barrier has been reiterated since then[51]. An NRA spokesman has said that the barrier was partially constructed before greenhouse forcing was considered a problem but the chances of the barrier being breached should sea level rise by 30cm was only '1 in 1000'[52].

Elsewhere in the world it will not always be feasible economically and practically to defend the coasts. In Bangladesh the coastline, where most of the population is concentrated, is that of a complex river delta with many mouths and channels. As well as rising sea levels, there is an added problem because low river flows mean that less sediment is being carried down from upriver, to be deposited at the delta. With time then the delta is eroded by the sea while not being replaced and built up by deposition. The net effect is a sinking of the delta, to exacerbate the problems of sea level rise. The best hope of protection may be to manage sediment deposition at the delta through action upstream, and to protect groundwaters, again by river management.

71% of Bangladesh is less than 1m above present sea level and 25% of the land - and 30 million of its population - is less than 3m above sea level. Global warming effects combined with subsidence mean that sea levels may rise by 2m by 2100. Since the most fertile land is most densely populated and the lowest-lying, this could have severe effects on Bangladesh's agriculture and thus economy - 85% of the population rely on agriculture as a livelihood. Even if land is not directly covered by seawater the effects of seawater incursion may be severe: at the moment it is thought that saltwater travels inland over 150km at some times of

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[47]e.g. *Coastal defence and the environment A guide to good practice* MAFF PB 1191 1993

[48]*Report of the Advisory Committee* MAFF/SO/NRA PB 0846 1992

[49]NRA *Flood Defence Strategy* 1993

[50]"Global warming could breach Thames Barrier" *New Scientist* 14 July 1988

[51]"Why global warming could take Britain by storm..." *New Scientist* 7 November 1992 and *The Potential Effects of Climate Change in the United Kingdom*, First Report of Climate Change impacts Review Group, DoE January 1991 p.50

[52]"Letter: Barrier methods" *New Scientist* 28 July 1990

year. The area covered by saltwater intrusion could double with a 1m sea level rise. As well as ruining agricultural land this would severely affect drinking water supplies[53].

Similarly, at the Nile Delta in Egypt around 12% of the country's arable land and 7m people would be affected by a 1m sea level rise. In eastern China a 0.5m sea level rise would affect an area the size of the Netherlands and over 30m people[54].

In the Netherlands dykes and sand dunes will have to be raised (embracing the ideas of using as natural or 'soft' a type of protection as possible) and pumping will be needed to stop saltwater incursion into freshwater. To protect against a 1m sea level rise it has been estimated that it will cost around $10,000 million[55].

At the First Meeting of the Parties to the UN Climate Change Convention in Berlin this March (see the accompanying Library research paper *Global warming: Policy responses*) the nations pressing for the most drastic measures, of a 20% decrease in carbon dioxide emissions by 2005, were those in the Association of Small Island States (AOSIS). This association of around 40 states was motivated at least in part by self-preservation. The Maldives consist of 1190 small islands, 50% of whose land would be inundated by a 2m rise in sea levels, and almost all of the Marshall Islands lie within 3m of sea level. Half a million people live on small islands and atolls. Many of the AOSIS states (which include Barbados, Antigua, Belize, Dominica, Grenada, Jamaica, St Lucia, Trinidad and Tobago, Comoros, Seychelles, Mauritius, Fiji, Papua New Guinea and Tonga) are at risk of losing valuable coastal land and centres of population[56].

IV. Habitats and Wildlife

A. Coastal ecosystems

Rising sea levels in the UK would affect many ecologically important landscapes: around 10% of National Nature Reserves and Sites of Special Scientific Interest occur near sea level on the coast[57].

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[53] John Houghton *Global Warming The Complete Briefing* pp93-4
[54] ibid
[55] ibid p.95
[56] *Guardian* 25 March 1995
[57] *The Potential Effects of Climate Change in the United Kingdom*, First Report of Climate Change impacts Review Group, DoE January 1991 p.33

Low and intertidal mudflats and saltmarshes would be among the natural habitats most affected by sea level rises. Both are habitats which support a highly-adapted range of flora and fauna; in other words, organisms that cannot live anywhere else, like some of the plants which live on saltmarsh. Mudflats may look unproductive to the unappreciative eye but in fact they are home to vast numbers of invertebrates (animals without backbones) and algae and these in turn help support the high numbers of birds which rely on coastal habitats.

For instance, over half of Europe's waders overwinter on UK coasts and 60% of redshank nest in saltmarsh[58]. The loss of nature reserves on coastlines in East Anglia and elsewhere could result in severe losses of other species including the brent and bean goose and the curlew[59].

The RSPB has calculated that rising sea levels as a result of climate change could affect between 22 and 26 UK Red Data Book (RDB) bird species. RDBs list species believed to be under threat of extinction. The RSBP stresses that wintering birds and waders are at risk especially on estuaries where there are hard sea defences, and add that a number of tern and gull species could lose the islands on which they breed[60].

The most recent Special Protection Areas for birds under the EC Birds Directive and Wetlands of International Importance under the Ramsar Convention to be announced have comprised saltmarsh, grazing marsh and mudflats on the Essex coast (the Blackwater Estuary and the River Crouch Marshes)[61]. In one study, it has been predicted that a sea level rise of 0.8m would cause almost complete loss of 'general saltmarsh' in one area of the Essex marshes (general saltmarsh is the zone characterised by sea lavender, sea meadow grass and sea purslane). On the Norfolk coast inundation of dunes (incursion by sea water into freshwater lagoons) would endanger plants in National Nature Reserves; the Norfolk Broad system could be damaged by seawater incursion changing salinity[62].

Around the world, coastal ecosystems are in the 'front line' of sea level rise. The problem is particularly bad because coastal habitats are often fragile and in a state of equilibrium which is easily upset. They are often bounded inland by buildings or by hard coastal defences, which stop them retreating, and they contain many species which are specially adapted and which can live nowhere else. Any losses from global warming would be occurring on top of those which have already happened because coastal areas have already been extensively developed by man, either for coastal defence, tourism or urban development. For instance, over 90% of wetlands have been destroyed already in California, New Zealand and Italy, and at least three quarters of mangroves in India, Pakistan and Thailand have been lost[63].

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[58] ibid

[59] *Some like it hot. Climate change biodiversity and the survival of species.* WWF International, 1993

[60] *The vital spark. The RSPB's policy on energy and biodiversity* RSPB 1994

[61] DoE News Releases No 143, 24 March 1995 and No 222, 12 May 1995

[62]*Some like it hot. Climate change biodiversity and the survival of species.* WWF International, 1993 p.29

[63]World Watch Paper 108 *Life Support: Conserving Biological Diversity*, Worldwatch Institute, April 1992

The threats to the Bangladesh and Nile river delta systems from subsidence and reduced sediment deposition were described in the above section. The Mississippi delta contains 41% of the coastal wetlands of the USA, and is already believed to be disappearing at around 40 ha a day. The problems presently facing the delta include subsidence, and up-river damming and flood control, which reduce sediment deposition, but global warming adds a further threat to the area. Under current warming scenarios it had been suggested that 39% of the Mississippi delta could disappear by 2100.

The east and Gulf US States could lose 11% of their coastal wetlands in all. Several species there live only on the lower shore and saltmarsh, including the loggerhead sea turtle, northern brown snake, Dukes salt marsh vole and plants such as the sensitive joint vetch. The World Resources Institute in the US has drawn up a list of 79 rare, threatened or endangered species which live only within 3m of sea level. Similar lists have been drawn up in New Zealand, the Netherlands and Australia.

To examine just one coastal ecosystem in detail, mangroves are a group of 34 tree species which are uniquely adapted to grow at the interface of the land and sea. They need sheltered shorelines where sediment can accumulate and they also need an inflow of freshwater to keep salinity in check. Many rare species (such as terrapins, turtles and the Bengal tiger) find protection in mangroves.

Sea level rise and changes in sediment deposition, salinity, rainfall, temperature and storm occurrence will affect mangroves around the world in different ways. Low island and coral coast mangroves may be most susceptible. The key factor will be whether build-up or elevation through sedimentation can keep pace with sinking through sea level rise. In the Bengal delta of Bangladesh, sea level rise is already exacerbated by the sinking of the delta itself (see above) at a rate of 1 cm per year - an order of magnitude higher than scientists think mangroves can keep up with. Mangroves there, including the Sunderbans forest, which is the main stronghold for the critically endangered Bengal tiger, are under severe threat[64].

B. Terrestrial species

The Institute of Terrestrial Ecology (ITE) has produced *Climate Change and rare species in Britain*, for Nuclear Electric plc[65]. This started off with records of present distribution for the UK's 251 Red Data Book (RDB) species. Altered geographical distributions were calculated for each species, under five different climate change scenarios, all of which involved an increase in mean temperature. A complex picture emerges.

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[64] *Some like it hot,* WWF International 1993 pp 35-37
[65] ITE Research Publications no.8, HMSO 1994

23% of the UK's RDB species were thought unlikely to be affected by the climate change scenarios. These included species with widespread distributions, such as the high brown fritillary butterfly and penny-royal plant.

47% would be threatened by a significant increase in rainfall. These included species presently confirmed to dry or continental east or southeastern parts of the UK, such as the lizard orchid, acrid lobelia and red helleborine plants, and Glanville fritillary and black hairstreak butterflies.

30% would be threatened by a significant decrease in rainfall. These included species presently confined to the humid north and humid southwest. Humid northern species, such as the Alpine Woodsia fern, and the tufted and marsh saxifrages, would also be adversely affected by warmer winters. Humid southwestern plant species, such as the sea knotgrass and western ramping fumitory, would be able to cope with warmer but not drier conditions.

Some of the RDB species which are presently confined to continental areas of the UK would be adversely affected by an increase in rainfall, but could become 'winners' if the climate became significantly hotter and drier. These include, for example, species which are presently at the northern edge of their range in the UK. However, there are major problems with such potential winners being able to take advantage of their situation, mainly because of lack of suitable habitat.

For example, the Adonis blue butterfly presently lives mainly on south-facing, well grazed hillside. It would be favoured by a hotter and drier climate, but since much flower-rich grazed grassland lower down the slopes has been ploughed or 'enriched' by fertiliser there would be nowhere for the species to expand into, so it would probably remain restricted to its south-facing slopes. In hotter and drier weather these sites would be prone to drought and populations of the butterfly could actually crash; suffering, not benefitting, from the hotter and drier weather[66]. The large blue butterfly faces very similar problems- it needs grazed short turf sites since it lays its eggs on the common thyme. Such sites are few and far between and, again, subject to drought.

Although rainfall patterns emerge as a crucial factor, this study illustrates the complexity of responses of species to climate change, and the vital importance of understanding species' precise habitat and climate requirements at present. It is believed that the immediate effect of predicted climate change will be to increase extinction rate, because although species have moved geographical range or adapted in the past to climate changes, the present changes would be happening on a very short timescale (although there is some evidence that climate has on previous occasions 'flipped' quickly, as described in section II.A). Some non-mobile and restricted species will not be able to move rapidly enough into new habitat or the habitat may not be available (for example, many arctic and alpine RDB species would have to go

[66]ibid, p.24

higher up their mountains, which might simply not be high enough) and many may be lost from Britain.

Decisions could be made to translocate species but this could only be done if suitable habitat were available. Difficult decisions might have to be made about mainland European species, not endemic to the UK, whose ranges might expand northwards with climate change (as the UK becomes warmer). Endangered species presently living in France might in the future be able to thrive in Southern Britain[67]
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There has already been some evidence that the UK's wildlife is responding to climate change. The British Trust for Ornithology has concluded in a draft report that between 1962 and 1993, 11 common birds started breeding or nesting progressively earlier. As well as this, magpies for instance have started producing larger brood sizes, with almost 1 extra chick on average per brood since 1974; the wren, robin, swallow, sparrowhawk, kestrel, barn owl, redstart and nuthatch have shown similar trends[68].

One recently published study examined the breeding behaviour of amphibians over the last 17 years at two sites in Southern England. The Natterjack toad and edible frog (which is not in fact a natural UK species) were found to have been spawning progressively earlier since 1974. On average, they spawned 2 and 3 weeks earlier respectively in 1990-1994 than they had in 1978-1982. Three species of newt, including the great crested newt, were found to have been arriving earlier at breeding ponds since 1974. By 1990-94 the first adult newts were arriving on average 5-7 weeks earlier than they had done in 1978-1982[69].

Over such a short timescale, these changes will be individual behavioral adaptations, not the result of natural selection or evolution. Thus they are indicators of temperature change and cannot be taken as long term responses to climate change. It is relatively simple for a bird or frog or newt to alter its behaviour and breeding patterns (egg and sperm production in amphibians is temperature dependent for instance). However, for less flexible aspects of behaviour and physiology, or for immobile organisms or entire ecosystems there may be more of a problem.

The IPCC calculated that an increase in temperature of around 1°C/decade was probably the maximum rate of increase that many ecosystems could tolerate. An increase of 0.2°C/decade (which is the warming rate most recently predicted by the Hadley Centre; see section III.B) would be likely to exceed the adaptive capacity of many ecosystems. Equating temperature change with latitude, this would imply a need to 'migrate' up to 10km each year to maintain

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[67]ibid, p.27
[68] *Daily Telegraph* 25 March 1995 "Global Warming theory given fresh impetus"
[69]"Amphibian breeding and climate" *Nature* vol.374 16 March 1995 p.219

climatic position; the Hadley Centre[70] considers that 'many species (particularly less mobile species) are unlikely to cope with this pace of change', implying at least local extinctions.

C. Marine organisms

Warming effects are not limited to land-based organisms, of course. Plankton are the tiny organisms that live suspended in water and drift passively with the currents. Phytoplankton are tiny plants, mostly diatoms (a type of alga) which photosynthesise (harness the energy from the sun to convert carbon dioxide into oxygen and organic compounds) and thus form the basis of aquatic food webs. Zooplankton are the tiny animals that feed on the phytoplankton and they themselves provide food for 'higher' animals such as fish.

Scientists at the Scripps Institute of Oceanography in San Diego have reported a 'plankton hole' off the coast of California. This has developed since 1951 and over the same time the ocean surface layer temperature has increased by around 1.5°C. The warming is thought to have caused stratification of ocean layers. Warmer water on the top layers not mixing with cooler water below has cut off the supply of nutrients from the lower layers to the phytoplankton in the upper layers. This in turn has reduced the numbers of zooplankton, and the numbers of birds which feed on the zooplankton such as sooty shearwaters, which are also depleted in the area. The researchers believe that similar plankton depletion may have occurred elsewhere in the Pacific.

One major fear is that if warming increases stratification and decreases plankton growth in the oceans, this may decrease the amount of CO_2 absorbed by the oceans, causing a positive feedback effect and amplifying temperature increases. Between 20-40% of anthropogenic CO_2 is currently absorbed by the oceans and plankton[71].

Iron may be a limiting factor on algal growth in parts of the oceans. A recent British-US experiment 'fertilised' a patch of ocean between the Galapagos and Tahiti with iron, boosting the growth of algae and increasing drawdown of carbon dioxide from the atmosphere to replace that consumed from the ocean in algal growth. This should not raise hopes of an easy 'technical fix' to global warming however; the outcome of such experiments is unpredictable (depending on the type of algae present; a similar experiment first tried last year failed) and algal blooms can be deleterious to other forms of marine life. Nevertheless, some scientists fear that the results may encourage 'eco-engineers' to try to repeat the experiment on a large scale[72].

Along the shoreline of Monterey Bay, California, although the water temperature has risen by just 0.75°C since 1931-33 there has been a marked change in the mosaic of species present (as is so often the case, cause and effect cannot be proven). 8 out of 9 'southern' species

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[70] *Modelling Climate Change 1860-2050,* February 1995 p.11
[71] "Pacific Plankton go missing" *New Scientist* 8 April 1994 p.5
[72] "Iron soup feeds algal appetite for carbon dioxide" *New Scientist* 1 July 1995 p.5

(which do not flourish much north of Monterey Bay) have increased in abundance, and 5 out of 8 northerly distributed species have decreased, while organisms with wider distributions have shown less change. Algal types have also changed[73].

D. Summary

At first then, global warming may affect most noticeably organisms at the edges or extremes of their geographical distributions, and may cause a shift in these distributions, or in species' abundance. It may also affect the more flexible aspects of behaviour, such as timing of breeding. Problems may occur with organsims that cannot shift their distribution easily (perhaps because they are sedentary, or because there is not suitable habitat to move into, such as with the Adonis and large blue butterflies in the UK). There may also be particular difficulties for organisms which cannot adapt their behaviour or physiology or distribution quickly enough, perhaps because little flexibility is 'built in' and changes have to be brought about by natural selection (the slow evolutionary process). Organisms which occur in isolated pockets or in ecosystems which are particularly at risk (many coastal habitats, for example) and organisms which are already highly adapted to a particular, extreme type of climate or habitat may be particularly at risk.

As ecosystems are affected, feedback effects may occur which exacerbate the warming. For instance, loss of marine algae may reduce the oceans' ability to absorb carbon dioxide, and deforestation may lead to less rainfall in an area. Overall however, we are simply not able to predict precisely the changes that will be brought about in terrestrial and marine ecosystems by changes in complex interacting climatic and physical systems.

V. UK agriculture, forestry and fisheries

A. Agriculture

1. Sea level rise

A good deal of agricultural land will be at risk particularly from any sea level rise, because in general, river flood plains and low lying land are more fertile than uplands (rivers tend to pick-up soil loads upstream and dump these and organic matter downstream when in flood or where the current slackens). Thus 52% of England and Wales' agricultural land, including nearly all Grade 1 agricultural land, is dependent on drainage in some way[74]. 8% of Grade

[73] "California coastline begins to feel the heat" *New Scientist* 18.2.95 p.14
[74] *Strategy for flood and coastal defence in England and Wales,* MAFF October 1993 deposited paper 9700

1-3 agricultural land in England and Wales is within 5m of present sea level and thus vulnerable with respect to the sea level rise.

Increasing flood frequency and a higher water level may downgrade Grade 1 land by at least 2 grades; reduction in productivity could cost around £25m[75] for winter wheat and £55m for sugar beet, for instance[76].

A sea level rise of 20cm by 2030 would have three main effects on UK soils:

- some marsh soils will be permanently flooded and new, acidic, anaerobic poorly drained marshland will be formed
- river levees will increase in height, making existing land drainage systems ineffective
- soils will become more saline, through direct seawater seepage and via groundwater penetration. Salt-tolerant plants only may be able to grow, concrete and metal structures (cables, pipelines, pylons) might need extra protection, and saline soils, which have poor soil structure, might need extra agricultural management.

2. Temperature

Temperature is probably the most critical factor affecting UK agriculture; it is the strongest factor affecting development of annual crops and the main limiting factor on the productivity of sown perennial grassland. The last frosts of Spring and first frosts of Autumn delineate the growing seasons of crops such as potatoes and tender horticultural crops[77].

Warmer temperatures would decrease the yield of 'determinate crops' such as cereals by making them rush through their stages of development (flowering, ripening and so on), so taking less time to absorb light, photosynthesise and produce a higher yield. Winter wheat yields decrease by about 6% for each 1°C rise in temperature. However, 'indeterminate crops' such as potatoes, sugar beet and grass just keep growing so long as the temperature remains suitable, so yields of these would increase with temperature as growing season lengthened; a 2°C rise in temperature alone might increase potato yields by 15-25%. However, potato virus diseases might also increase and there might no longer be virus-free areas for seed potato production in warmer climates (see also section 4 below). As temperatures increase it may be possible to introduce new crops to Britain, such as sunflower and grain maize, which presently grow on the continent[78].

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[75]Gross Margins: 1990 estimates
[76] *The Potential Effects of Climate Change in the United Kingdom*, UK Climate Change Impacts Review Group first report for the DoE, January 1991 p23
[77]ibid, pp.38-41
[78]ibid

3. Carbon dioxide as a crop fertiliser

As well as being a GHG, carbon dioxide is of course essential for plant growth - during photosynthesis carbon dioxide is taken in from the atmosphere and its carbon converted to sugars and carbohydrates; the plant 'breathes out' oxygen. Experimental evidence is suggesting that CO_2 can thus act as an 'aerial fertilizer' - higher concentrations in the air leading to faster growing and higher yielding plants, at least in unnatural agricultural situations.

The effects of increased CO_2 levels on natural ecosystems is not at all well understood, however. Not all plants metabolise carbon in the same way; under high CO_2 conditions American beech seedlings have been found to nearly double their biomass (weight) but white pine seedlings only increased by 20%.

Many important agricultural plants (such as wheat and rice) belong to the type of plant ('C3 plants') that could benefit most from high CO_2 levels. Expensive, large scale field experiments, pumping CO_2 into crop fields, have indicated increases in cotton yields of as much as 50%, and 10% increases in wheat yields; 'very good news for agriculture', in the words of one US researcher[79].

Of course, things are not so simple. If CO_2 boosts growth, more fertilizers may be needed to be added to capitalise on this, or else lack of other nutrients may limit plant growth; fertiliser is expensive and beyond the means of many developing nations.

CO_2 enriched air will also encourage insects and weeds, and some important crops (such as sugar-cane and corn) belong to the type of plant ('C4 plants') that will not benefit so much from increased CO_2. Plants growing in higher concentrations of CO_2 may produce poorer quality forage for animals, because they have less concentrated nitrogen in their leaves.

In natural ecosystems, there is some evidence that plants may 'acclimatise' to enhanced CO_2 levels, so there are no long-term beneficial effects. Although there is some argument, it is thought that this is because, unlike crops (where water, nutrients and fertiliser can be added), plants in natural ecosystems are ultimately limited by other factors, such as light, water and nitrogen or other nutrients[80].

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[79] "Will Plants Profit from high CO_2?" *Science* vol. 268, 5 May 1995 p.654
[80] ibid

4. Pests

The World Wide Fund for Nature (WWF) considers that 'winners' from global warming are likely to be highly adaptable, rapidly reproducing colonisers, which are 'probably already common and may be pests in some areas'[81].

Examples of invasive plant species in the UK are Japanese knotweed and rhododendrons; climate change is likely to further favour these by reducing the vitality of native plants, especially those which are less opportunistic, and increasing fragmentation of vegetation[82].

Bacterial and fungal plant diseases are directly affected by changes in temperature and humidity, and they are indirectly affected by changes in the susceptibility of host plants. In the mild winter of 1988/89, when average temperatures were 2.5-3^{o}C warmer than average, rust and mildew diseases of crops were widespread.

The mild conditions of 1988-89 favoured the pests but also favoured weed and other plants growing throughout the winter, providing a 'green bridge' on which the pathogens could thrive before infecting new spring crops. Insect pests, such as aphids (the main carriers of plant viral diseases) are also harboured by such 'green bridges'.

A strong correlation exists between mean winter temperature and the number of aphids trapped in the spring, and also the date on which they are first trapped, each year. In other words, warmer winters mean more pests, appearing earlier. Opportunistic weeds are able to quickly take advantage of mild winters. Extra weed control might be needed in future if winters were milder and frost did not help kill off herbicide-treated weeds.

Some potentially serious pests such as the Colorado beetle (potatoes) European ground beetle (cereal crops) and rhizomania (sugar beet) could become more widespread if temperatures increased, since they are presently thought to be temperature-limited[83].

B. UK Forestry

Some native broadleaved tree species and native Scots pine might not be able to withstand temperature increases of more than 2^{o}C. Some such species also need winter chilling to start their seeds developing. Commercial forests might need to be restocked with different species but more native or exotic broadleaved tree species could be introduced or planted throughout the UK.

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[81] *Some like it hot,* WWF International 1993 p. 107
[82] ibid p. 72
[83] *The Potential Effect of Climate Change in the United Kingdom*, DoE January 1991 p.42

However, UK forests are susceptible to high windspeeds and great storms. A major constraint on forestry in upland areas is always the risk of windthrow. To overcome such risks trees need to be planted closer together and felled before they reach an optimum height; this need would increase should storm frequency or wind speeds increase (although there is as yet no proof that this will happen -see section VII.A.).

If hot dry summers such as 1976 and 1990 increased in frequency, in southern Britain there might be an increased likelihood of major forest fires.

Leaving aside wind damage, pests and forests fires, however, a 1-2^{o}C rise in temperature would probably enhance forest growth, especially in the uplands, provided rainfall was adequate. (Sitka spruce in particular needs humid conditions.) Hot dry summers combined with air pollution can damage tree health; a lot depends on the amount of stress (water and nutrient deficiencies) trees are under to begin with[84].

C. UK Fisheries

The National Rivers Authority (NRA) has produced a report on climate change[85] and one chapter considers fisheries. Most UK species are expected to be little affected although the native brown trout and grayling are thought most at risk among river species. Trout growth rate would be much slower - at higher temperature they would need large amounts of food because their metabolic rate increases; in practice this would lead to smaller trout, less able to survive the winter. Many sport fisheries could be lost. The charr and whitefish might be most affected among lake fish. Rainbow trout populations might increase, possibly at the expense of native Salmonids.

Fish diseases might increase - common carp deaths are highest in the warmest months from abdominal dropsy. However, some fungal infections might decrease because fishes' immune responses work better at higher temperatures.

As the UK warms, summer droughts and lower river flows may lead to a water quality deterioration and more frequent fish kills. Invertebrates, which are an important fish food source, might alter in distribution along rivers. Exotic (foreign) fish species might become established or better established in UK rivers. The rainbow trout is probably the most important alien species that could benefit from climate change, but the zander, which has become established in a few English lowland rivers and is a voracious predator, might be able to spread.

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[84]ibid

[85] *The implications of Climate Change for the [NRA]* Institute of Hydrology R&D report 12, March 1994

The effect of climate change on fish migration patterns would probably be very complex. North Atlantic circulation and temperature patterns might affect salmon migratory routes and thus salmon abundance in UK rivers. Reductions in river flow regimes might delay migrations and run-times.

VI. Health Effects

A. Direct effects

In his recent book *Small is stupid*[86] Beckerman writes that 'one simple piece of evidence' proves that 'alarm over the predicted effects of global warming is vastly exaggerated'. The argument is that humans live in a wide band of temperatures across the globe, and moreover that in the past Huns, Vandals, Romans, North American settlers and others have migrated into drastically changed local climates, greater than the changes that will occur under global warming.

A World Health Organisation (WHO) Task Group pointed out in 1990 that human beings can live in virtually every climate on earth and cope with extremes much better than any other species[87]. The impact of climatic stress would depend on the ability and willingness of a population to accept change: a vast number of expensive and sacrificial adjustments might need to be made.

However, while populations as a whole might be able to adapt, the WHO report says that individuals with low adaptive capacity (with perhaps cardiovascular, respiratory, renal, endocrine or immune deficiencies) would be first to suffer, along with those with immature or reduced regulatory systems, such as the elderly, infants and physically handicapped.

The effect of climate stress (the increase in morbidity and mortality from non-communicable diseases) on a population would depend on the frequency distribution [number and concentration in a population] of such vulnerable groups.

The WHO considers that although global warming will exert a 'minor deleterious thermal stress on populations', adaptation to heat stress will readily occur with prolonged and gradual warming. However, extreme variations and rapid thermal changes (especially in densely populated urban areas and at low latitudes) will carry an increased risk of heat-related disorders[88].

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[86] *Small is stupid. Blowing the whistle on the greens,* 1995 p.90
[87] *Potential Effects of Climate Change* Report of a WHO Task Force. WHO 1990 p.16
[88] ibid

Climatologists at the University of Delaware have developed computer models showing how global warming-induced hot spells might affect mortality in urban centres during summers. With global warming of 2-4°C, the model predicts the number of heat-related deaths per summer will rise, from 320 to 880 a year in New York, from 84 to 824 in Los Angeles and from 281 to 1125 in Cairo. Mitigating factors such as air-conditioning might be expected to lower the rate by 25-30%, but not in cities such as Cairo[89]. (Heat disorders include loss of fluid balance and dehydration, salt depletion, health exhaustion syndromes and heat stroke and, perhaps most importantly in unacclimatised people in cities and urban areas, increased cardiovascular strain.)

The CFCs which are partly responsible for high-level ozone depletion are also greenhouse gases. Thus although ozone depletion and greenhouse forcing can be considered as separate phenomena, they are interlinked climate change processes. Effects of ozone depletion (which tend to be more direct than those of greenhouse forcing) are generally included in considerations of health effects of climate change.

The main concern is of course the increase in ultraviolet (UV) radiation that could reach the Earth's surface. The main consequences may include; increases in non-melanoma and malignant melanoma skin cancer, possible alterations in the immune response, and increases in eye disorders such as cataracts and retinal damage[90].

B. Indirect effects

Indirect effects of climate change may arise through poor distribution or inadequacy of food supplies, loss of land through sea level rise, and loss of water for irrigation. Plant pathogens and pests may thrive, resulting in more spoiled food. Malnutrition, nutrient deficiencies, poverty and famine are therefore predicted to rise[91].

A good deal of attention is being paid to the likely effects of global warming on communicable disease transmission. Diseases can here conveniently be split into two categories; those *spread* by vectors (insects and so on) and non-vector borne diseases (diseases in either category can be caused by micro-organisms).

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[89] *Science* vol 267 17 February 1995 p.958

[90] *Potential Effects of Climate Change* Report of a WHO Task Force WHO 1990 pp 20-23, *The Lancet* "Healthy and Climate Change: Stratospheric ozone depletion" vol 342, 6 November 1993 pp 1156-8, and *The Lancet* "Ozone depletion and the immune system" vol 342, 6 November 1993 pp 1159-60

[91] WHO op cit, p.29

1. Vector Borne Diseases

Such diseases are found mostly in tropical and subtropical regions. They include malaria, yellow fever, dengue fever and filariasis (spread by various species of mosquito), schistosomiasis (which relies on water snails as an intermediate host), river blindness (spread by the blackfly) and sleeping sickness (spread by the tsetse fly).

These diseases affect over 600 million people a year, killing over 2 million, and epidemiologists' models predict increased prevalence as mosquitoes and similar pest species expand their ranges. (Since such cold blooded animals are highly sensitive to temperature change even a small temperature rise may extend their ranges.) Malaria is thought highly likely to change its distribution, and with changes of 5°C, areas of elevated risk predicted by computer models include much of Europe.

European Commission scientists working at Ispra in Italy have used five models to simulate effects of changes in rainfall, temperature and humidity on the malaria organism itself and on its mosquito vectors. For malaria to take hold in an area, temperatures above 20°C and humidity above 55% is generally needed. In areas where malaria is endemic people develop some immunity, so expansion of range would affect previously unexposed populations and be likely to produce higher death rates. One of the climate models (produced, incidentally by the British Meterological Office) indicates that seasonal malaria, one of the more dangerous forms of the disease which kills 1 in 10 people infected, could increase its range by more than half by the second part of the next century, in the UK spreading as far north as central Scotland. All five models indicate that large parts of Britain will be affected by seasonal malaria[92].

One microbiologist working on spread of diseases with warming at the USA's Environmental Protection Agency has commented that

> "The spread of infectious diseases will be the most important public health problem related to climate change"[93].

Thus global warming is expected to reap its worst effects in the developing world. One ecologist has linked a 1°C average temperature increase in Rwanda in 1987 to a 337% rise in malaria incidence that year. The mosquito which carries dengue and yellow fever (*Aedes aegypti*) has been extending its range into mountainous areas in Costa Rica, Columbia, India and Kenya[94].

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[92] "Global alert over malaria" *New Scientist* 13 May 1995 pp4-5
[93] *Science* vol 267 7 February 1995 pp 957-8
[94] ibid

Modelling has indicted that an average global temperature increase of 3°C in the next century could result in 50-80 million new malaria cases each year, although there are many uncertainties attached; desertification, for example, does at least create mosquito-free habitats[95]. Some species of the malaria mosquito, *Anopheles*, will be favoured by rising sea levels, and all by increases in temperature and rainfall; the WHO report concludes that[96]

> "It should be clear ... that climate change will affect the distribution and prevalence of vector borne diseases dramatically, and that these changes cannot be ignored."

2. Non-vector borne diseases

Water-borne diseases include diarrhoeal disease (caused by pathogenic *E. coli* and other organisms), hepatitis A and poliomyelitis, and amoebic dysentery. The effects of migration and resettlement and the lack of access to safe drinking water will be important factors affecting the prevalence of such diseases. With lack of water comes poor sanitation, hygiene and washing; diseases such as bacillary dysentery, one variety of cholera and internal parasitic infections would be likely to increase. Drought towards the equator may result in a widening of the cerebrospinal meningitis belt.

If climate changes disrupt ecosystems large numbers of people (environmental refugees) could migrate into new zones. This could happen particularly because of loss of coastal areas through sea level rise or loss of agricultural land through delta sinkage or saltwater inundation. Already today, in response to natural disasters, humans often migrate to temporary camp areas, where the provision of proper vaccination, pest control, food, sanitation and water is of the essence; such migrations may become more commonplace.

The WHO report considered that climatic changes could precipitate uncontrolled urbanisation, poor access to health care, overcrowding and under-nutrition, favouring such diseases as TB, leprosy, skin infections, measles, external parasites and possibly bubonic plague.

Experience from the past, following major dam resettlement projects, has indicated that the incidence of diarrhoeal, vector-borne, other parasitic and sexually transmitted diseases will be increased. The number of mental health problems, accidents and nutritional problems may also be affected. All past resettlement projects have failed to include adequate strengthening of public health services. The WHO considers that countries will have to decide whether to build sea defences, or start planning in detail for major resettlement[97].

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[95] ibid
[96] op cit, p.42
[97] op cit p.46

VII. Extreme events

A. Predictions

The IPCC concluded in 1990 that at a particular location, changes in the frequency of extreme events and variability of weather will have more impact on ecosystems and human populations than gradual warming events.

However, there is no clear evidence that weather variability will change systematically in the future (with the possible exception of more intense showers). If anti-depression tracks or anticyclones (large scale weather features) shift their positions, this may alter weather extremes and variability at particular locations, but this may or may not happen.

Tropical storms (typhoons and hurricanes) develop over seas that are warmer than 26°C. The area of sea which is warmer than this will increase as the weather warms, but in a warmer world the critical temperature of 26°C may itself change. Climate models give no consistent indications whether tropical storms will increase or decrease in intensity or frequency.

Mid-latitude storms (tracking across the North Pacific and North Atlantic and thus sometimes affecting UK coasts) are driven by the pole-equator temperature gradients and might be weakened, but current climate models do not have sufficient resolution to predict such detailed events[98]. The World Meteorological Organisation (WMO) recently issued its summary of the state of the global climate during 1994 and stated [99]:

> "While extreme climatic anomalies and weather events were as numerous and destructive as ever in 1994, there is still no scientific evidence that would indicate an increase frequency of such events."

Such extreme events in 1994 included; severe cold conditions in North America in January, hot and dry summers in Western North America and Europe causing bushfires, drought affecting agriculture in Australia, Brazil, Indonesia and China, and a heavy wet season in the Western Sahel. 12 tropical cyclones hit China in 1994. The WMO considers that increases in fatalities and destruction linked to extreme events are, however, often related to population increases[100].

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[98] Intergovernmental Panel on Climate Change *Climate Change The IPCC Scientific Assessment* WMO/UNEP 1990 pp. xxiii-xxvi

[99] WMO Press Release 561 *WMO issues summary of the state of the global climate during 1994* 13.3.95

[100] ibid

B. The insurance industry

Following the Great Storm of 1987 in the UK, and Hurricanes Hugo, Andrew and Gilbert in America, there has been intense press speculation that the frequency of intense storms could be set to increase, and that this is attributable to global warming[101].

The global insurance business has incurred great losses since the late 1980s. Before 1987, only one event (Hurricane Alicia in 1983) had cost insurers more than $1 billion. Between 1987 and 1994 13 such events occurred. The most expensive was Hurricane Andrew, which hit Louisiana and Florida in August 1992, and was perhaps a turning point. After this, rates of catastrophe insurance renewal increased drastically (to 50-200% higher than previously). Hurricane Andrew cost insurers $15-20 billion, but it also followed years of heavy losses, and forced several smaller insurers out of business. Several insurance companies started speaking of the fear that global warming would lead to many more storms and violent events[102].

In fact, these expensive events included those such as the 1994 Los Angeles earthquake, unrelated to global warming. Moreover the cost of rising claims is partly due to increases in the value of insured property, and to more extensive insurance. However, at one conference last year a meteorologist warned that indications had "hardened that the beginning climatic changes have an ever-growing influence on the frequency and intensity of natural disasters"[103].

A leading Lloyd's underwriter voiced very similar fears more recently, speaking in advance of the Berlin meeting. Figures released in March 1995 by Munich Re, the world's largest reinsurance company, showed that the costs of large natural disaster insurance claims is now 14 times as high as in the 1960s. Insurance cover was apparently being withdrawn in some parts of the world (such as the Caribbean) because of wind storm fears, and some UK companies were accused of 'cherry-picking' the most attractive risks to underwrite. Insurers feared accelerated risks form global warming, whatever was agreed at Berlin[104]. At around the same time there was speculation that London Transport might find it impossible to renew its flood insurance when current cover expires[105].

Dr Andrew Dlugolecki, the chief manager of operations of General Accident, who has also been working with the IPCC, has said that a storm event in the US costing $50bn insured loss could happen at any time, and a £5-10 bn event in the UK could cause severe problems for the insurance industry. Dr Dlugolecki has said there is 'evidence' for climatic changes resulting from global warming, including more Atlantic storms, fewer hurricanes, more intense

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[101] e.g. *Guardian* 21 September 1989, "Greenhouse effect powers hurricanes, say scientists", and *Today*, 24 July 1989 "... Killer storms like the 1987 Hurricane could soon hit Britain every five years"
[102] *The Economist* 20 August 1994 "Insurers get that sinking feeling ..."
[103] *Lloyd's List* 28 June 1994 "Changes in Climate will hit insurance market"
[104] *Financial Times* 25 March 1995 "Disasters 'to increase cost of insurance'"
[105] *The Guardian* 27 March 1995 "Insurers sound alarm about cost of warming"

storms, fewer frosts and the unusual duration of the [present] El Niño event (see section II.C). However, there was no conclusive proof of a link[106].

Major insurers have started to work with environmental groups such as Greenpeace and with the IPCC. They can be expected to press for high construction standards. US insurers, in particular, are advocating partnerships with government to produce financial safety nets against truly catastrophic events.

The IPCC's next report, its full Second Scientific Assessment, will include for the first time a chapter on financial services, drawing insurers further into the warming debate[107]. This report is due out in March/April 1996, by latest estimates[108].

Global Warming: Economic Consequences

I. Economic costs

A consensus is emerging, at least within the scientific community, that global warming is a real, very serious problem. It may be thought that the reaction to a worldwide environmental crisis of this severity would be to adopt an emergency programme to do whatever needs to be done to save the world from this serious threat. Yet the approach of economists is completely different and many economists conclude that it would not be wise to commit resources to such policies at this stage.

Economists are not in a position to re-evaluate the scientific data, and their contribution has to be in terms of costs and benefits of the various policies. A common argument is based on the assumption that one can estimate the economic effects of global warming at a certain point - for example when the level of carbon dioxide in the atmosphere has doubled. They then convert that cost to present value by means of a discount rate. That figure is then compared with the cost of prevention policies undertaken now. Each stage in the calculation is important, although this section will concentrate on the very low results estimated for the economic effect of doubling CO_2 .

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106 *Lloyd's List* 4 April 1995 Insurance File p.5
107 ibid
108 *The Newsletter of the Scientific Assessment Working Group of the [IPCC]* No 5 February 1995

The respected US economist W. Nordhaus discussed estimates of worldwide effects[109]

> These reflections lead to a surprising conclusion : our best guess is that CO_2 -induced climate change will produce a combination of gains and losses with no strong presumption of substantial net economic damages. However, these changes are likely to take place over a period of a half century or more and may get lost in the background noise of social, economic and political change. This conclusion should not be interpreted as a brief in favour of climate change. Rather, it suggests that those who paint a bleak picture of desert Earth devoid of fruitful economic activity may be exaggerating the injuries and neglecting the benefits of climate change.

Nordhaus's estimate of the effect of temperature increase begins with the USA, pointing out that only a tiny proportion of the economy appears vulnerable. About 3% of US national output originates in climate-sensitive sectors, and another 10% in sectors modestly sensitive to climate change, leaving around 87% in sectors negligibly affected. Then, an increase in temperature would not spell total disaster in the affected sectors. Estimates suggest that US agriculture might either benefit or lose from likely global warming over the next few decades. Clearly, with even moderate effects on sectors of such small size, the overall effect on the US economy is going to be tiny. His conclusion is that the central estimate of the effect of a doubling of CO_2 levels is likely to be around a quarter of one per cent of US national income[110].

The effects predicted for other countries are larger, but still very small. Even if a country like China were to lose 5% of national income, which was the extreme conclusion, that would be outweighed by a single year's economic growth. There are, of course, a few countries particularly vulnerable to climate change, particularly if it involves a rise in the sea level. The appropriate reaction to these very special cases - of which Bangladesh is the most important - might be to build special sea defences or even to compensate the people so that they can live elsewhere. It is not necessarily to spend a huge amount of money on trying to adjust the rest of the world's climate.

Although there are disagreements between different estimates of these effects, the overall conclusion that the effects are very small holds in all of them. A study by the OECD[111] compared four such estimates, in each case examining the effect on the US economy of doubling CO_2 which is taken as equivalent to raising the temperature by 2.5^{o} C : Nordhaus (1993); Cline (1992); Fankhauser (1993); Titus (1992). There were notable differences in estimating effects on particular sectors, for example agriculture where Nordhaus estimated the damage to be $1b, but Cline estimated $15.2b. For coastal areas, Nordhaus estimated the effect at $10.7b, while all the others estimated it at between $2b and $3b. Overall, however, the effects were very similar. Nordhaus 1% of GDP; Cline 1.1%; Fankhauser 1.3%; Titus 2.4%. In addition, Fankhauser extended his estimate to the world as a whole, producing an

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[109] "Economic approaches to global warming," in R.Dornbusch & J.M.Poterba, Global Warming: Economic Policy Response, 1991

[110] op. cit. p.44

[111] Global Warming : Economic Dimensions and Policy Responses, 1995, p.153

effect of only 1.5%. Cline extended his estimate to consider also the effect of long-term warming of 10° C, which he estimates would reduce US income by 6%.

These are not fringe estimates. A paper by Samuel Fankhauser and David Pearce, who is the best-known environmental economist in the UK[112] comments on the same studies and noted that the range of damage to the US economy of CO_2 doubling is surprisingly robust. In other words, a considerable change in the assumptions only makes a relatively small change in the result.

> Even when picking the most pessimistic figure for each damage category, the total only modestly exceeds 2% of GNP. Conversely, it does not fall below 0.75%, even in the most optimistic case.

A recent work by the British economist Wilfrid Beckerman[113] explicitly attacks arguments used by environmentalists, using such estimates as his background. Like most economists, he cannot resist commenting on the scientific debate, but his main points concern the economic impact (Chapter 7). He begins by disputing the view that the human race is some tender plant that can only survive in a narrow band of plus or minus 3°C, pointing out the wide dispersion of the human race in places of varying temperatures (p.90).

> For example, taking the average temperatures in the coldest month in the countries concerned, 32.3% of the world's population live in a band of O°C to 3°C, whereas 18.8% live in the band 12°C to 15°C and 14.6% in a band 24°C to 27°C ! The same wide dispersion exists if we take average summer temperatures. Furthermore, across countries as a whole there is no correlation at all between average temperatures and income levels (even excluding Middle Eastern oil states).

He argues that changes in temperatures would pose little problem, noting the extent of changes faced by people moving within the USA, or in numerous historic migrations. Beckerman repeats the above arguments on agriculture and dismisses the problem of sea level rise, partly by suggesting that such estimates have been greatly reduced over the past decade. He cites an estimate by the US Environmental Protection Agency that if the sea level did rise by one metre, it would cost about $100 billion to protect US cities by sea walls (p.93).

> Applying a 1.5% per annum compound growth rate to the present US GNP of about $6 trillion would give a GNP by the year 2090 of about $27 trillion, so that as a fraction of GNP in the year 2090 the once-for-all capital cost of the sea walls would be about 0.4%!

Beckerman accepts problems for Bangladesh, but suggests that it would cost the world $20 trillion to prevent a one-metre rise in the sea level. It would therefore make more sense to let the sea rise and to give some proportion of the $20 trillion - perhaps $4 trillion to the Bangladeshis. Everybody would be better off. After dismissing various other possible effects such as increased frequency of storms, he sums up robustly (p.96).

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[112] The Economics of Climate Change, OECD 1994 p.74
[113] Small is Stupid, 1995

> Hence it seems impossible to escape the conclusion that, even under pessimistic assumptions, the annual cost to the world as a whole of global warming associated with a doubling of CO_2 concentrations is likely to be almost negligible by comparison with the value of world output over the period in question. Such estimates as have been made of the overall effect on the world economy of a doubling of the CO_2 concentration suggest that world output or income would be reduced by about 1% or 2%. Suppose these estimates are much too conservative. Suppose the real impact is that world output would be reduced by 10 times as much - i.e. by 10% by the end of the next century below what it would otherwise be. Then, instead of average world income per head being 4.4 times as great as it is now, it would be only 3.96 times as great.

His conclusion, of course, is that it would be completely illogical to incur high costs now in order to avoid something which would involve such tiny costs. Far better to delay, then to act in the future when technical progress will have reduced the cost of so doing.

Most economists avoid such arguments and suggest instead the adoption of the so-called "no regrets" policies which make sense in their own terms. For example, there are good arguments in favour of promoting energy conservation irrespective of global warming, partly because any method of electricity generation will impose some environmental cost, such as acid rain. However, it is clearly unsatisfactory to leave open the question of whether or not global warming matters.

II. How valid are the economists' arguments?

It is, at first, difficult to believe that the economists and scientists are writing about the same thing. Global warming can hardly both be a unique threat to life on earth and also of negligible importance economically. The reason why, in general terms, the estimates of the economic effects are so low can be explained.

The strongest argument is not that people live in locations with widely different temperatures. True enough as a debating point, but it says nothing about population densities at various temperatures nor whether an increase in world temperatures would actually change ecosystems into ones where equivalent numbers of people could live, let alone prosper. Any climate change which resulted in desertification of an area currently producing crops for large numbers of people might result in mass destitution or migration. Nor is it clear whether large numbers of people currently living in hot countries could stay living in them if they became still hotter. The result might be the drying up of water sources and an end to viable communities.

In one sense, the low result for the effect on US agriculture is not surprising. After all, most crops are planted afresh each year and can be chosen to conform to the climate for the year. The USA is also a continent with a vast range of temperatures, so that it is not difficult to see crops being planted in different locations to avoid losses from increasing world temperatures. The obvious problem is to know what will happen to water supply, since there might be radical changes in the pattern of rainfall within a given world total for the year. Yet one can see why the USA would be confident of fixing the problem of water supply within the continent, perhaps by pipelines, even if the unexpected did happen. Indeed, from a USA-perspective or indeed a European one, a loss in crop output of perhaps 10% might be positively beneficial. Overproduction is currently a serious problem, requiring costly solutions in terms of disposal of surplus stock.

Other industries use raw materials, but it does not matter much where they come from, because means of transport are so efficient. Even if some raw materials were no longer available at reasonable prices, the result would be far from disastrous. After all, the development of synthetic substitutes is improving all the time, and the commercial incentive resulting from a price increase following on a shortage would stimulate enormous development activity to find a replacement, almost certainly with success. Perhaps the prices would be a little higher, but even so, most final industrial prices are not heavily dependent upon small changes in raw material prices.

There is another way of looking at the low estimates. Beckerman cites estimates for economic effects in terms of monetary costs, but assumes that economic growth can continue, unaffected by any changes. He can easily show, therefore, that growth in national output overweighs any particular effects from environmental changes. Yet that assumption might not be correct. For example, the oil price increases in 1974 and 1979 caused a slowdown in economic growth in the industrial world from which it has not really recovered, despite the oil price fall in 1986. Western Europe was introduced to mass unemployment for the first time since the 1930s, and most people now believe that this mass unemployment is here to stay. Of course, it can be argued that such results come from poor economic policy rather than from the change in oil prices, but it is always easier to produce good results for alternative economic policies on a computer simulation than in reality. In truth, economists are very bad at explaining why growth is high or low, and they are really in no position to be sure that particular changes will not affect the growth rate.

Another way of making the point is to see the likely environmental effects as unpredictable changes in income/wealth between different areas, which is also what the 1974 and 1979 oil price increases were. Even if the winners gain as much as the losers lose, there is an enormous practical problem for the world in coping with the results.

Further potential problems might result from a spread of tropical diseases such as malaria (see section VII.B.1 above). Debilitating diseases of this type mean that productivity and enterprise tend to be low in countries like Nigeria. Similar effects in Europe would be disastrous. On the other hand, it would be naive to think that it is impossible for fast economic development to take place in hot, humid countries, as one can see from the example of south Asia.

Industrial countries may be best able to cope with change, because they have the money to buy goods on the world market, along with the technological strength to develop new methods of production, whether in industry or in farming. It would be more difficult for third world agriculture to adapt to climate change. Crop varieties have been selected and plants have evolved for particular conditions and particular areas, to an extent which we are only now understanding, and there would need to be replaced by other varieties, even if growing of the same crop could satisfactorily continue in the area. The question of payment for the crops, patent rights over new seed varieties and difficulties over irrigation could very easily transform a viable subsistence farming area into destitution. Again, this is partly a problem of handling sudden changes in income distribution. A large country might have winners and losers within its borders, but smaller countries might be dramatic losers. It is no answer to say that the international community could provide economic aid, partly because we are now far more aware of the weaknesses of aid-giving as a way of boosting welfare.

Water may be the key to what happens. Problems of rainfall distribution are discussed in section III.C. It is important not to be too confident that irrigation can solve any problems resulting from drought. Large numbers of vast irrigation projects have been undertaken but the results have been mixed. In many cases there have been serious losses of agricultural land through waterlogging and desalinisation[114]. It is far from clear that the principles of damming rivers to irrigate the land will in fact allow an increased area of land to be farmed. Many of the best dam sites have already been taken, but the reservoirs often silt up in a few decades. It is perfectly arguable that there will be less scope for irrigation in fifty years time than at present. It is difficult to believe that irrigation could be adopted on a large enough scale to cope with any major disruption to current patterns of rainfall, except at a vast cost and in the very short term.

Beckerman's view of the future is one where scientists can use genetic engineering to develop the crops which are needed, so that the contribution from nature could be dispensed with. Yet it is unclear whether such a vision is realistic. New strains of crops are currently developed by exchanging characteristics from existing strains, and the process is a long, expensive one. It would not be easy to develop new strains to cope with changing conditions in terms of temperature and rainfall. It is not always wise to assume that brilliant scientists with plenty of money will solve any problems that may come up. Nor is this a problem to be swept aside by the arguments of compound growth or the small agricultural sector in industrial countries. Most people would probably agree that the rapidly increasing world population poses enormous problems in increased food, and opinions differ as to whether the extra production will be feasible. If global warming were to make that harder, it could potentially result in a widespread famine by the middle of the next century. Again, the arguments depend upon whether we can assume that compound growth will overcome almost any difficulty, but it is easier in this case to see why compound growth is not automatic but something that has to be worked for. For example, new seeds and new fertilisers have to be developed, or else the growth in yields will stop.

Another consideration is how to treat uncertainty. Scientists might have wrongly estimated the effects of global warming, although they quote uncertainty ranges and there are now indications that computer climate models are robust (see section III.B). The most alarming

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[114] see Fred Pearce, *The Dammed: rivers, dams and the coming world water crisis*, 1992

possibility is that cumulative temperature growth might be set off, in a way that might be difficult or even impossible to stop, by feedback mechanisms such as those described in this paper (see sections III.C and III.D). In that case, the cost of allowing the world to become 2.5^{o}C warmer might suddenly turn out to be very high, or even infinite in the worst scenario. One reaction is to argue that because the possible damage of global warming is infinite, even a small probability of such an event would justify extensive expenditure at this stage.

Economists tend to counter by saying that our lives are not, in practice, based upon taking enormous efforts to eliminate the smallest risks, even though such risks could be extremely serious. For example, the act of driving a car entails some finite risk of being killed in a road accident, yet that possibility does not stop people from driving. It is possible, then, to think of arguments to challenge the widespread view of economists that global warming will only impose a negligible cost on the world. However, none of these arguments is any sort of refutation, more an indication of how the economic calculations might turn out to be inaccurate. It is not easy to know the appropriate framework for thinking about a major world-change of this type. Economists may be too complacent, but ultimately decisions about policy responses are decisions about how to spend public money. Environmentalists might argue that the effects of global warming would be very serious, even though they would not be reflected in any economic cost, but it is difficult to see that such an argument will persuade governments to spend large amounts of money in trying to reduce carbon emissions.