Global Atmosphere Research Programme

Annual report 2002 to 2003

Summary of research programme

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Department for Environment
Food and Rural Affairs

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To note: Evidence is growing that Arctic Sea ice is thinning and decreasing in extent. The Met Office Hadley Centre predicts that summer sea ice may well disappear by the end of the century.

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November 2003

Department for Environment
Food and Rural Affairs

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Foreword

Henry Derwent, Director of CEER

My remit as Director of CEER covers a wide range of challenging and topical environmental issues within Defra – climate change, GM crops, chemicals and radioactive waste among them. I therefore know first hand the importance of sound science underpinning Government policy. Without the hard evidence that there is a real problem, and that something must be done about it, we can make no progress in meeting sustainable development objectives for our society.

That is why I am particularly pleased – and proud – to present the results of another year's worth of research commissioned by the Global Atmosphere Division on climate change and stratospheric ozone depletion. This research ranges from the core science of climate change to understanding the impacts it will have on society and assessing how we should respond, both in terms of limiting our emissions and adapting to its effects.

Although the stratospheric ozone problem is well characterised and understood scientifically, we still maintain research into observing UV and ozone levels over the UK, and measuring levels of ozone depleting substances in the atmosphere to be sure that controls are working.

We fund the world class climate prediction facility at the Hadley Centre with an £8 million programme per annum, to develop our understanding of the problem through sophisticated climate modelling. We also fund research into observed changes in the atmosphere and the ocean, contributing to international programmes in this area.

We track the levels of emissions of greenhouse gases in the UK – and make future projections – to judge the success of our policies in meeting international reduction targets. And we assess how the UK and other countries should begin to prepare for the impacts of climate change and develop adaptation responses.

This is a challenging programme, but also an essential one if the UK is to show leadership in the world and ensure our policies, many of which have major economic impacts – are based firmly on the best scientific assessment possible. The scale of the future challenge is huge. We will need deep cuts in emissions – 60% or more – if dangerous levels of climate change are to be avoided, and inaction could cost us dear both in the way it affects human societies and the wider environment.

The quality of the science in GA's research programme is first rate, and shows how seriously the UK takes this problem. I would like to thank all the researchers and administrators, both inside and outside Defra, who have contributed to it and made it possible.

Henry Derwent
Director of CEER

Organogram showing how Global Atmosphere Division fits in Defra

- **Permanent Secretary** — *Brian Bender*
  - Other Director Generals:
    - Food Farming and Fisheries
    - Land Use and Rural Affairs
    - Chief Veterinary Office & Director General Animal health and Welfare Veterinary Head of Profession
    - Operations and Service Delivery
    - Chief Scientific Advisor and Head of Science Directorate
    - Solicitor & Director General, Legal Services
  - **Director General: Environment** — *Bill Stow*
    - **Environment Protection Strategy** — *Robert Lowson*
      - Environment Agency — *Stephen Claughton*
      - Secretary to Sustainable Development Commission — *Scott Ghagan*
      - Environment Protection International — *Roy Hathway*
      - Europe Environment — *Helen Marquard*
      - Environment Protection Statistics and Information Management — *John Custace*
      - Sustainable Development Unit — *Bronwen Jones*
    - **Environment Quality and Waste** — *Neil Thornton*
      - Air and Environment Quality — *Martin Williams*
      - Waste Management — *Sue Ellis*
      - Waste Strategy — *Linsday Cornish*
      - Environment Business and Consumers — *Bob Ryder*
      - Waste Implementation Programme — *John Burns*
    - **Climate Energy and Environmental Risk** — *Henry Derwent*
      - Chemical and GM Policy — *Colin Church*
      - **Global Atmosphere** — ***Sarah Hendry***
      - Radioactive Substances — *Richard Wood*
      - Sustainable Energy Policy — *Jeremy Eppel*
      - Joint Environmental Markets Unit — *Stephen de Souza* (joint unit with DTI)
    - **Water** — *Richard Bird*
      - Drinking Water Inspectorate — *Prof. Jeni Colbourne*
      - Marine and Waterways — *John Roberts*
      - Water Quality — *Daniel Instone*
      - Water Supply and Regulation — *Rodney Anderson* (until Dec 2003)
      - Flood Management — *Sarah Nason*
      - Chief River and Coastal Engineer — *Reg Purnell* (reports to Sarah Nason)

Executive summary

During 2002/2003, the Global Atmosphere (GA) Division of Defra commissioned research worth £12 million on climate change and stratospheric ozone depletion.

Climate change

The climate change research commissioned by GA falls within three main work streams:

- Climate Assessment and Prediction Programme, dealing with the science of climate change;
- Climate Impacts Programme, dealing with climate change impacts and adaptation; and
- Climate Mitigation Programme, dealing with responses to climate change.

GA also commissions research into climate observations to measure changes in the atmosphere and the ocean and contributes to international programmes in this area.

Recent trends

Global climate data analysed by the Hadley Centre shows that 2002 was the second warmest year in the 143-year record. The warmest was 1998 and the top 10 warmest years on record occurred between 1990 and 2002. Central England temperature data records show that 2002 was 1.1ºC warmer than the 1961-1990 average.

Model studies by the Hadley Centre showed that climate change in the second half of the 20th century cannot be attributed to solar variability. Even with enhanced solar variability, the models fail to reproduce 20th century trends unless anthropogenic forcing is also included. The Climate Research Unit at the University of East Anglia also found that trends in summer temperature data cannot be explained by natural variability.

Measurements of greenhouse gases at Mace Head in Ireland have shown that baseline concentrations of the main direct greenhouse gases – carbon dioxide, methane and nitrous oxide – reached the highest levels in the atmosphere ever recorded in 2002, the latest year for fully validated data.

Climate change research

The Hadley Centre's ground-breaking carbon-climate model has shown that as temperatures rise, the uptake of carbon by soils and vegetation could decline – strongly accelerating global warming. Experiments with different scenarios show that stabilisation of carbon dioxide concentrations in the atmosphere would thus require larger than previously predicted cuts in emissions if this feedback is included.

The Hadley Centre's regional model was used to simulate retrospectively the extreme precipitation associated with the floods in England in late 2000. The accurate simulation of that event gives added credence to simulations of the future, which predict that extreme precipitation events such as flooding, which currently occur on average about every 20 years, now can be expected to occur every 2-3 years by the end of the century.

A "climate prediction index" is under development and will provide a way of measuring the ability of models to simulate the present day climate and subsequently identify the best models for making predictions of future climate.

The Advanced Along Track Scanning Radiometer (AATSR) – launched at the end of February 2002 on the Envisat satellite – continues to orbit Earth and is sending back excellent data on sea surface temperatures. The data is being used to monitor trends in the climate.

Future climate change and its impacts

Climate change scenarios for the UK, developed by the Tyndall Centre using predictions from the Hadley Centre Regional Climate Model (RCM), were launched in April 2002. The scenarios are the first to combine internationally agreed Intergovernmental Panel on Climate Change (IPCC) emissions scenarios with a high resolution regional model.

The climate change scenarios indicate that:

- Annual temperature averaged across the UK may rise by between 2 and 3.5ºC and some areas could warm by as much as 5ºC by the 2080s;
- Heavy winter rainfall events that occur every 2 years are expected to increase in intensity by between 5 and 20%; and
- Relative sea-level around the UK could rise perhaps by as much as 86 cm in southern England by the 2080s, with extreme sea levels being experienced more frequently.

The UK Climate Impacts Programme (UKCIP) was set up in 1997, to encourage private and public sector organisations to assess their vulnerability to climate change, so that they can plan their own adaptation strategies. Recent studies include the impacts of climate change on health, water demand, biodiversity and the built environment. Regional studies to assess impacts in Northern Ireland and Yorkshire and Humberside were also completed.

The Climate Impacts LINK project disseminates Hadley Centre results to the wider climate research community and provides support for other users. Recently the LINK project has assisted with the distribution of European-level data associated with the 2002 UKCIP scenarios.

Projects to assess the regional impacts of climate change on a range of issues (for example, agriculture, water resources and human health), in India and on Chinese Agriculture have continued in collaboration with their respective governments.

Intergovernmental Panel on Climate Change (IPCC)

In July 2002, UK scientist Professor Martin Parry took up post as co-chair of Working Group II of the IPCC dealing with Impacts, Adaptation and Vulnerability. A new Technical Support Unit is running at the Met Office, to provide support for this Group. Activities have focused on the design and structure of the IPCC's Fourth Assessment Report (AR4) which will be published in 2007.

Climate mitigation

As a Party to the United Nations Framework Convention on Climate Change (UNFCCC), the UK has more than met its commitment to return emissions of carbon dioxide and all other greenhouse gases to 1990 levels by the year 2000. Emissions have fallen between the base year and 2001 by 12.3% for all greenhouse gases and by 5.3% for carbon dioxide.

The UK has a target under the Kyoto Protocol to reduce a basket of six greenhouse gases to 12.5% below 1990 levels by 2008 – 2012 and; a domestic goal of a 20% reduction in carbon dioxide emissions below 1990 levels by 2010.

Emission projections for all greenhouse gases, analysed by economic sector and by gas, were reported in the UK's Third National Communication to the UNFCCC (published in 2001), and the UK's Climate Change Programme (published in 2000). It is estimated that the policies and measures outlined in these reports could reduce the UK's greenhouse gas emissions to 23% below 1990 levels by 2010 and carbon dioxide emissions to 19% below 1990 levels by 2010. The UK's carbon dioxide emissions could fall still further, through the impact of other measures that cannot be quantified, allowing the 20% goal to be achieved. A formal review of the programme will be conducted in 2003/2004.

The UK met its annual inventory reporting requirements to the UNFCCC and to the European Union for the period 1990 to 2001. Regional greenhouse gas inventories were produced for the period 1990 to 2000 for England, Scotland, Wales and Northern Ireland.

Stratospheric ozone layer

The Antarctic ozone 'hole' reached a record 28 million km^2 in 2000, subsequently decreasing to 26 million km^2 in 2001. In 2002 the 'hole' was even smaller but in 2003 nearly reached the record of 28 million km^2 in late September. The variation in size is thought to be due to meteorological factors. Significant depletion is still expected to occur from time to time over the next decade due to high atmospheric residence times of ozone depleting substances (ODS) but slow recovery should take place thereafter in response to controls of ODS under the Montreal Protocol.

Continued monitoring of ozone levels at Lerwick and Camborne in the UK indicate that ozone levels over the UK have fallen at an underlying rate of 3% per decade, with potential consequences for the population such as increased cancer incidence. Recently, ozone trends appear to be levelling off although no firm conclusions can yet be drawn.

Continued monitoring of solar ultraviolet (UV) radiation at sites in Manchester and Reading have not yet indicated any clear trend in solar radiation reaching the Earth's surface at these locations, but it illustrates the way in which atmospheric variables other than ozone affect UV.

Global Atmosphere (GA) Division takes the lead within Government on developing policy responses to climate change (also referred to as global warming) and depletion of the stratospheric ozone layer. See **Boxes 1.1** and **1.2** for a brief summary of these issues.

Policy objectives

GA's objectives are to:

- negotiate the implementation and strengthening of international agreements to reduce greenhouse gas emissions;
- ensure effective implementation of the UK domestic programme of measures to control greenhouse gas emissions and to work with other government departments to set the UK on a long term path to a low carbon economy;
- negotiate effective international and EU controls on ozone depleting substances;
- ensure effective UK input to the international scientific assessments of ozone depletion and climate change; and
- assess the impacts of climate change and the need for adaptation responses.

The issues of human-induced stratospheric ozone depletion and climate change are global in extent, long-term in scope and inherently complex in nature. They require considerable further investigation in order to understand the basic processes involved and develop solutions. Trends in long-term data need to be observed; impacts need to be monitored and projected into the future; and effective ways to respond to these considerable challenges need to be devised. To this end, GA commissions a programme of scientific research, supporting the development of policy responses to these issues.

Research aims

The key aims of the GA research programme are to:

- improve understanding of uncertainty in climate predictions;
- improve climate impact assessments and adaptation strategies;
- meet the UK's national and international commitments for assessing trends in greenhouse gas emissions and future projections;
- improve assessment of mitigation options and costs;
- help to build internationally acceptable approaches to responding to climate change in the long term;
- continue long term measurement of changes occurring in the ocean and the atmosphere; and
- continue to measure levels of ozone and UVB over the UK.

This report summarises the key results of the GA research programme for the financial year 2002/2003. The research programme budget was £12 million and details of the various strands of work undertaken within the programme during the year are outlined in following chapters. Detailed results of all strands of work are provided in Global Atmosphere Research Programme Annual Report 2002/2003 – Research Results available from the climate change pages on the Defra website:
www.defra.gov.uk/environment/climatechange/index.htm

Science Strategy

As part of a Defra-wide initiative, GA has set out its strategy for scientific research covering the period 2003–06. To view Defra's Science and Innovation Strategy and GA's contribution to it, please visit the science pages at:
www.defra.gov.uk/science/s_is/default.asp

Box 1.1: The greenhouse effect and climate change

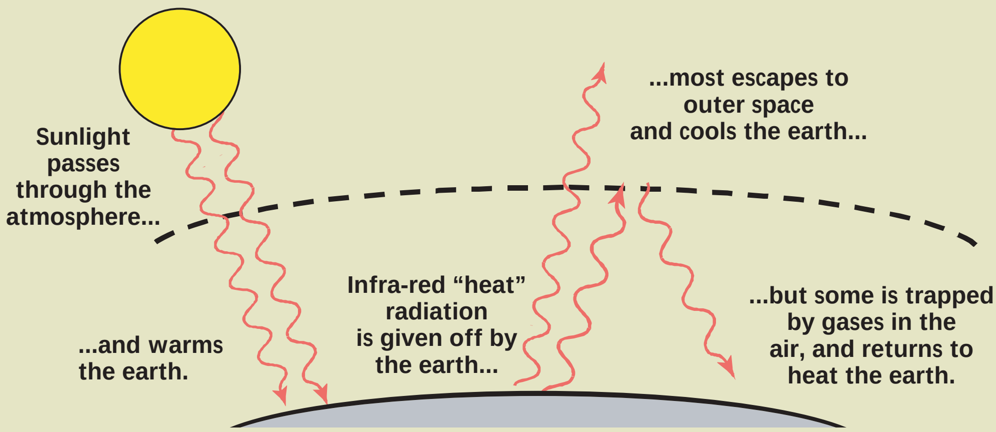
A balance between energy coming in from the sun in the form of visible radiation (sunlight) and energy constantly being emitted from the surface of the earth to space determines the temperature of the earth. The energy coming in from the sun can pass through the atmosphere almost unchanged and warm the earth, but the infrared radiation emitted from the earth's surface is partly absorbed by some gases in the atmosphere – often referred to as 'greenhouse gases' – and so further warms the Earth's lower atmosphere. This term 'greenhouse' is used as the process is analogous to the way in which a greenhouse allows sunshine to penetrate the glass and then traps heat to create an artificially warm environment, in which plants can grow.

On average, for the earth as a whole, the incoming energy from the sun is balanced by the outgoing energy from the earth. Any factor which alters this balance or which alters the redistribution of energy within the atmosphere, and between the atmosphere, land and ocean, can affect climate. A change in the net energy available to the global earth/atmosphere system is called radiative forcing.

Greenhouse gases – principally water vapour, but also carbon dioxide (CO_2), ozone (O_3), methane (CH_4) and nitrous oxide (N_2O) occur naturally. These gases keep the average air temperature near the surface of the earth around 33ºC warmer than it would otherwise be.

The enhanced greenhouse effect

Since the industrial revolution (around the middle of the 18th century) the atmospheric concentrations of a number of greenhouse gases have changed as a result of human activities. This has led on balance to a positive radiative forcing i.e. an enhanced greenhouse effect. Changes in the concentrations of the long-lived greenhouse gases, CO_2, CH_4 and N_2O, have contributed most to the enhanced greenhouse effect, with amounts rising by about 30 per cent, 150 per cent and 16 per cent respectively over the period. These trends are largely due to human activities, primarily fossil fuel use, land use change and agriculture. Water vapour has also increased as a result of warming as a warm atmosphere can hold more water. This is a feedback effect which enhances the effect of the other greenhouse gases, though the size of this effect is more uncertain.



Box 1.2: Stratospheric ozone depletion

Ozone is a naturally occurring substance and is present at very low concentrations throughout the atmosphere. The concentration of ozone is highest in the stratosphere, which is the atmospheric layer between approximately 15 to 50 km above the Earth's surface. This ozone 'layer' filters out much of the potentially harmful ultraviolet (UV) radiation from the sun that enters the atmosphere.

Ozone is continually created and destroyed in the stratosphere by a cycle of chemical reactions. Depletion of the ozone layer is caused when halogenated compounds such as chlorofluorocarbons (CFCs) are broken down in the stratosphere by sunlight to release chlorine and bromine atoms which then catalyse (or facilitate) the reactions that destroy ozone. Depletion of the ozone layer results in an increase in UV radiation reaching the Earth's surface, which can cause harm to our environment and health (for example through increased incidences of skin cancers). In polar regions, ozone depletion is particularly rapid during the winter and spring and in recent years the ozone hole in the Antarctic has covered an area equivalent to the United States of America.

The history

In 1974, scientists suggested that the rapidly increasing use of man-made chemicals containing chlorine and bromine such as CFCs and halons, emitted as a result of their use in a variety of applications such as spray can propellants, refrigerants, foam-blowing agents and in fire extinguishers caused ozone depletion in the stratosphere. Discovery (in 1985) of a 'hole' in the ozone layer, by scientists at the British Antarctic Survey, added weight to this theory.

The international response

This evidence prompted international agreement in 1987 to limit the production and consumption of ozone depleting substances through the Montreal Protocol to the Vienna Convention. The Protocol has led to substantial reductions in the production and consumption of ozone depleting substances since the mid 1980s. Atmospheric measurements suggest that as a result of global compliance with the Protocol, chlorine loading in the stratosphere peaked in the mid-1990s and has started to decline. It is anticipated that stratospheric ozone will return to pre-1980s levels by the middle of this century. Rising atmospheric concentrations of greenhouse gases is, however, leading to a cooling of the stratosphere; this could have a negative impact on ozone levels and may delay recovery of the ozone layer in the short term.

Climate change

The research funded by GA Division has a broad remit, reflecting the areas covered by the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC – see **Box 2.1** below), (**www.ipcc.ch**) namely:

- The Scientific Basis of Climate Change;
- Impacts, Adaptation and Vulnerability; and
- Mitigation (i.e. the reduction of greenhouse gas emissions).

Science

The scientific basis of climate change is still an essential area of research. Particular emphasis is given to improving climate predictions, particularly at a regional scale, quantifying uncertainties and increasing understanding of often complex climate processes. This area of work has a direct political impact, both nationally and internationally, and guides policy decisions. In future, it will help to define the level of cuts in emissions needed on a global scale to stabilise greenhouse gases in the atmosphere at a level that avoids dangerous climate change – the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC). The Climate Prediction Programme at the Hadley Centre (**www.metoffice.com/research/hadleycentre**) continues to underpin policy needs for basic climate understanding and prediction, at a cost of approximately £8 million per annum.

Impacts & adaptation

The assessment of climate change impacts and adaptation responses has steadily grown in importance during recent years, particularly as the public has become aware of the potential impacts of climate change, for example, in the wake of the flooding events experienced in the UK in 2000 and 2002, and the record breaking high temperatures in summer 2003. The UK Climate Impacts Programme (UKCIP) (**www.ukcip.org.uk**) – funded by GA at an annual cost of £0.5 million – is a stakeholder-led programme which helps local authorities and organisations assess the impacts of climate change on their activities. UKCIP coordinates climate impacts assessment activities and provides common tools and data sets for use within such assessments. In addition, projects aimed at the global and regional assessment of climate change impacts, especially in particularly vulnerable parts of the world, will help to identify the level of greenhouse gas mitigation required to avoid the worst effects.

Mitigation

GA's research programme enables the UK to continue to meet its international reporting commitments to the UNFCCC (see **Box 2.2**) (**www.unfccc.int**). The UK reports an annual inventory of greenhouse gas emissions by sources and removals by sinks, and approximately every three to four years a national communication. The latter sets out the policies and measures in place and planned to meet its Kyoto target (12.5% reduction below 1990 levels by 2008-2012) and domestic goal for carbon dioxide (20% below 1990 levels by 2010). Research is undertaken to underpin development of the UK Climate Change Programme and identify cost-effective measures to reduce emissions across many sectors of the UK economy. The mitigation research programme also assesses policies on climate change in other countries, particularly in developing countries, and this work will help to inform future negotiations on the shape of commitments beyond Kyoto.

Box 2.1: The IPCC

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO). The Panel – including scientists and policy makers from across the globe – was given the task of assessing the state of the Earth's climate system, the environmental, economic, and social impacts of climate change, and the possible ways in which people could respond to the issue (e.g. by different options for reducing emissions). Activities are divided into three working groups, namely:

- Working Group I: the science of climate change;
- Working Group II: climate change impacts, adaptation and vulnerability; and
- Working Group III: mitigation of climate change.

The scientific assessments and special reports of the IPCC underpin international negotiations by providing authoritative, balanced and unbiased assessments of the state of knowledge on climate change. However, the IPCC does not conduct research itself, but relies on work funded largely through national governments, international mechanisms and private sources. The UK has taken a strong lead in funding research on climate change, and the work of the Hadley Centre has been a key input into the IPCC's assessments and has strongly influenced its conclusions. The IPCC depends on the voluntary participation of many thousands of scientists from all over the world. It prepares its requests in an open process and maintains a high standard of research through a multiple peer and governmental review process.

The IPCC's First Assessment Report was published in 1990 and confirmed the scientific evidence for climate change. This had a powerful effect on both policy-makers and the general public and provided the basis for negotiations on the Climate Change Convention. The second report (1995) concluded for the first time that the balance of evidence suggested that human activities were affecting the climate system. This gave added impetus to negotiation on the Kyoto Protocol. In its Third Assessment Report, the IPCC concluded that: *'Most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations'*. This statement was based on the strongest evidence yet that man's activities affect the climate.

The IPCC's Fourth Assessment Report is due for publication in 2007.

The overall chair of the IPCC is currently Dr. Rajendra Pachauri. Each IPCC working group has two co-chairs, one each from a developed and a developing country. The government of the developed country co-chair in each working group assumes responsibility for funding the associated Technical Support Unit (TSU). The IPCC Trust Fund assists the developing country co-chair. The UK provides the co-chair for WGII, Professor Martin Parry, who with his TSU, are supported by the GA Research Programme.

Box 2.2: The UNFCCC

To tackle the threat of climate change, 181 governments and the European Community signed the United Nations Framework Convention on Climate Change (UNFCCC) which came into force in March 1994. Under the Convention, developed countries, including the UK, agreed to take measures aimed at returning emissions of greenhouse gases to 1990 levels by the year 2000. The UK exceeded this target as emissions of the 'basket' of six greenhouse gases were 12.3 per cent below 1990 levels in 2001.

The Kyoto Protocol

In recognition of the fact that a greater global effort was needed to reduce emissions, the Kyoto Protocol was adopted at the third Conference of the Parties (COP3) to the UNFCCC held in Kyoto, Japan in December 1997.

The Protocol provides for developed countries to have legally binding targets which would reduce their overall emissions of greenhouse gases by 5.2% below 1990 levels during the first commitment period, 2008 to 2012. The EU adopted a collective target to reduce emissions by 8%; Japan and Canada by 6% and Russia and the Ukraine to stabilise their emissions. The USA had a 7 per cent reduction commitment, but announced in spring 2001 its intention to withdraw from the Protocol. Australia has subsequently expressed that it is not in the country's interest to ratify although it still intends to meet its commitment to limit its increased emissions to +8%.

In order for the Kyoto Protocol to enter into force it must be ratified by 55 countries, including developed countries accounting for at least 55 per cent of the total carbon dioxide emissions of this industrialised group in 1990. All EU member states, including the UK, ratified the Protocol on 31 May 2002. As at end of September 2003, 84 Parties have signed and 119 Parties have ratified or acceded to the Kyoto Protocol. These only represent 44.2% of total carbon dioxide emissions from developed countries so the Protocol cannot enter into force. In the absence of the US, it requires Russia to ratify for this to occur.

Stratospheric ozone depletion

Policy on stratospheric ozone is relatively mature and actions under the Montreal Protocol have already arrested the rise in ozone depleting substances in the atmosphere. There is less controversy over the science than for climate change so research in the UK has focused more on evaluating the effectiveness of international controls and maintaining observations of ozone and UVB levels over the UK to meet domestic and international commitments. Basic research in the UK continues to be supported through the research councils and the EU. The problem is not yet resolved, however, and the ozone layer is only anticipated to recover to a pre-1980s state by 2050. Progress will depend on continued international compliance with the terms of the Montreal Protocol and future legislation on any new substances that are found to have ozone depleting potential. Research is also needed into the interactions between climate change and stratospheric ozone, in particular to identify whether this could delay recovery of the ozone layer.

Future research

Looking ahead to the next few years, the GA research programme aims to better quantify, understand and reduce uncertainty in climate predictions, improve impact assessments particularly through better integration between sectors and quantification of effects, and adaptation strategies, improve assessment of mitigation options and costs, and assist in building internationally acceptable approaches to the negotiation of a long-term international response to climate change. Further details are provided in **Chapter 7**.

Under the Spending Review (SR2002), GA was successful in securing additional funding to cover enhanced supercomputing requirements to improve high resolution regional climate predictions and to improve the assessment of changes to extreme weather events. This was prompted by the floods of 2000 and work in this area will be reported on in GA's research report for 2003/2004.

Links with other research programmes

GA Division encourages participation of research contractors in wider national and international programmes, and to contribute to such programmes to ensure benefits to the UK are optimised. To this aim, we make the best efforts to integrate the results of projects funded within GA's research programme with climate change and atmospheric research outputs from research programmes of the research councils and other government departments.

Coordination between key funding agencies is undertaken in the UK within the Global Environmental Change Committee (GECC) chaired by Defra's Chief Scientific Adviser. The committee seeks to ensure that there are no significant gaps or unnecessary overlap in the UK's overall research effort on climate change. Coordination and collaboration occurs at the sub-programme level, for example between UKCIP and the Tyndall Centre, and between the Hadley Centre and the atmospheric science programmes of the Natural Environment Research Council (NERC).

Key elements of GA's research programme, such as the UK climate change scenarios and the Hadley Centre's climate modeling, have provided valuable information to support the work of other Defra policy divisions dealing with flood management, water resources, agriculture and the marine and terrestrial environments.

Internationally, we continue to press for greater coordination of policy relevant climate change research within the EU and will work to influence and make best use of the EU's 6th Framework Programme of Research. The UK was instrumental in setting up a sub-group for science under the EU's Working Party on Climate Change (WPCC) which coordinates EU policy on climate change. The sub group supports input to negotiations on scientific issues under the UNFCCC. The UK will continue to press for more focused concerted action on specific areas such as meeting the ultimate aim of the Convention, impacts and adaptation and proposals for greater coordination of European research on climate change. Additionally, through various research activities, we collaborate with research organisations further afield (for example, through the climate impacts projects in India and China).

Although major advances have been made in our ability to assess and predict climate change, the need for ever-improved predictions, particularly at the local level continues. Consequently the Hadley Centre programme remains a key element of GA's research together with the basic need for better observations over the oceans.

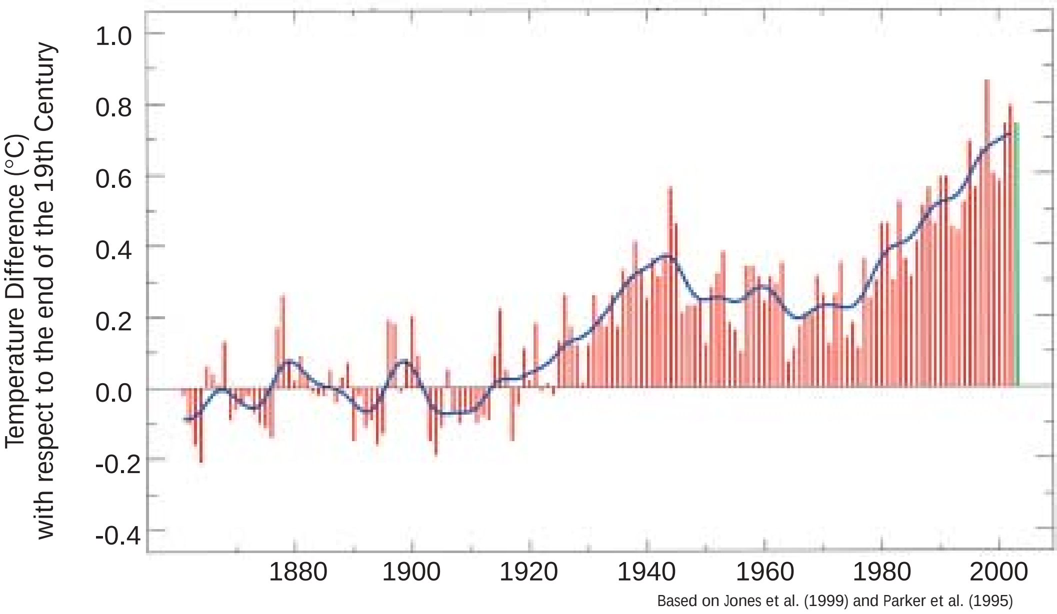
Climate Prediction Programme at the Hadley Centre

The Climate Prediction Programme at the Hadley Centre (**www.metoffice.com/research/hadleycentre/index.html**) underpins policy needs for basic climate understanding and prediction. The Programme is let as a three year rolling contract, at an approximate annual cost of £8 million. The Centre's two principal objectives are to assess current climate change and the extent of human influences, and to develop the best possible regional and global predictions of climate change.

Observational record

Detailed observational records are used to track trends in the climate system and assess the degree to which the climate is changing. Globally, 2002 was the second warmest year in the 143 year global record. The top 10 warmest years on record have occurred since 1990; only 1998 was warmer than 2002. Provisional data for 2003 indicate that it is shaping up to be the third warmest year on record (see **Figure. 3.1**). The Northern Hemisphere has the warmest land and SST (Sea Surface Temperature) anomaly on record for September. The Southern Hemisphere has the warmest land only temperature anomaly on record for June 2003.

Figure 3.1: Global average near-surface temperatures 1860-Sep 2003.



Hadley Centre for Climate Prediction and Research

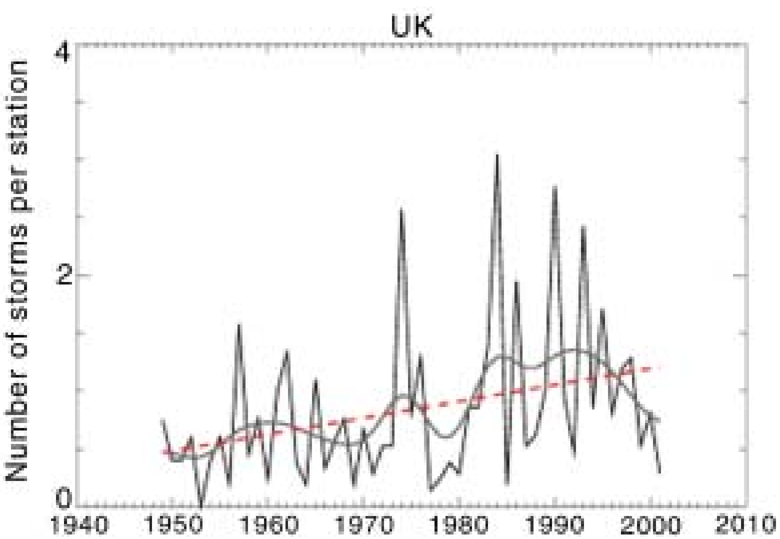
Both satellites and balloons can be used to monitor the temperature of the lower regions of the atmosphere (the troposphere), although satellite measurements have only been available since 1979. Between 1979 and 2000, based on satellites and balloons, the lower-tropospheric warming trend has been +0.04±0.11°C/decade and 0.03±0.10°C/decade, respectively. By contrast, surface temperature trends for 1979 to 2000 were greater, at 0.16±0.06°C/decade. It is very likely that these significant differences in trends between the surface and lower troposphere are real and not solely an artefact of measurement bias, though differences in spatial and temporal sampling are likely to contribute. The differences are particularly apparent in many parts of the tropics and sub-tropics where the surface has warmed faster than the lower troposphere. In some other regions, e.g., North America, Europe and Australia, lower-tropospheric and surface trends are very similar.

The Hadley Centre continues to contribute to the Global Climate Observing System (GCOS) by archiving and analysing radiosonde data, including those from the GCOS Upper Air Network (GUAN). The Defra-sponsored Advanced Along Track Scanning Radiometer (AATSR) satellite instrument, which monitors sea surface temperatures to within an accuracy of 0.3K, was launched in late February 2002 and continues to operate successfully.

Observations of various kinds are crucial not only for monitoring trends but also for understanding how the climate system works, and verifying climate models. For instance, observations show that the tropical troposphere is not warming as fast as climate models predict, and this is an active area of research.

A new focus on “extremes” has been added to the Hadley Centre’s work programme, and an initial study of trends in extreme storms over the UK was completed in 2002. The results show a significant trend of increased storm activity for the UK (see **Figure 3.2**). This may indicate that the North Atlantic storm track has moved south over the last 50 years but more analysis would be required to confirm this conclusion.

Figure 3.2: Time series of changes in October-March extreme storms for the UK. The vertical axis represents the number of ‘storms’ occurring over each region divided by the number of stations reporting; the smoothed line shows decadally averaged values and the dashed line a least squares fit to the data.

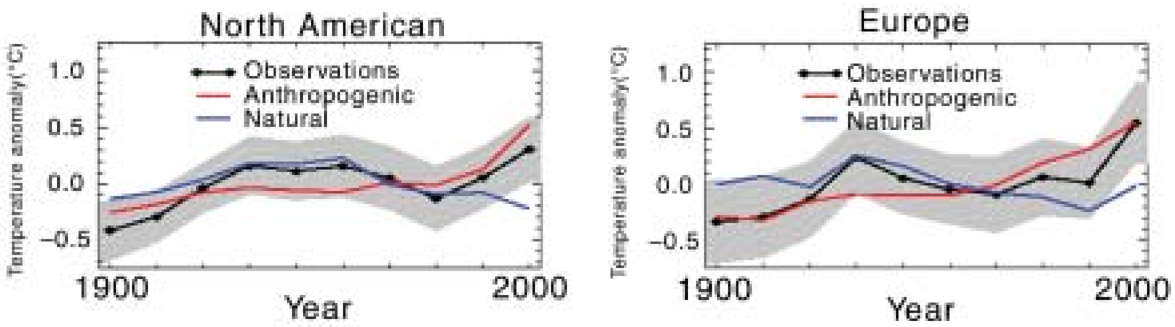


Observations – detection and attribution of climate change

Simulations of past climate, using a computer model, can be compared with the observational record to identify the causes of climate change. The model can be run with different combinations of forcing mechanisms (e.g. solar, greenhouse gases, volcanic aerosols and tropospheric aerosols) to assess how each contributes to the historical record. The Third Assessment Report of the IPCC concluded that most of the warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations. However the forcing due to aerosols, especially due to the indirect effects on clouds, is still very uncertain. The Hadley Centre conducted attribution studies in which the climate response to aerosol forcing was allowed to vary widely. The results showed that the IPCC conclusion is robust to a wide range of uncertainty in the climatic response to aerosols.

Earlier work on detection and attribution of climate change at the global level has been taken a stage further, in that a similar study has been made of change at the regional scale. Warming due to greenhouse gases was detected over North America and Europe. **Figure 3.3** summarizes the results of these studies, showing, in particular, the significant increase in the relative contribution of anthropogenic forcing in recent decades for both Europe and North America.

Figure 3.3: Estimated contributions to temperature changes in North America and Europe from anthropogenic and natural factors.



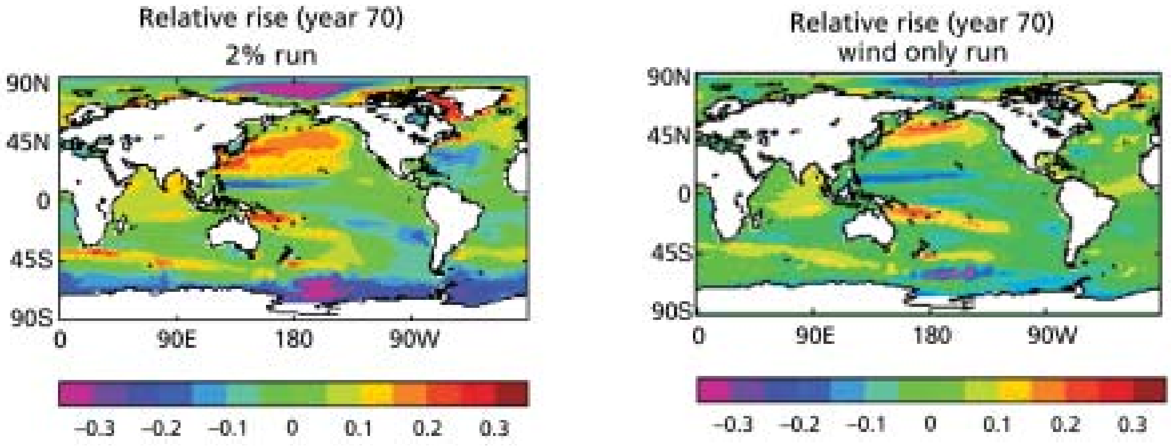
Predictions of future climate change

Global climate projections are undertaken to provide the fundamental predictions of global climate change for a range of emission scenarios. They provide the basis for higher-resolution regional models. Impacts modellers use both global and regional projections to identify effects and provide input to policy outcomes on mitigation and as a basis for adaptation. Both policy relevant scenarios (non-mitigation and stabilisation) and idealised scenarios are used. A significant fraction of the output now involves making assessments of the mechanisms of change, which is important because it allows us to better appreciate the realism of the predictions and often highlights where model improvements are needed.

Some of the exercises undertaken this year include a study of the factors affecting the regional pattern of sea-level rise, projections of changes in Arctic sea-ice, a projection of climate change under the SRES emission scenario A1B, an observationally based (ie model-independent) estimate of climate sensitivity, and projections of storm surge heights around the United Kingdom for the SRES future emissions scenarios.

The study on regional patterns of sea-level change (**Figures 3.4 and 3.5**) showed that when wind anomalies from an increasing CO_2 simulation were applied to a control simulation, sizeable sea level changes occur in some regions. This occurs because the changed wind patterns drive changes in the transfer of heat and salty water within the ocean; this in turn leads to changes in the density of ocean water in different regions (water that is warm and less salty has a lower density). This leads to corresponding changes in the volumes occupied by ocean water in different regions and thus a direct effect on sea level. These results are important because they suggest that, although changes in wind speeds are not important to global average sea level rise, they are important in determining the pattern of sea level rise across different regions.

Figures 3.4 and 3.5: Regional pattern of relative sea-level change after 70 years of a 2% per year increasing CO_2 simulation (left panel). When the wind anomalies from this simulation are applied to a control simulation (right panel) sizeable sea level changes occur in some regions.



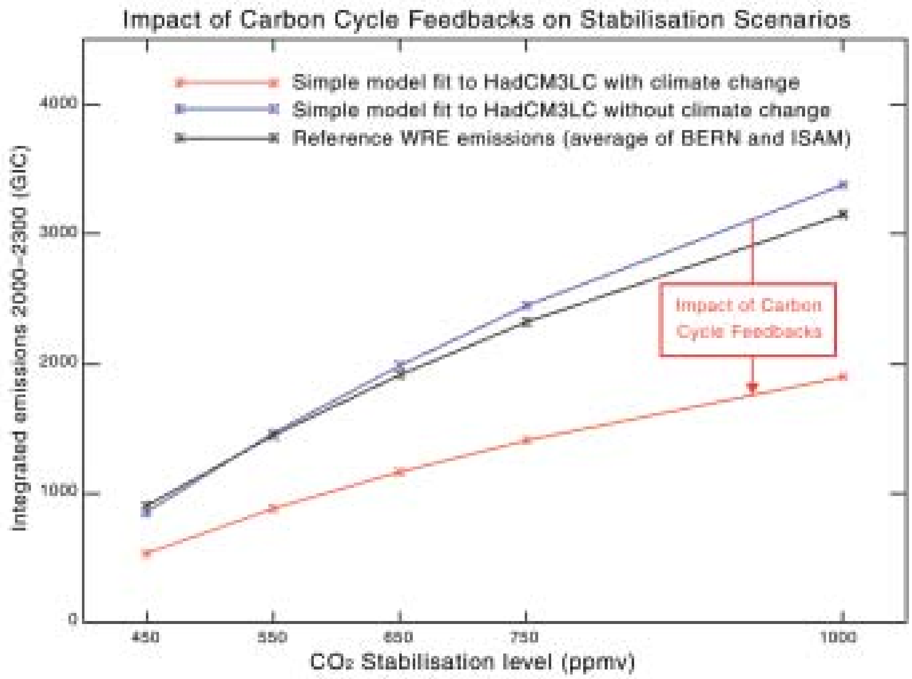
Improving model predictions – water vapour and carbon cycle

Atmospheric warming can affect physical processes in the atmosphere in such a way that the initial warming is enhanced, or reduced. These effects are known as positive and negative feedbacks. Two climate-related examples of feedbacks are water vapour feedback and the carbon cycle, which can both affect the outcome of climate predictions.

Recent work on water vapour has combined satellite information with information from analysis of meteorological data to improve the accuracy of cloud modelling. Representation of some types of cloud in the Hadley Centre model has improved, and will be used to increase understanding of cloud processes and water vapour feedbacks.

The Hadley Centre has used their coupled carbon-climate model to investigate the causes behind their earlier results that showed an acceleration of global warming due to the carbon cycle feedback. Results this year predict that increasing CO_2 levels would lead to substantial dieback of the Amazon, which could have a huge impact on the climate. Studies of critical points in the climate-carbon cycle interactions have shown that the land carbon cycle will act to slow climate change until CO_2 concentrations in the atmosphere reach a critical level of about 550ppm, at which point the land carbon cycle will start to accelerate climate change. If confirmed, it implies that much greater cuts in emissions will be required to meet particular stabilisation levels of CO_2 in the atmosphere than are currently anticipated.

Figure 3.6: Impact of climate-carbon cycle feedbacks on the allowable emissions (from 2000 to 2300) for stabilisation at each CO_2 concentration. The black line is from the standard "WRE" scenarios (developed by Tom Wigley and colleagues in 1996), and the red and blue lines are fits to the Hadley GCM with and without climate-carbon cycle feedbacks.



Improving model predictions – black carbon

Sub-models that allow simulation of fossil-fuel black carbon aerosol (FFBC) and biomass smoke were included in the latest Hadley Centre model. Particular attention was paid to exploring the climate sensitivity to FFBC, as some published work had asserted that this is higher than the sensitivity to increasing CO_2 and other greenhouse gases. However, Hadley Centre results suggest that the climate sensitivity to FFBC is, if anything, rather lower than the sensitivity to CO_2. The explanation for this is that some of the feedback mechanisms in the climate system, especially those involving changes in clouds, respond differently to radiative forcing from FFBC compared to greenhouse gases – and these feedbacks are simulated with differing levels of sophistication and accuracy in different models. This work is very important because it shows that the concept of radiative forcing (commonly used to compare the importance of different climate perturbations) has certain limitations because the temperature change in response to radiative forcings of equal magnitude (but from different causes) is not always the same.

Improvements to the chemistry in the models are enabling the modelling of climate change impacts on tropospheric ozone and methane levels in the atmosphere.

Improving model predictions – oceans

The oceans play a central role in the climate system. The oceans and atmosphere interact, and can transfer energy, mass, momentum and trace gases to one another (for example, when water vapour evaporates from the surface of the ocean, to form clouds and the oceans are an important site for man made CO_2). The transfer of heat from the ocean to the atmosphere by the warm Gulf Stream keeps the UK climate milder than other countries at a similar latitude (e.g. Poland). The Gulf Stream is also driven by complex interactions between the oceans and the atmosphere. It is therefore important that the ocean is accurately simulated when studying climate.

Oceans absorb heat and carbon dioxide, which affects the temperature and composition of the atmosphere. The extent to which the ocean can do this is limited by the rate at which water masses are mixed; cold, carbon-poor water can rise from the deep ocean to the surface, where it will absorb much more heat and carbon dioxide than warm carbon-saturated water that has been at the surface for some time. The Hadley Centre has improved the model representation of mixing processes in the ocean, by which heat, salt and chemical tracers are transmitted from the surface to the deep ocean, in order to simulate more realistically atmosphere/ocean interaction. Additionally, the Centre has improved simulation of local atmospheric conditions, by increasing the resolution of modelled oceans, in order to more accurately represent small-scale ocean processes which can actually be responsible for the transfer of significant amounts of heat across large areas of ocean.

Previous work at the Hadley Centre has shown that the Thermohaline Circulation (THC), an ocean circulation pattern that incorporates the Gulf Stream and helps to maintain the mild European climate, would be affected by climate change. Cold salty water sinks at high latitudes, allowing warm water to flow into its place. As the warm water flows north (passing the UK), it eventually cools and sinks and, in return, oceanic circulation is established. A change in atmospheric conditions will affect the ocean temperatures and salinity and could change this circulation pattern, which could subsequently affect the UK's climate. The Hadley Centre showed that the THC could become unstable and trigger a period of substantial and rapid climate change in the Northern Hemisphere. Work has continued to assess the processes that would affect the THC and to identify means of monitoring it. The Hadley Centre is also involved in a major research programme on rapid climate change (RAPID), which is funded jointly by the Natural Environment Research Council (NERC), the Research Council of Norway (RCN) and the Nethelrands Organisation for Scientific Research (NWO).

Regional models

Although global models can be used for impact assessment, their coarse resolution prevents them from being used to provide anything more than a broad picture. Generally a much finer resolution is required (less than 50 km) than for the typical global model (greater than 150–250 km). Running a model with fine resolution consumes far more computer time and power so, for practical reasons, fine resolution models must be run for relatively small regions. (It would require a significant increase in the amount of computing power and/or computer time to run a global model at such high resolution.) As regional climate is clearly affected by global climate it is necessary to use predictions from the global models as input at the regional model boundaries. The Hadley Centre regional model can simulate realistically high rainfall over the mountainous regions in the west of the UK. The resulting predictions of local atmospheric conditions can not be simulated by a much coarser-resolution global model.

The regional climate models were used to produce the most recent UK climate scenarios. These scenarios are discussed in greater detail in **Chapter 4** dealing with the impacts of Climate Change on the UK. The model results focused on the variation of distribution and intensity of storms, precipitation and temperature extremes in the future. An opportunity to validate the accuracy of the regional model was taken following the floods in Autumn 2000 and the model was able to simulate realistically extreme precipitation associated with the floods. Future predictions using the regional model, to investigate impacts of climate change in the UK, indicate that the frequency of extreme precipitation events is expected to increase greatly by the end of the century; events that now recur every 20 years are predicted to recur every 2–3 years.

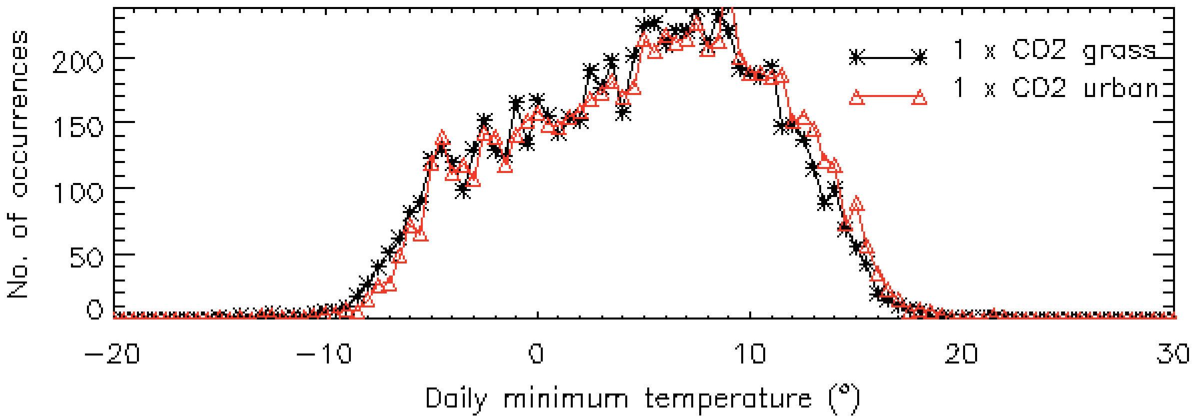
The Hadley Centre has developed a regional model for use in developing countries and, with assistance from the Department for International Development (DFID), has started to provide appropriate technology and training to allow its widespread application. The transfer of the model to run on computing platforms accessible to developing countries has been very successful and has involved the development of a user-friendly PC-based regional climate modelling system (PRECIS – Providing Regional Climates for Impacts Studies). Presentations of PRECIS at international conferences have generated a large amount of interest and will be used to support a World Bank climate change impacts and adaptation project for Africa.

Physical, chemical and biological processes

Impact studies often need to focus on specific types of area, to assess the effects on particular environments or communities. Urban areas tend to be warmer than rural areas, especially at night (**see figure 3.7**) but due to their relative insignificance in terms of land area they tend to be given little attention in climate models. However, in terms of predicted impacts of climate change on human populations, urban areas are clearly very important. The Hadley Centre land-surface scheme has been adapted to include parameterisations of urban areas, and results this year have shown that greenhouse gas induced warming is different over urban areas compared with non-urban areas.

Figure 3.7 illustrates the difference in night-time minimum temperatures in urban and rural areas in the climate model. The red and black curves show the number of nights simulated with each minimum temperature on urban and rural ("grass") land respectively. The red curve is biased more towards high temperatures, showing that the warmer temperatures are seen more often on urban land than rural land.

Figure 3.7: Daily minimum temperature frequency for urban and non-urban (grass) areas simulated for the London area.



Another impact on society due to climate change is alteration to river flow. The Hadley Centre has included a river-routing scheme in its models, which has improved the agreement of modelled river flow with observations, enabling further work to be carried out on the impact on society and the levels of freshwater reaching the oceans.

Near-term climate forecasting

The Hadley Centre has started to investigate the possibility of making climate change predictions for the near-term (i.e. 5–15 years into the future), which is a much shorter timescale than is usually studied for climate predictions. It is unlikely that we can do anything to prevent climate changes on such a short time scale, but near-term predictions will assist with the formulation of policies to encourage potentially vulnerable sectors within the UK to prepare for climate change, and to make adequate plans for adaptation to mitigate the effects, whilst capitalising on any predicted benefits. This timescale represents a considerable challenge as natural , decadal variability is comparable to the underlying trend due to external forcing.

Climate observations and model validation

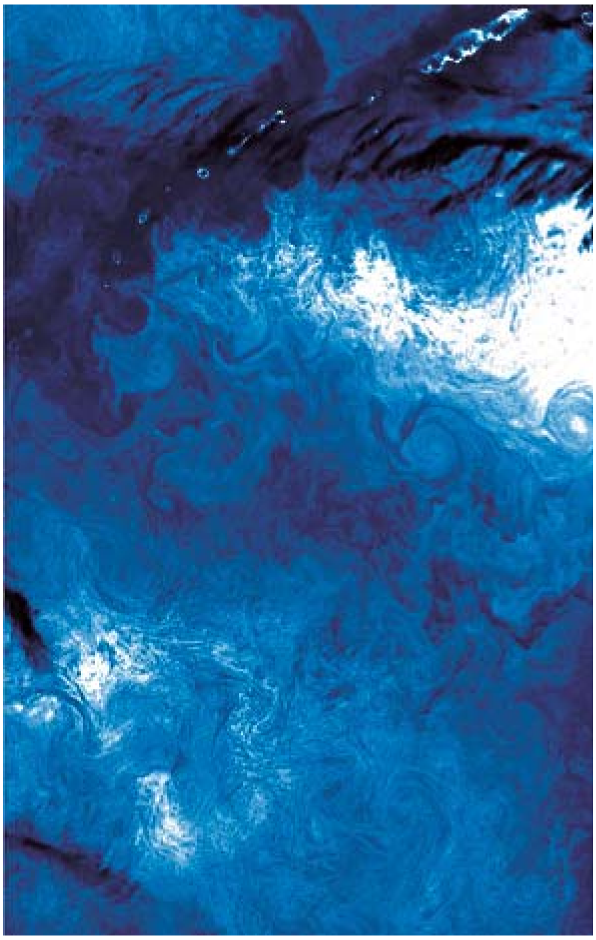
Confidence in the results from climate research continues to grow, as increasing numbers of studies are reaching similar conclusions. The Climate Research Unit (CRU) at the University of East Anglia recently reported UK climate trends, as observed from historical data records, constructed from a record of tree-ring measurements and compared with model simulations of past climate. Model simulations showed less variability than the observational record, and this is thought to be partly due to the omission of natural forcing (such as solar or volcanic). Irrespective of whether model or observational data is used, however, recent trends in summer temperature appear to be outside natural temperature variability, suggesting a recent anthropogenic influence on the UK's climate. The CRU assisted with the validation of Hadley Centre climate models by making comparisons with observational data sets, and showed that the models performed well.

Earth observations of sea surface temperature

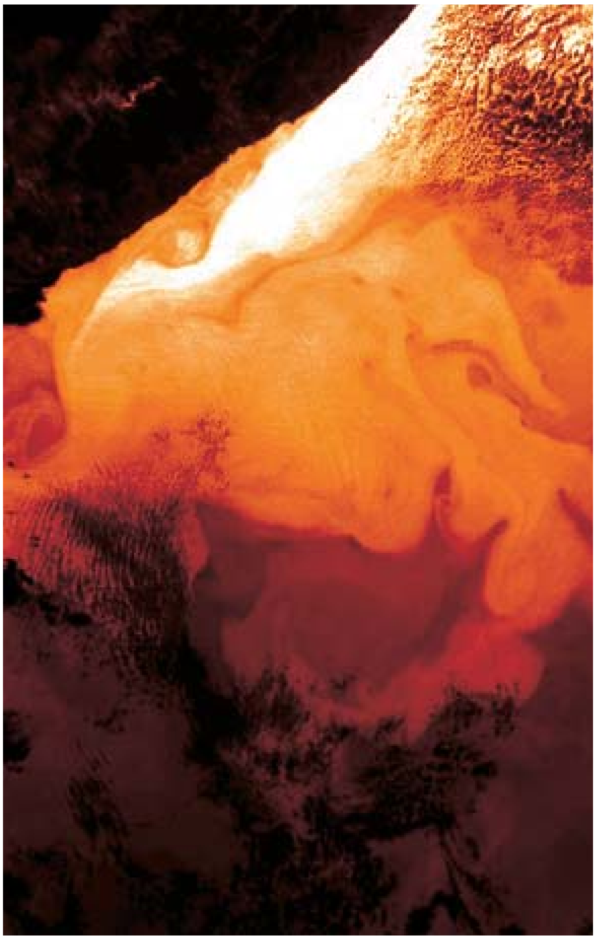
Accurate monitoring of climate trends relies on the availability of observational data. Although it is relatively easy to make measurements on land, there are large gaps in the data record over the oceans. Defra has supported the production of an Advanced Along-Track Scanning Radiometer (AATSR), a remote sensing instrument capable of making accurate measurements of sea surface temperatures.

Figure 3.8 shows thermal images of estimated sea surface temperatures taken in May and July 2002 by the AATSR satellite instrument in two different locations – Japan and South Africa. The Japanese image (left) shows a range of sea surface temperatures of 275.5 K (dark blue) to 280.5 K (white). The range of sea surface temperatures for the South African coast image (right) is 286 K (dark red/brown) to 239 K (white).

Figure 3.8: Thermal images from AATSR



North of Hokkaido



Coast of South Africa

Box 3.1: AATSR satellite instrument

The Advanced Along-Track Scanning Radiometer (AATSR) was launched on ENVISAT satellite in March 2002. AATSR is the third in a series of similar instruments, which started with ATSR-1 on the ERS-1 satellite launched in July 1991, and continued with ATSR-2 on ERS-2, launched in April 1995. Defra is the lead agency for the AATSR, and provided 70% of the costs of the instrument, with other costs being provided by NERC and the Australian Department of Industry, Science and Tourism. The Department's primary objective for the AATSR programme is to continue the consistent, long-term set of global sea surface temperature measurements started by ATSR-1 and ATSR-2. The Hadley Centre will use the data set to improve climate models (particularly the oceanic component) and to identify the anthropogenic signal of climate change in the oceans. Land surface temperatures are also being retrieved by the instrument and will be studied by the Australian Bureau of Meteorology.

Astrium Limited (formerly British Aerospace Space Systems Limited) completed the satellite instrument in early 1999. More recently they provided support during the launch of the satellite and the commissioning period, which finished at the end of 2002. The Rutherford Appleton Laboratory performed a number of pre-launch tests and developed a suite of plans, procedures and tools to ensure that all the technology was in place to support the instrument during the commissioning phase and routine operational phase. The Department also supports a Principle Investigator (PI) and Validation Scientist at the University of Leicester, who will validate the AATSR data and eventually ensure that the data is correctly exploited to provide useful scientific information for Defra. (www.leos.le.ac.uk/home/aatsr)

Ocean measurements from ocean buoys

ARGO (www.wmo.ch/hinsman/en/ap9-22.htm) a global array of profiling ocean floats, is an important international programme, endorsed by the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC), that will benefit all nations. It is a major contribution to the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS) www.wmo.ch/web/gcos/gcoshome.html. ARGO has the potential to greatly enhance our understanding of the oceans, providing significant benefits to our ability to predict climate change. The expectation of ARGO is to have approximately 3,000 floats deployed globally by 2006, to which the UK has indicated it is willing to contribute 50 floats per year. Since its inception in 1999 15 nations (Australia, Canada, China, Denmark, France, Germany, India, Japan, New Zealand, Norway, Republic of Korea, Russia, Spain, UK and USA), along with the European Commission, have committed support towards building the ARGO array.

At April 2003, 80 UK floats had been deployed during the pilot phase, providing much useful information about their characteristics and performance. Further UK deployments will be made in the North and South Atlantic, the Southern Ocean and the Indian Ocean. The deployment regions are determined in consultation with Hadley Centre scientists (who advise where additional observations would be most useful scientifically) and are co-ordinated internationally through the ARGO science team.

It is widely recognised that society is locked into some degree of climate change, no matter how successful we are at cutting greenhouse gas emissions. The UK therefore needs, along with the rest of the world, to assess the potential impacts of climate change, and to devise pro-active adaptation plans in order to minimise these impacts. To this end, Global Atmosphere Division supports a programme of policy-led research on climate change impacts and adaptation, applied both to the UK and other parts of the world.

Impacts of climate change in the UK

The UK Climate Impacts Programme (UKCIP)

The UK Climate Impacts Programme (UKCIP) was set-up by Defra (then DETR) in 1997, with the aim of establishing a research framework for the integrated assessment of climate change impacts in the UK.

At the heart of UKCIP is a Programme Office based at the Environmental Change Institute (part of the University of Oxford). The Programme works in a 'bottom-up' mode, supporting organisations carrying out studies, to assess their vulnerability to climate change impacts and the ways in which they could respond to any potential threats or opportunities (for example, by adapting).

The Programme is an established link between stakeholders and researchers, and helps to make connections between partners to stimulate climate change impacts studies. It is intended that this broad-based approach should lead to an integrated national assessment. To assist the achievement of this aim, UKCIP facilitates the sharing of information and provides core data sets and a common 'toolkit'.

For further details about the Programme, access to the UKCIP toolkit and assessments, please visit the UKCIP website, at: **www.ukcip.org.uk**.

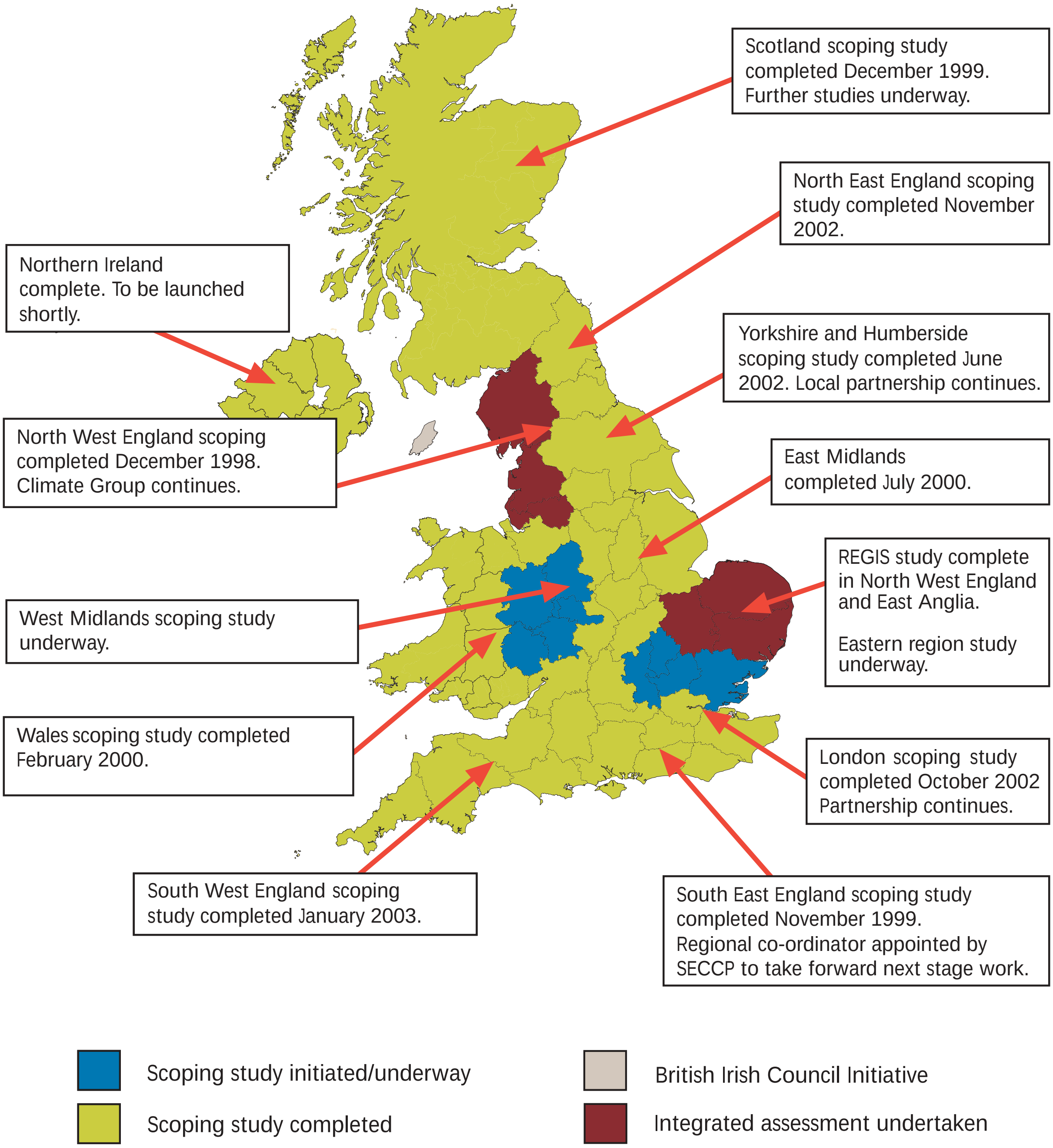
UKCIP activities during 02/03

UKCIP continues to be at the forefront of UK climate impacts research, being actively engaged in some thirty regional and sectoral studies to date. Additionally, development of the UKCIP toolkit has continued apace. Details of some of the research completed during 02/03 are given in the following sections.

Regional studies

All the English regions, together with Scotland, Wales and Northern Ireland have completed, or are undertaking climate impacts scoping studies, which give a basic idea of the impacts that are likely to be of significance to that particular region. The current status of the various regional assessments (at October 2003) is shown in **Figure 4.1**.

Figure 4.1: Current status of UKCIP regional assessments (October 2003).



Reports of four regional scoping studies (Yorkshire/Humberside, London (see **Box 4.1**), the North-East and the South-West) were published during 02/03. Only two English regions (East of England and West Midlands) are yet to report, and these scoping studies are expected to be produced in the coming year.

Table 4.1: Summary of potential climate change impacts on London's environment (derived from 'London's Warming' Technical Report – London Climate Change Partnership, 2002).

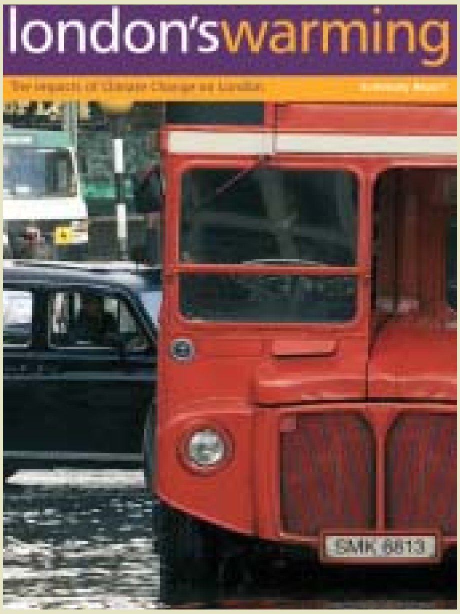
Issues	Potential impacts could include…
High urban temperatures (particularly in summer)	Increased summer heat stress and mortality Higher temperatures on London Underground Increased use of air conditioning Increased risk of fires Higher rates of refuse decay Increased water demand Reduced need for winter space-heating
Air quality	Increased concentrations of air pollutants Acute asthma epidemics Export of air pollutants to a wider region Negative impacts on urban vegetation and infrastructure
Water resources	Reduced summer soil moisture Lower summer/higher winter river flows Deteriorating water quality Increasing water demand More leakage from underground pipes
Flood risk	More heavy rain- or snow-fall days in winter Fewer heavy rainfall days in summer More frequent flooding of London Underground More frequent closure of the Thames Barrier More localised shallow groundwater flooding
Biodiversity	Changes in physical habitat availability Changes in species reproductive success, community structure and behaviour Coastal 'squeeze' of Thames estuary intertidal habitats More pressure from tourism at conservation sites Extended range of some exotic species

Sectoral studies

Built environment

The research portfolio 'Building Knowledge for a Changing Climate' was launched during early 2003. This portfolio is the result of collaboration between UKCIP and the Engineering and Physical Sciences Research Council (EPSRC), aimed at engaging stakeholders in the setting and running of a research agenda to study the potential long term impacts of climate change on the built environment, transport and utilities in the UK. EPSRC have, so far, funded these projects to a value of £2.2 million.

Box 4.1: UKCIP – A user's experience (Matthew Chell, Senior Policy Adviser, Greater London Authority)



The London Climate Change Partnership carried out its impact study, *London's warming*, during 2002/03. It is a broad-ranging study and required a consortium of consultants to carry it out. It was able to be undertaken so swiftly because many of the tools it required were already available through UKCIP.

The UKCIP climate change scenarios have been developed and robustly tested against other climate change models and are regularly compared to actual changes over time. These scenarios were the basic ingredient in our climate impacts study.

The existence of the climate change scenarios is important for two reasons. Firstly, without them the LCCP would have had to commission our own scenarios, leading to added cost and, more importantly, delay. Secondly, the fact that the scenarios are of high quality and generally accepted in the scientific world means that there were no arguments within our Partnership about whether climate change was really happening or about the exact levels of climate change. We were able to move immediately to consider the impacts.

The London study also benefited from the experience of other regions, through the knowledge accumulated by UKCIP and the understanding of their staff. In particular, UKCIP is aware of the importance of the process of producing the study, and the need to engage and maintain involvement of the key stakeholders. Involvement promotes ownership of the results and facilitates joint working on future projects, such as on adaptations. UKCIP were able to supply appropriate contacts in relevant organisations, saving us considerable time.

Gardens

The sectoral scoping study *Gardening in the Global Greenhouse – the impacts of climate change on gardens in the UK* was launched in November 2002. The study provides a summary of the best information currently available, and identifies key information gaps in assessing the impacts of climate change on gardening, heritage gardens and commercial horticulture and, consequently, defines a future research agenda.

UKCIP toolkit

UKCIP02 climate change scenarios

Recognising the need to update the 300km resolution UK climate change scenarios developed in 1998, 50km resolution scenarios (called the 'UKCIP02' scenarios) were produced by the Hadley Centre and the Tyndall Centre and launched in April 2002.

The UKCIP02 scenarios are the first to be produced for the UK from a regional climate model, and related to the internationally-agreed set of socio-economic storylines developed by the IPCC (see **Box 4.2**). These four SRES (Special Report on Emmissions Scenarios) storylines are used to represent possible future worlds, in which greenhouse gas emissions could be 'Low, 'Medium-Low', 'Medium-High' or 'High'.

Since the launch of the UKCIP02 scenarios, licences for their use have been issued for 80 studies, conducted by a range of organisations including academic researchers, public bodies and technical consultants, in addition to charities and companies.

All recent UKCIP climate change studies have used the UKCIP02 scenarios, including regional studies for Yorkshire & Humber, South West England, London, East of England, and the West Midlands (latter 2 due out during winter 2003) and sectoral studies on gardens, biodiversity, health, land use and water demand. Other recent key studies that have used the new scenarios include the Foresight Flood and Coastal Defence Project, the Environment Agency Southern Region regional guidance on the application of UKCIP02 scenarios for water resource studies, and the UK Water Industry Research Limited (UKWIR) report *Effects of climate change on river flows and groundwater recharge: UKCIP02 scenarios,* which presents a procedure for rapid assessment of climate change impacts by the 2020s. Forthcoming studies from the Building Knowledge for a Changing Climate portfolio (see UKCIP sectoral studies) will also use the UKCIP02 scenarios.

Findings from the research studies are placed in the public domain, and so contribute to the wider body of knowledge and understanding of climate change impacts. UKCIP is uniquely placed within the network of climate change research and information to create links, identify gaps and ensure that new research builds on the success of earlier studies.

For more information about the UKCIP02 scenarios, visit the scenarios gateway (**www.ukcip.org.uk/scenarios**) on the UKCIP website.

Box 4.2: IPCC special report on emissions scenarios – projections of a future world

The IPCC Special Report on Emissions Scenarios (or SRES scenarios) describes four storylines (given the names 'A1', 'B1', 'A2' and 'B2') which represent possible ways in which the world will develop throughout the 21st century. Depending on the way in which global society develops over the next century, each storyline projects certain changes in population and social, economic, and technological development. These changes are then translated into different levels of future greenhouse gases and aerosols, and associated changes in the Earth's climate and sea level within the world's oceans. The SRES scenarios are not predictions of the future state of the world, but instead provide an idea of the way in which the world *could* develop in the future.

The four scenarios can be summarised as follows:

A1 Series (high greenhouse gas emissions) describes a future world of very rapid economic growth, a global population that peaks in the mid 21st century and then declines, and the rapid introduction of new and more efficient technologies.

B1 (Low emissions) describes a future world similar to that within A1, but assumes a rapid transition towards a cleaner (less carbon-dependent) economy, based on services and information.

A2 (Medium-high emissions) describes a future world where population continues to increase, and with an emphasis on self-reliance and preservation of local identities. Per-capita economic growth and technological change are slower and more fragmented than the other storylines.

B2 (Medium-low emissions) describes a future world that emphasises local solutions to sustainability, with a slowly by steadily growing population, with medium economic development and less rapid and more diverse technological change than in the B1 and A1 storylines.

None of these scenarios explicitly assumes that the Climate Change Convention is implemented or that policies are adopted to achieve the Kyoto Protocol's emissions targets. Nevertheless, they do include scenarios which involve lower dependence on fossil fuels than at present.

A summary of this report for policy makers is available on the web at:
www.ipcc.ch/pub/sres-e.pdf

British-Irish Council climate change scenarios

The British-Irish Council (BIC) is an institution that was created under the Good Friday Agreement between the British and Irish Governments. At the first British-Irish Council Summit it was agreed that the UK Government would take responsibility for advancing cooperation on the environment and take forward work on a number of specific areas of interest to Members. This included the establishment of a subgroup on climate change impacts and adaptation which was set up to:

- exchange national information on the impacts of climate change and adaptation between the BIC member countries; and
- co-operate on areas of mutual interest, with the view to developing a fuller understanding and greater awareness within and between the BIC countries of the vulnerability to climate change and how they might adapt.

A key output of the group's activities are the BIC Climate Change Scenarios. These were produced in 2003, with a view to helping improve understanding of the impacts of climate change in the different BIC administrations (particularly the islands), so that they are in a better position to prepare to adapt to any potential consequences.

The Hadley Centre (see **Chapter 3**) undertook the necessary climate modeling work at a higher resolution (25km) than had previously been achieved within the UKCIP02 scenarios (50km), as the higher resolution would more accurately represent the major islands of the BIC area (e.g. Shetland Isles, the Isle of Man, Channel Islands). Changes in summer and winter average temperature and precipitation between a recent climate (1961-1990) and the 2080s (2071-2100), for a Medium-High scenario of future emissions, are shown in **Table 4.2**.

Table 4.2: Changes in summer, winter and annual average temperature and precipitation between a recent climate (1961-1990), and the 2080s (2071-2100), for a Medium-High greenhouse gas emissions scenario.

Region	Mean temperature (°C)			Precipitation (%)		
	Annual	Summer	Winter	Annual	Summer	Winter
Channel Islands	+3	+3.8	+2.4	-4	-45	+24
Isle of Man	+2.4	+2.7	+1.7	-1	-36	+20
Western Isles	+1.8	+1.5	+1.4	0	-22	+8
Orkney Islands	+2	+1.8	+1.6	-1	-27	+10
Shetland Isles	+2.2	+1.9	+1.8	+2	-19	+10

Further information about the climate change scenarios for the British-Irish Council region can be obtained by visiting the climate change pages of the BIC website: www.british-irishcouncil.org/climatechange/ .

International/global impacts of climate change

In addition to UK-focused impacts and adaptation activities, GA Division is concerned about the impacts of climate change in other parts of the globe. To this end, the GA research programme contains work elements that are targeted towards addressing the issue of climate change impacts and adaptation internationally.

The LINK project

The Climate Impacts LINK project, based at the University of East Anglia, has been used as the interface between the Hadley Centre and the national and international climate change impacts communities since 1991.

LINK's main purpose is to facilitate the exchange of climate impacts-related ideas and information; it manages to achieve this in several ways. For example, the LINK website (**www.cru.uea.ac.uk/link**) hosts the following readily-accessible information:

- Hadley Centre's climate model results, from the most recent climate change experiments (in addition to results from earlier models);
- A climate change research community database, including details of data users, project details and publications that have used results from the Hadley Centre's climate change experiments;
- Datasets for the IPCC Data Distribution Centre (see below); and
- A database containing observed climate data, including global and regional datasets.

Scientific and technical advice is provided to members of the climate change research community by staff at the University of East Anglia's world-renowned Climatic Research Unit.

A large proportion of work undertaken within the LINK project during 2002/2003 involved the distribution of UKCIP02 scenario data sets to climate impacts researchers. LINK now hosts an on-line archive, containing over one and a half terabytes of data.

A new contract was started in March 2003. The data handling capabilities of the LINK service needed to be improved in order to cope with increasing demands on IT infrastructure, as model complexity (and, consequently, file size) increases. The successful bid, therefore, involved coordination of the previous LINK service with the ongoing data provisions of the British Atmospheric Data Centre (BADC). Data extraction, processing and archiving activities have therefore been moved from the Climatic Research Unit to BADC, allowing faster data transfer rates and increased storage capacity, and enabling users to customise their data requests.

As part of the UK's commitment to the ongoing activities of the IPCC, the LINK project also jointly operates the IPCC's Data Distribution Centre (DDC), along with organizations in Germany and the US. The DDC has been functioning since early 1998 and supports the activities of the Technical Support Units of Working Groups I (scientific basis), II (impacts and adaptation) and III (mitigation).

More specifically, DDC activities include:

- collating new climate model datasets that meet the quality control criteria of the IPCC's Task Group on Scenarios for Climate Impact Assessment (TGCIA);
- enhancing and extending Guidance Material;
- widening the range of accompanying climate, environmental and socio-economic datasets that currently exist and those that become available; and
- encouraging climate modelling centres to make available daily data.

The DDC is web-based (**http://ddcweb1.cru.uea.ac.uk**) and the site receives approximately 35 000 unique hits per year.

Intergovernmental Panel on Climate Change (IPCC)

Fulfilling the UK's obligations to the IPCC, Global Atmosphere Division provides support (directly and through support of a Technical Support Unit (TSU)) of UK-based scientists who have been elected to play a role in the IPCC (see **Box 2.1 in Chapter 2** for more information about the work of the IPCC).

For the first half of 2002, the UK-based Sir John Houghton completed his duties as co-chair of Working Group I (WGI – investigating the scientific basis of climate change), for which the TSU (based at the Met. Office) continued to support WGI activities until responsibilities were transferred to the new WGI (based in the USA).

At a meeting of the UNFCCC in April 2002, the UK successfully proposed Professor Martin Parry as co-chair of Working Group II (WGII impacts, adaptation and vulnerability). Professor Parry took up this post during July 2002 and is expected to remain as WGII co-chair until the IPCC's Fourth Assessment Report is delivered, in 2007. During 2002/2003 the Met. Office was successful in its bid to host the WGII TSU.

Since being set up, WGII TSU activities have focused on deciding the design and structure of the IPCC's Fourth Assessment Report (AR4), which will be published in 2007. Two expert meetings were organised in support of this process, both focusing on appropriate topics to serve as major cross cutting themes in AR4.

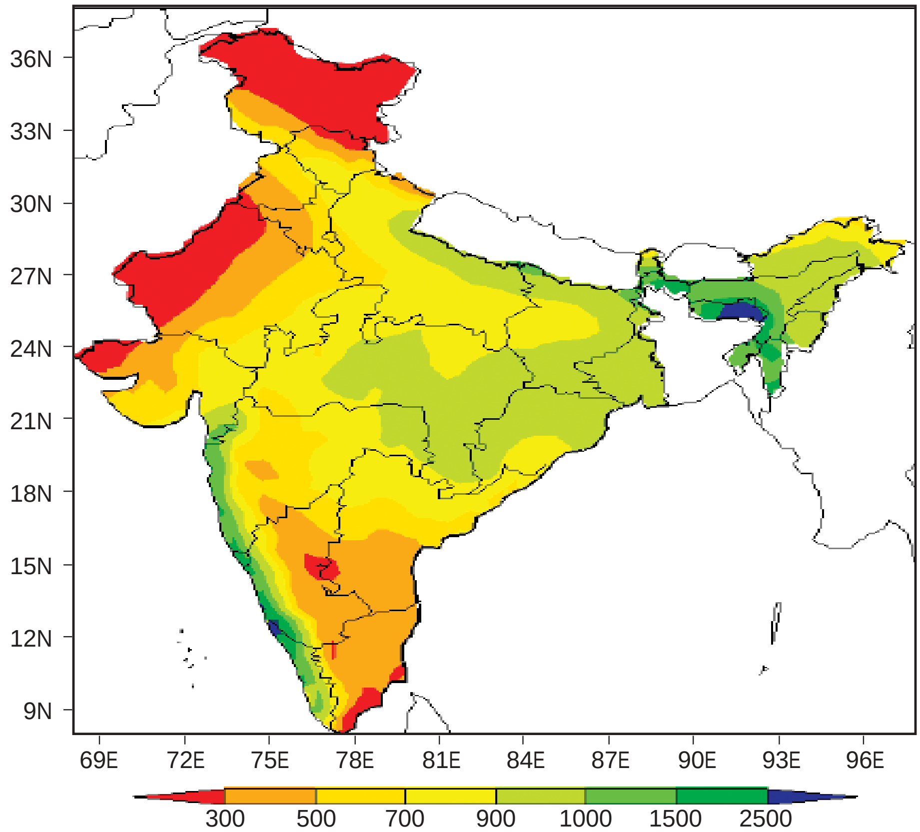
Impacts of climate change in India

In terms of climate, India occupies a very important position in the South-East Asian region. The factors which control the climate of the country – for example high monsoon rainfall (see **Figure 4.2**) and temperature – provides India with a great wealth of natural resources, such as water resources and vegetation. The prediction and assessment of the impacts of climate change on India is still an emerging field and a great deal of research needs to be undertaken in order to understand the possible magnitude and potential consequences of the projected climate change on the region.

GA Division supports a four year collaborative research programme with the Indian Ministry of the Environment and Forests (MoEF). The programme, managed by Environmental Resources Management (ERM) and involving research carried out by Indian research scientists, builds on India's existing expertise, to:

- assess the sectoral impacts of climate change;
- reduce uncertainties in prediction models; and
- make a valuable contribution to international climate science.

Figure 4.2: Mean summer monsoon precipitation distribution over India (coloured bar indicates mm of precipitation over the monsoon season).



Research on climate change scenarios and socio-economic scenarios provide basic assumptions on key impact variables such as temperature increase, sea-level rise, precipitation, population and economic growth for the time periods 2020, 2050 and 2080. Six further studies are using the climate change and socio-economic scenarios to assess the impacts on:

- Sea level variability (a sea level rise of 1 metre could displace 7 million people if there is no change in current policies or populations);
- Water availability and quality (annual river runoff may fall by 70% in some areas);
- Forests (for which biomass production may drop significantly);
- Agriculture (which currently occupies two thirds of the labour force and will be vulnerable to changing crop yields and water availability);
- Health (e.g. increased incidence of malaria is a likely consequence of climate change); and
- Energy, industry and transport infrastructure (which will be vulnerable, particularly to sea level rise in coastal areas).

The project is due to be completed in June 2004. Further information can be found via the ERM website (**www.erm.com**)

Impact of climate change on Chinese agriculture

A collaborative project investigating the impacts of climate change on Chinese agriculture was initiated in 2001, between Defra and the Institute of Agrometeorology at the Chinese Academy of Sciences.

The project, managed by AEA Technology, is assessing the potential impact of climate change on various key Chinese agricultural crops (wheat, rice, cotton, maize) and will highlight particularly vulnerable regions of China.

The project involves the development and application of climate and socio-economic scenarios for China, and applies these in conjunction with land-use forecasts, to provide an improved estimate of the expected changes in agricultural crop yields in the light of projected rises in atmospheric greenhouse gas concentrations.

The Hadley Centre PRECIS (higher resolution regional climate) model was successfully run to produce predictions of climate change in China for the 2070s.

Early results from the project suggest that, by the 2070s, the occurrence of extreme low temperature events would decrease during winter, of extreme high temperature events would increase during summer and of extreme precipitation events would increase. Initial agricultural impacts modelling indicates that projected changes in climate could result in a reduction of between 5 and 10 percent in the production of the main crops in China in the next 30 years.

Climate impacts modelling work has also been carried out at the sub-national scale and early results indicate that, under certain scenarios, southern China could change from being a net exporter of grain to a net importer, while grain production in the north could increase rapidly.

The modelling work is continuing throughout 2003/2004, with a range of climate change scenarios being produced and impacts modelling relating specifically to the different crops.

Project activities during 2002/2003 also involved workshops, training visits, and study tours, which enabled a continued healthy and productive exchange of information between Chinese and British research scientists and policy makers.

Further details can be obtained by visiting the project website: **www.ami.ac.cn/sino_uk**

'Fast track' global impacts studies

In order to obtain an overview of the possible global impacts of climate change, a number of 'broad brush' studies were commissioned, to investigate the global impacts of climate change on human health, natural vegetation, agriculture, the coastal zone, and water resources.

These studies (referred to as 'Fast Track') used projections of possible climate change and sea level rise associated with the IPCC SRES scenarios (see **Box 4.2**). Climate predictions from the Hadley Centre, based on SRES, were then used to assess the various sectoral impacts.

This work is among the first investigating global impacts of climate change, utilising the SRES scenarios. Earlier fast-track studies (see previous GA Research Programme Annual Reports) were not based on the SRES scenarios; this may explain any contrasting results between the results of this and the earlier fast-track work. This research is yet to be published in a peer-reviewed journal, but preliminary results are summarised below.

Impacts on the global coastal zone

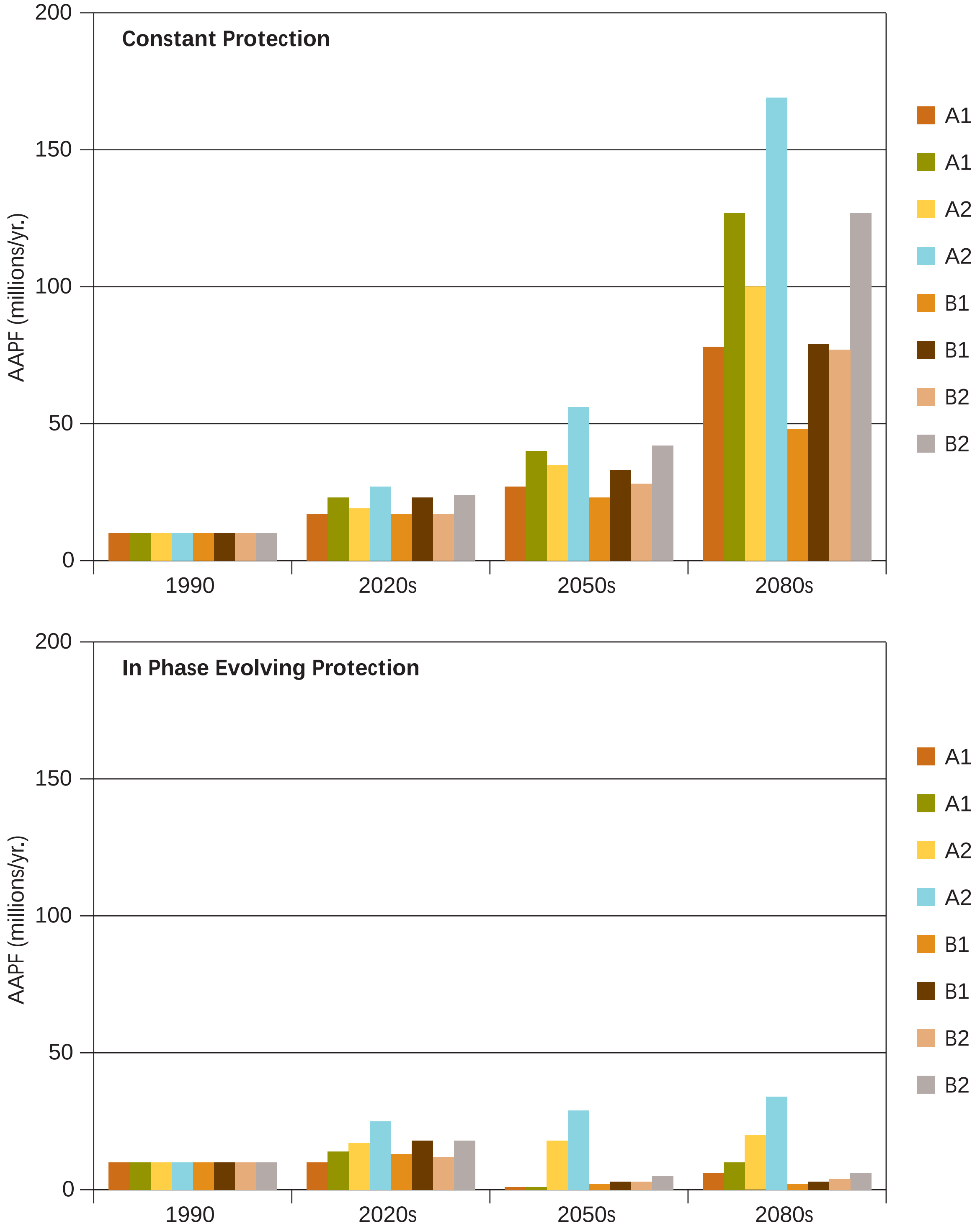
Overall, the global coastal zone impacts study shows that the impacts of climate change will be strongly influenced by socio-economic factors (such as population growth and standard of coastal flood protection – see **Figure 4.3**) as well as the magnitude of climate change and sea-level rise.

The projected rise in sea level under each of the SRES scenarios is nearly identical during 2050s, but becomes distinct between scenarios by the 2080s, with a net global rise of 22, 25, 28 and 38cm for the B1, B2, A2 and A1FI worlds, respectively. The number of people deemed to live within the coastal flood plain will consequently increase, as a result of an increase in the size of the flood plain, as sea-level rises.

Furthermore, the model projects that globally, the number of people living within coastal flood plains would increase under all SRES scenarios. By the 2080s, it is likely to increase to between 286 millions (A1 scenario, low coastal population growth) and 840 million people (A2 scenario, high coastal population growth), significantly increasing the global population at risk of coastal flooding.

Investigation of impacts at the regional (i.e. sub-global) scale reveals small island regions (e.g. the Pacific Islands) as experiencing significant flood impacts under all of the SRES scenarios. This reinforces earlier conclusions about the vulnerability of these small island regions and the particular need for adaptation to sea-level rise in these regions.

Figure 4.3: Average Annual People Flooded (AAPF) under the SRES Scenarios, with Constant Protection and In Phase Evolving Protection. The paired values for each storyline represent low and high population growth scenarios, respectively.



Impacts on global human health

The human health study has indicated that many more people are projected to be at risk of contracting malaria as the climate warms. Furthermore, changes in climate will cause the area meeting conditions suitable for transmission of malaria to change (and hence the spatial distribution of malaria cases to change).

The vast majority of the people projected to be exposed to malaria will be located in developing countries. The ability of developing countries to manage any climate-induced increase in malaria will depend on their capacity to develop and sustain malaria control programmes.

Net reductions in the population at risk due to climate change are indicated in many areas where reductions in precipitation are projected by the Hadley Centre. These locations vary between climate scenarios although most scenarios indicate reduced transmission in tropical South America, Central America, Pakistan, north-west India and around desert regions. Different mosquito species, however, vary in their dependency of precipitation in relation to the availability of breeding sites.

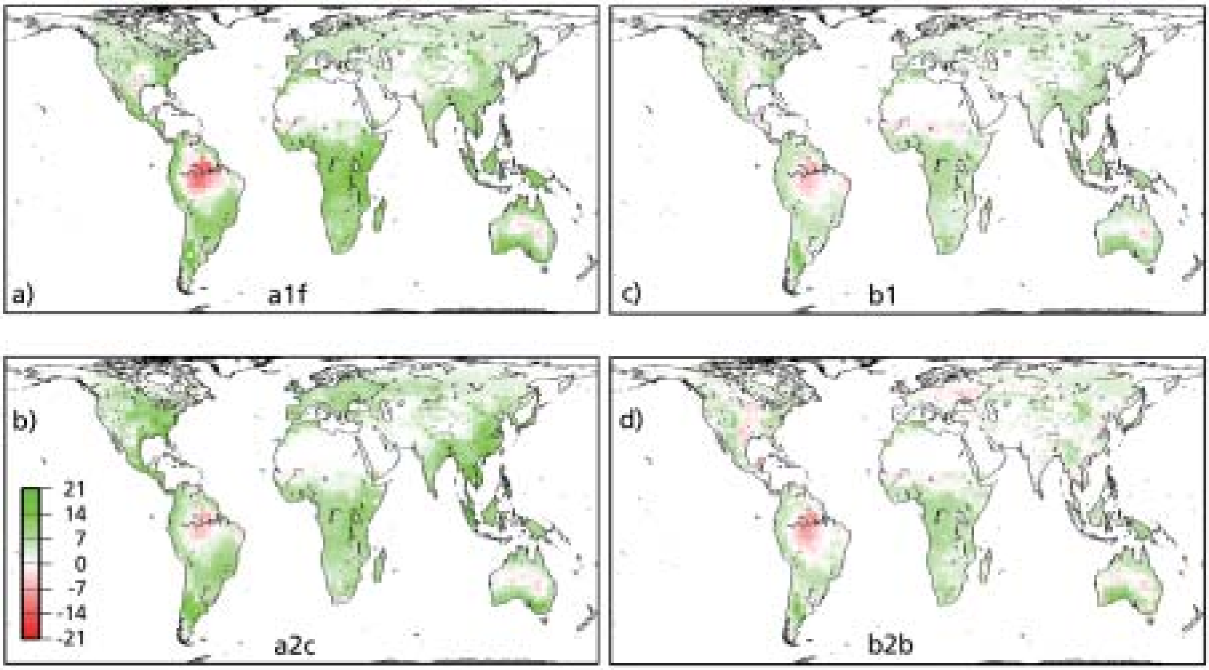
For those countries that currently have a limited capacity to control the disease (e.g. least developed countries in Africa and South America), the model estimates an additional population at risk (defined as living in an area in which malaria is transmitted for at least 1 month of the year) of between 90 million (A1 scenario) and over 200 million (B2 scenario) by the 2080s.

Regions in South East Asia and the Eastern coast of the United States are highlighted as particularly vulnerable to changes in socio-economic conditions (e.g. population changes) with respect to malaria. The assessment also shows that climate change will expand the "potential" transmission zone in developing countries and that the most important regions with respect to climate-related impacts on the current distribution of malaria are likely to be Africa and Asia. However, the time at which individual countries achieve the capacity to control the disease will also have a significant impact on the future distribution of malaria cases.

Impacts on global natural vegetation

The natural vegetation study simulated the growth and distribution of different vegetation types under the various SRES scenarios, incorporating the effects of projected changes in land use. Preliminary results indicated that the world's terrestrial biosphere could be a net sink (i.e. absorber, as opposed to contributor) for carbon over practically all of the 21st century for each SRES scenario. However, biosphere absorption of carbon could peak around 2050 and then diminish rapidly towards the end of the century. **Figure 4.4** shows the global distribution of the change in total ecosystem carbon (plant plus soil) projected by the model for 2100 under all four SRES storylines. The spatial pattern is broadly similar in all scenarios, with natural vegetation losses consistently being seen in Amazonia, the Sahel, south central USA and central Australia. These are the regions projected to be at greatest risk from the damaging effects of climate change.

Figure 4.4: Predicted change in total carbon (plant + soil, kg of carbon per square metre) between 1990 and 2100 in the four SRES scenarios (shades of green indicate a net increase, whilst shades of red indicate a net decrease).



The study indicated that the largest influence over distribution of natural vegetation throughout the 21st century is the concentration of carbon dioxide in the atmosphere; the effect of climate change is projected to be of lesser influence initially, and counteracts the effects of elevated carbon dioxide. However, the impacts of climate change are shown to become increasingly important throughout, and beyond, the 21st century.

Changes in future land use change (for example, an increasing area of agricultural land to support the food needs of an increasing global population) may enhance or counteract the carbon sink status of natural vegetation, depending on the SRES scenario.

This study can be seen as complementary to the work being carried out at the Hadley Centre on climate-carbon cycle feedbacks (see **Chapter 3**). A different land carbon cycle has been used here, with human land-use change effects included, but climate feedbacks omitted. By contrast the Hadley Centre study focusses on interactions between the carbon cycle and climate change, but currently neglects land-use change.

As a result of these differences, the two studies differ in their detailed projections of the global land carbon sink in the 21st century, although they agree on many of the key features. For example, there is agreement that climate change will tend to suppress land carbon sinks, most obviously where rainfall is reduced. Both models produce an alarming “dieback” of the Amazonian rainforest under similar Hadley Centre climate change projections.

However, there are differences in how the two studies see the global land carbon sink evolving through the 21st century, with the coupled Hadley model projecting that the world's terrestrial biosphere will become a source of carbon by 2100, and the CEH model projecting a reduced sink. These differences indicate remaining uncertainties in the response of vegetation and soils to climate change. The use of different land carbon cycle models is critically important as this encourages a focus on reducing these uncertainties. The Hadley Centre and CEH are both involved in international model intercomparison projects which will accelerate progress in this area.

Impacts on global agriculture

Climate change will affect crop yields differentially across the globe. Decreases in agricultural productivity are witnessed under all the SRES scenarios, and are projected to be the most severe in Africa and Eurasia (ranging between -30% and -10%). A more modest downturn in potential cereal yields is also expected in tropical and equatorial parts of Asia and South America.

Comparing the biophysical impacts on agricultural crops witnessed under each of the four SRES scenarios, A1FI (large increase in global temperatures) exhibits the greatest decrease in yields, especially by the 2080s. In contrast, under the least severe climate change scenario (B1) future decreases in cereal yield never exceed 10% anywhere in the world (**Figure 4.5**).

Decreases in cereal yields are estimated to cascade through the agricultural system. The worst-case scenario (global cereal prices increasing in response, as much as doubling by the 2080s in the A2 world) could result in approximately 600 million additional people being placed at risk of hunger as a result of climate change (**Figure 4.6**).

While the world, for the most part, may be able to continue to feed itself under all of the SRES scenarios during the rest of this century, the more favourable effects on yield in temperate regions (which in turn lead to the less impacted world futures) depend to a large extent on full realisation of the potentially beneficial direct effects of higher atmospheric CO_2 concentrations on crop growth – a factor that remains open to debate. It is clearly demonstrated, however, that regional differences are likely to grow stronger through time, leading to a significant polarisation of effects, with beneficial effects on yields and production occurring in the developed world and negative effects in the less developed world (excluding, perhaps, China).

Figure 4.5: Potential changes in regional cereal yields in the SRES A1FI and B1 worlds by the 2080s, including the direct effect of increased atmospheric CO_2 concentrations.

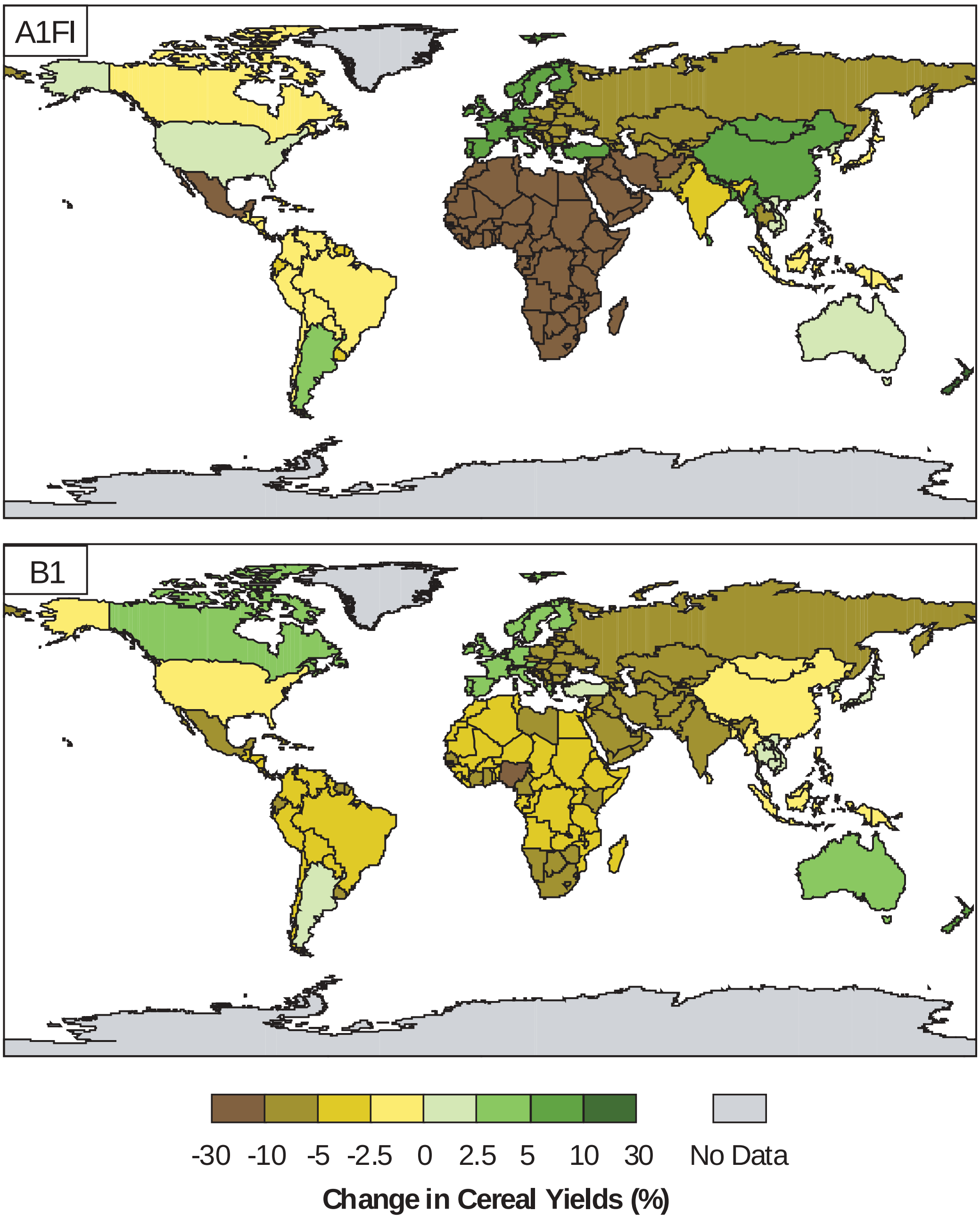
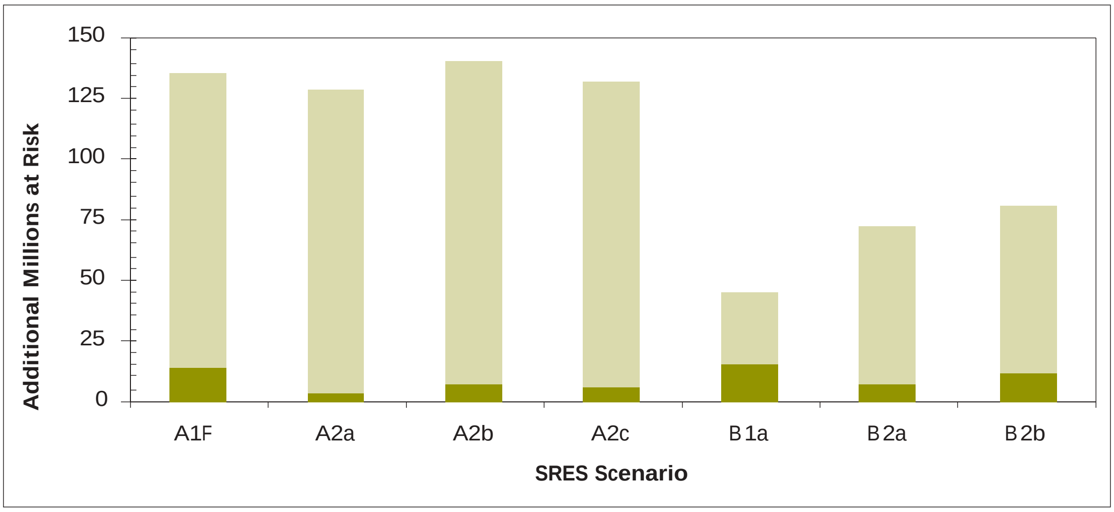


Figure 4.6: Estimated changes in the number of people at risk of hunger with respect to 1990 levels. The lightly coloured bars represent the additional number of people at risk of hunger in the absence of the beneficial direct CO_2 effect on crops. The solid bars represent the adjusted change in the number of people at risk of hunger assuming the full realisation of the CO_2 fertilisation effect on global cultivars.



Impacts on global water resources

Climate change is likely to affect the distribution and availability of water, from region to region across the globe. Each of the SRES scenarios produces a similar pattern of change in average annual runoff. The water resources impact model, when driven by the HadCM3 climate simulations, shows runoff:

- declining across much of North America, South America, Europe, the Middle East, central and southern Africa, and eastern Australia; and
- increasing in high latitudes in North America and Asia, and in south east Asia.

Although the patterns of change are similar between the scenarios, by the 2050s and 2080s there is increasing divergence in the magnitude of change: change is greatest under the A2 scenario, and least under B1. The estimated changes in runoff due to climate change (using the HadCM3 model) will be greater than the effects of natural long-term variability in approximately half of all global watersheds by the 2020s, and in most by the 2050s.

The absolute numbers of people adversely affected by changes in the availability of water depend not only on the rate of climate change, but also on the rate of population growth and the criteria used to define water stressed conditions (for example, this study assumed water stressed watersheds have less than 1000 cubic metres water available per person, per year). A2 has the highest population growth rate and so sees the greatest impact of climate change. By 2025 between 395 and 1660 million people are projected to be adversely affected by impacts on water resources as a result of climate change; and by 2055 the numbers adversely affected are between 800 and 1200 million under the A1/B1 scenarios, between 1200 and 2000 million under the A2 scenario, and between 1100 and 1200 under the B2 scenario.

Mitigation of climate change requires concerted international action to control greenhouse gas emissions. The framework for such action is through the United Nations Framework Convention on Climate Change (UNFCCC), agreed in 1992, and its Kyoto Protocol, agreed in 1997.

UK progress

As a Party to the UNFCCC, the UK has more than met its commitment to return emissions of carbon dioxide and all other gases to 1990 levels by the year 2000. Emissions have fallen between the base year and 2001 by 12.3% for all greenhouse gases and 5.3% for CO_2.The UK also has a target under the Kyoto Protocol, to reduce a basket of six greenhouse gases to 12.5% below base year levels (for definition see **Box 5.1**) by 2008-2012; and a domestic goal of a 20% reduction in CO_2 emissions below 1990 levels by 2010. These trends and targets are illustrated in **Figure 5.1** below.

Box 5.1: Basket of greenhouse gases

The basket of six direct greenhouse gases controlled by the UNFCCC and the Kyoto Protocol are:

Gas	GWP
Carbon dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous oxide (N_20)	310
Hydrofluorocarbons (HFCs)	140-11,700
Perfluorocarbons (PFCs)	6,500-7,000
Sulphur hexafluoride (SF_6)	23,900

Base year

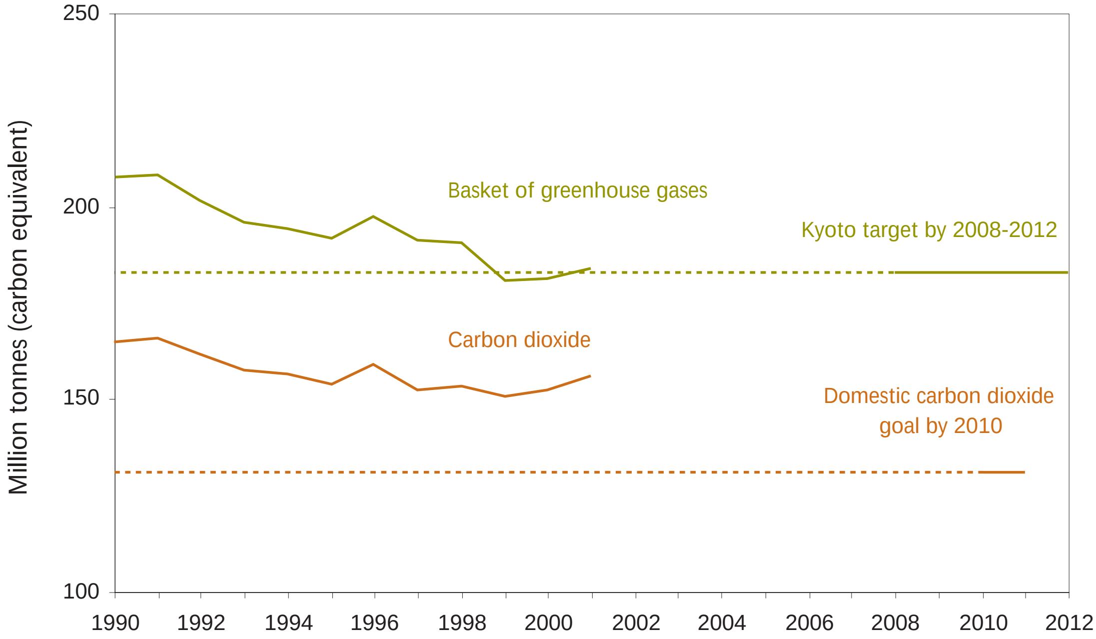
The base year for the main naturally occurring greenhouse gases – CO_2, CH_4 and N_2O – is 1990. For the remaining man-made fluorinated gases – HFCs, PFCs and SF_6 – the UK has chosen a 1995 base year in accordance with Article 3.8 of the Kyoto Protocol.

Global warming potential (GWP)

Greenhouse gases have different degrees of effectiveness in contributing to global warming. The Global Warming Potential (GWP) is a simple measure of the relative radiative effects of the emissions of different gases. It is defined as the cumulative radiative forcing between the present and a future time horizon caused by a unit mass of gas emitted now, expressed relative to that of CO_2. It is necessary to define a time horizon because each gas has a different lifetime in the atmosphere. By weighting the emission of a gas with its GWP, it is possible to estimate the total contribution to global warming of a country's greenhouse gas emissions.

The GWPs of the basket of greenhouse gases as shown above are defined on a 100-year time horizon. The ranges given for HFCs and PFCs reflect the large number of species in these categories, each with its own GWP.

Figure 5.1: UK emissions of greenhouse gases 1990 – 2001



A comprehensive and integrated package of measures to mitigate climate change in the UK is set out in the UK Climate Change Programme (**www.defra.gov.uk/environment/climatechange/cm4913/index.htm**) – published in November 2000 – and in the UK's Third National Communication to the UNFCCC (**www.defra.gov.uk/environment/climatechange/3nc/default.htm**) – submitted in October 2001. It is estimated that the polices and measures outlined in these reports could reduce the UK's greenhouse gas emissions to 23% below 1990 levels by 2010 and carbon dioxide emissions to 19% below 1990 levels by 2010. The UK's carbon dioxide emissions could fall still further through the impact of other measures that cannot be quantified to reach the 20% goal. These reports also address plans to adapt to the impacts of climate change in the UK and outline action to prepare for deeper cuts in emissions in the longer term.

UNFCCC Review

The UK's Third National Communication was reviewed by a team of experts from the UNFCCC in Autumn 2002. Their report concluded that the UK had made a notable achievement in reducing its greenhouse gas emissions over the last decade, and in doing so had decoupled emissions from economic growth. It regarded the evaluation of the effectiveness of climate change policies and measures in the UK as 'outstanding' and 'rigorous'. Work in the UK on the greenhouse gas inventory was particularly commended for its strength in quantifying uncertainties. The UNFCCC report is available at: **http://unfccc.int/resource/docs/idr/gbr03.pdf**.

Climate mitigation programme

GA supports research to ensure that the UK meets its legal international reporting requirements to the UNFCCC and the Kyoto Protocol, and to support the development of domestic and international policy teams in the Division. This research can be divided into 3 broad categories:

- estimating emissions and removals;
- inventory verification; and
- emissions projections.

Estimating emissions and removals

UK greenhouse gas inventory

To fulfil UNFCCC requirements and to underpin the development of a national programme, the UK is required to develop, publish and regularly update national inventories of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies. The UK is also required to submit an annual greenhouse gas inventory to the EU Monitoring Mechanism, which separately reports an inventory for the European Community as a whole to the UNFCCC. All UNFCCC and EU inventory reporting requirements were met during 2002-2003.

The annual UK inventory is compiled by the National Environmental Technology Centre (Netcen) on behalf of Defra. Inventory estimates for the six gases are calculated using a top-down approach, using activity data and emissions factors, and adhering to IPCC Reporting Guidelines and Good Practice Guidance. Removals by sinks are calculated by the Centre for Ecology and Hydrology (CEH) – see section below – and are published separately, within the inventory. UK inventory estimates are reviewed annually and updated to reflect improvements in methodology or availability of new information. Any changes are backdated each year to 1990 to ensure a consistent time series.

Box 5.2: Calculating uncertainties in greenhouse gas emissions estimates

Quantitative estimates of uncertainty in the emissions are calculated using Monte Carlo simulation, which is equivalent to a Tier 2 approach as defined by the IPCC. The overall uncertainty of inventory estimates on a GWP weighted basis in 2001 was estimated as 13%, ranging from an uncertainty for CO_2 estimates of 2.2% to 204% for nitrous oxide estimates. The analysis of uncertainties for nitrous oxide is particularly difficult because emissions arise from a diverse range of sources – from agricultural soils to industrial plant – and few data are available to form an assessment of the uncertainties in emissions from each source.

A summary of the latest inventory estimates, by gas, is given in **Table 5.1** below. This shows that emissions of the basket of six greenhouse gases, weighted by global warming potential, fell by 12.3% between the base year and 2001. Over the same period there was a 5.3% fall in emissions of CO_2. Removals of CO_2 by terrestrial carbon sinks are identified separately and increased by 10% over the period. These data and detailed methodological approaches are presented in the UK's Greenhouse Gas Inventory 1990-2001 (www.naei.org.uk/reports.php).

Table 5.1: Estimated total UK emissions of the basket of six greenhouse gases on an IPCC basis(i), weighted by Global Warming Potential: 1990-2001.

Expressed in million tonnes carbon equivalent (MtC)			
Gas	**Base year(ii)**	**2001**	**% change from Base year(ii), (iii)**
Carbon dioxide	164.8	156.1	-5.3
Methane	21.0	12.6	-40.0
Nitrous oxide	18.5	11.6	-37.6
Hydrofluorocarbons	4.1	2.4	-42.9
Perfluorocarbons	0.3	0.2	-35.5
Sulphur hexafluoride	0.3	0.5	+55.5
Total (Emissions)	**209.1**	**183.3**	**-12.3**
Carbon dioxide removals	-2.9	-3.2	+10.0
Carbon dioxide (net emissions)	161.9	153.0	-5.6
Total (Net emissions)	**206.2**	**180.1**	**-12.6**

Notes to table

(i) Emission inventories based on the methodology developed by the Intergovernmental Panel on Climate Change (IPCC) are used to report UK emissions to the Climate Change Convention.

(ii) The base year is the sum of 1990 totals for CO_2, CH4 and N2O and 1995 totals for the fluorinated compounds – HFCs, PFCs and SF6, in accordance with Article 3.8 of the Kyoto Protocol.

(iii) The percentage changes presented in this table are calculated from inventory emission estimates held at full precision. The emission estimates quoted in the table are values rounded from emission estimates held at full precision. The percentages quoted in this table may therefore differ slightly from percentages that could be calculated from the emission estimates presented in the table.

Regional greenhouse gas inventories

Some of the measures to deliver greenhouse gas emission reductions are the responsibility of the devolved administrations. Defra therefore agreed with the Scottish Executive (SE), the National Assembly for Wales (NAW) and the Department of the Environment in Northern Ireland (DoENI), to produce greenhouse gas emission inventories for England, Scotland, Wales and Northern Ireland. Inventories have now been produced covering the period 1990 to 2000 (www.naei.org.uk/reports.php). The regional distribution of CO_2 equivalent greenhouse gas emissions in 2000 were: England, 73.6%; Scotland, 10.9%; Wales, 8%; Northern Ireland, 3.2%; with 4.2% unallocated[1].

1 Emissions from certain sources cannot be allocated to a country e.g. shipping, aviation, military aviation, naval and offshore oil and gas, so were recorded in an unallocated category

Methane emissions from abandoned coal mines

In 1994, the Watt Committee concluded that methane emissions (which could potentially contribute to climate change) from abandoned UK coal mines were negligible. Defra commissioned AEA Technology to review the evidence. This work, completed in two stages indicated that methane emissions from this source could lie in the range 0.1 to 1.7 million tonnes of carbon equivalent per annum (the wide range indicating the uncertainty of the estimates). No internationally agreed methodology currently exists for estimating emissions from abandoned mines and inclusion of this source in the UK inventory requires a methodology that is acceptable to international review.

Defra is currently funding a 2.5 year research contract with International Mining Consultants (IMC) that is using a combination of empirical data and modelling to develop a verifiable methodology for generating accurate and reliable annual inventory estimates of methane emissions from abandoned coal mines in the UK. The work is expected to produce results by February 2005, when Defra will consider including this category in the UK greenhouse gas inventory to be submitted to the UNFCCC by 15th April 2005.

(Photo: IMC)

Closed colliery vent site (Westoe)

Carbon sinks and land use change

The amount of CO_2 in the atmosphere is partly affected by the net flow of CO_2 between the atmosphere and the terrestrial biosphere. This is strongly affected by human use of land. To explore the effects of land use change, the Centre for Ecology and Hydrology – Edinburgh (CEH – www.ceh.ac.uk) has used a global dynamic vegetation model to predict the impact of changes in climate, CO_2 and land use, as prescribed by the IPCC SRES scenarios (see **Box 4.2**), on natural vegetation and terrestrial carbon fluxes. The choice of scenario had a large influence on the simulated net terrestrial carbon sink in 2100, ranging from about 5 gigatonnes of carbon (GtC) per year (A2C scenario) to near zero (B2B scenario). Land use change induced a carbon sink in three SRES scenarios where cropland was abandoned and natural vegetation regrew. In further scenarios where cropland area was assumed to change in proportion with population growth, the flux from land use change counteracted the effect of CO_2 uptake, leading to a net source of CO_2 of up to 3 GtC/y over the 21st century. Given that global man-made emissions are currently around 7GtC/y this could be very significant. However the future flux from land use change is highly uncertain and will depend on socio-economic and agricultural trends.

Under the Kyoto Protocol, Parties may account for the additional uptake of CO_2 by forestation and land management. To assess such effects, CEH has further refined understanding of changes in UK terrestrial carbon stocks. Recently published measurements of carbon uptake and loss by vegetation and soils, in areas of afforestation on peat in Scotland, have been extrapolated to the UK forest estate. These calculations show that, due to previously unaccounted increases in soil carbon in coniferous forest, the net uptake of carbon by UK afforestation may be approximately 1.6 MtC/y greater than the previously reported rate of 2.5 MtC/y. On the other hand, the estimated rate of deforestation has been refined to 1,375 ha/y, which is greater than previously thought. Such a rate of forest loss would be equivalent to an emission of approximately 60 ktC/y. Current estimates show that emissions from land use change and forestry have contributed 14% to the UK's total reduction of CO_2 emissions between 1990 and 2001.

CEH has also investigated the geographical distribution of the net uptake of carbon due to afforestation. This took into account the variation in planting rates and growth conditions across Great Britain. **Figure 5.2** shows the geographical variation in afforestation rates since 1920 summarised for conifers and broadleaves in England, Wales and Scotland. **Figure 5.3** shows how the net carbon flux in 1990 due to prior afforestation in Great Britain (ktC/y) was distributed across the country.

Figure 5.2: Annual afforestation rate (thousands of hectares per year) since 1920 of conifer and broadleaf species in England, Wales and Scotland.

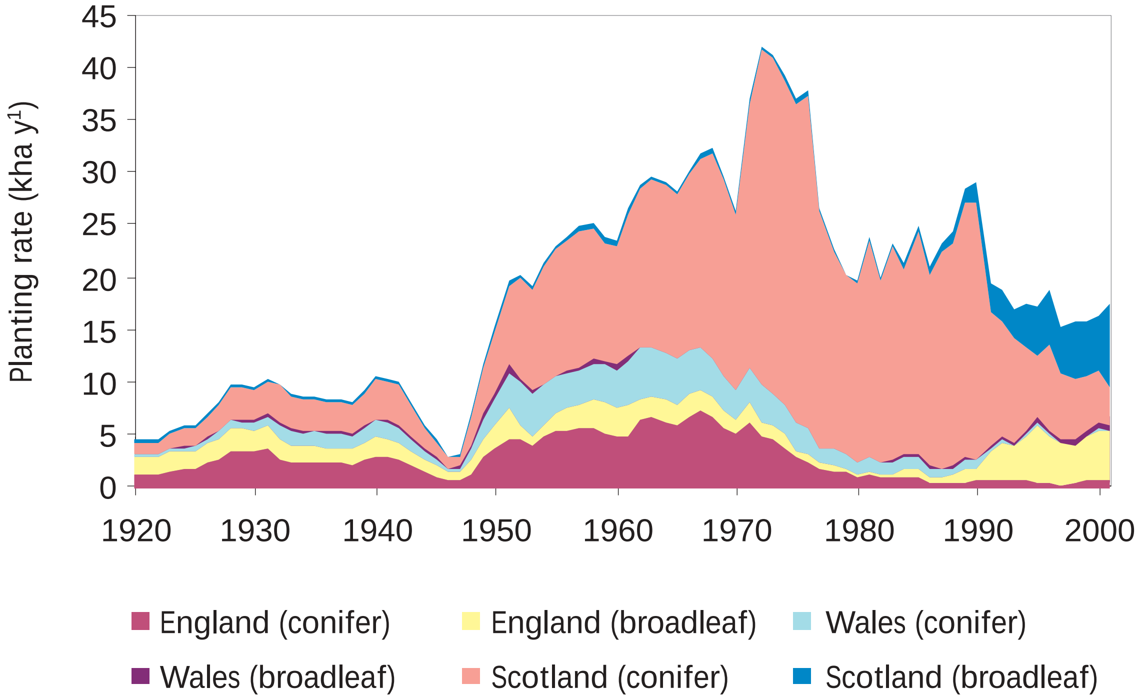
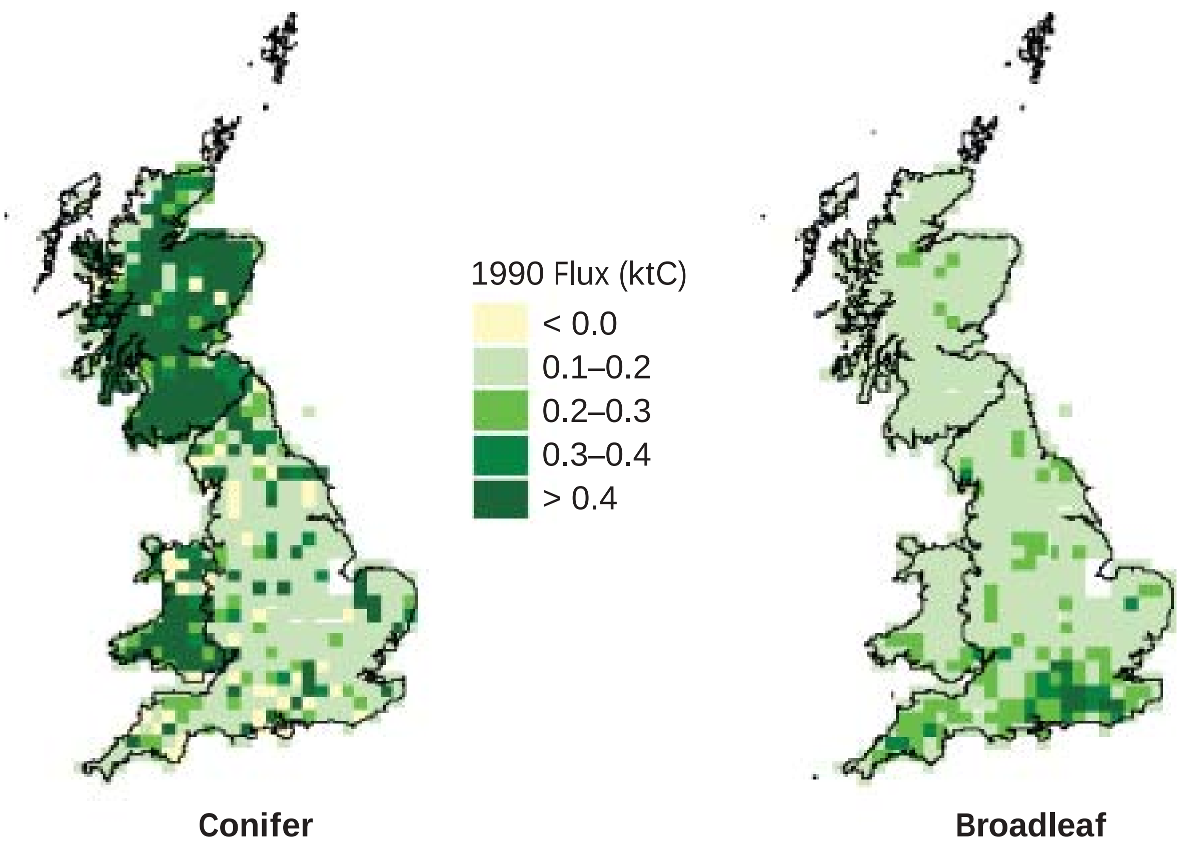


Figure 5.3: Net flux (+ve is uptake) in 1990 of carbon due to conifer and broadleaf afforestation in Great Britain.



Inventory verification

The accuracy of greenhouse gas emission inventory estimates is verified by the measurement and analysis of atmospheric concentrations of the major greenhouse gases (in addition to many industrial gases) at Mace Head, in the Republic of Ireland. Mace Head is one of the stations involved in the Advanced Global Atmospheric Gases Experiment (AGAGE) and is particularly well located, as winds coming over the Atlantic will bring relatively unpolluted air that can be filtered (to remove local influences) and analysed, to give baseline concentrations of substances in the atmosphere. Site data is also used to monitor the levels of pollution that are associated with Europe when the direction of winds is appropriate.

Measurements of the radiatively active trace gases at Mace Head in Ireland have shown that baseline concentrations of the main direct greenhouse gases – carbon dioxide, methane and nitrous oxide – reached the highest levels in the atmosphere ever recorded in 2002, the latest year for fully validated data (see **Figures 5.4** and **5.5**).

Methane baseline concentrations have fluctuated during the last decade, due predominantly to the eruption of Mount Pinatubo and meteorological disturbances (such as El Niño).

Figure 5.4: Trend in methane and nitrous oxide baseline concentrations 1987–2002.

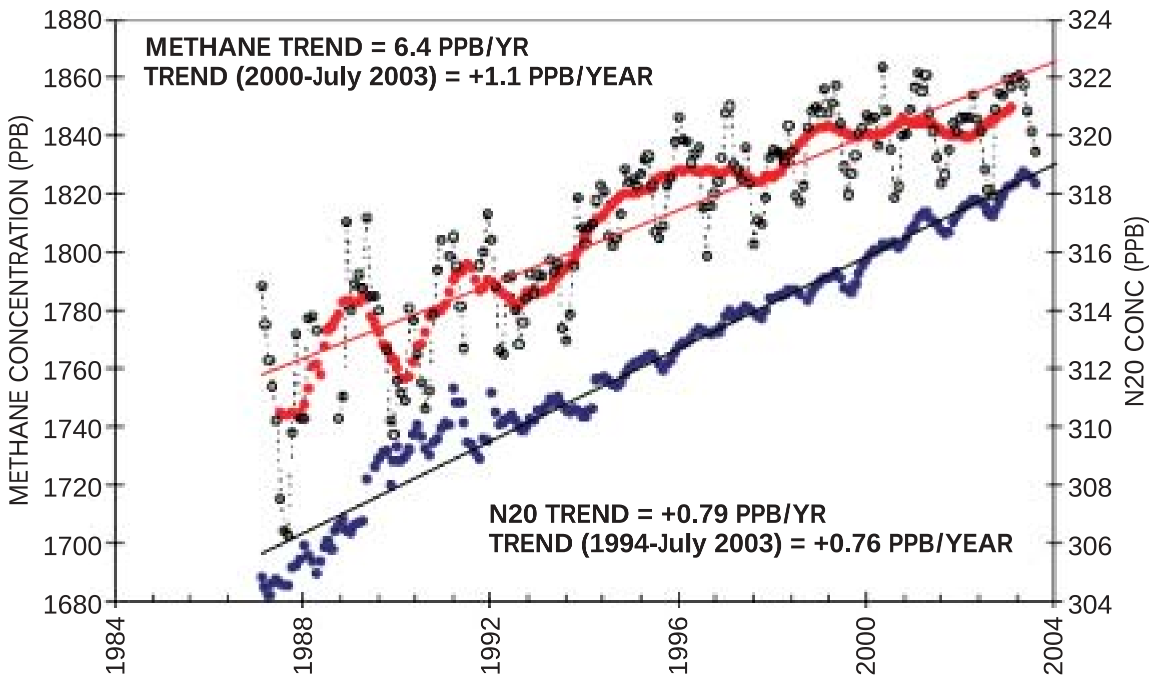
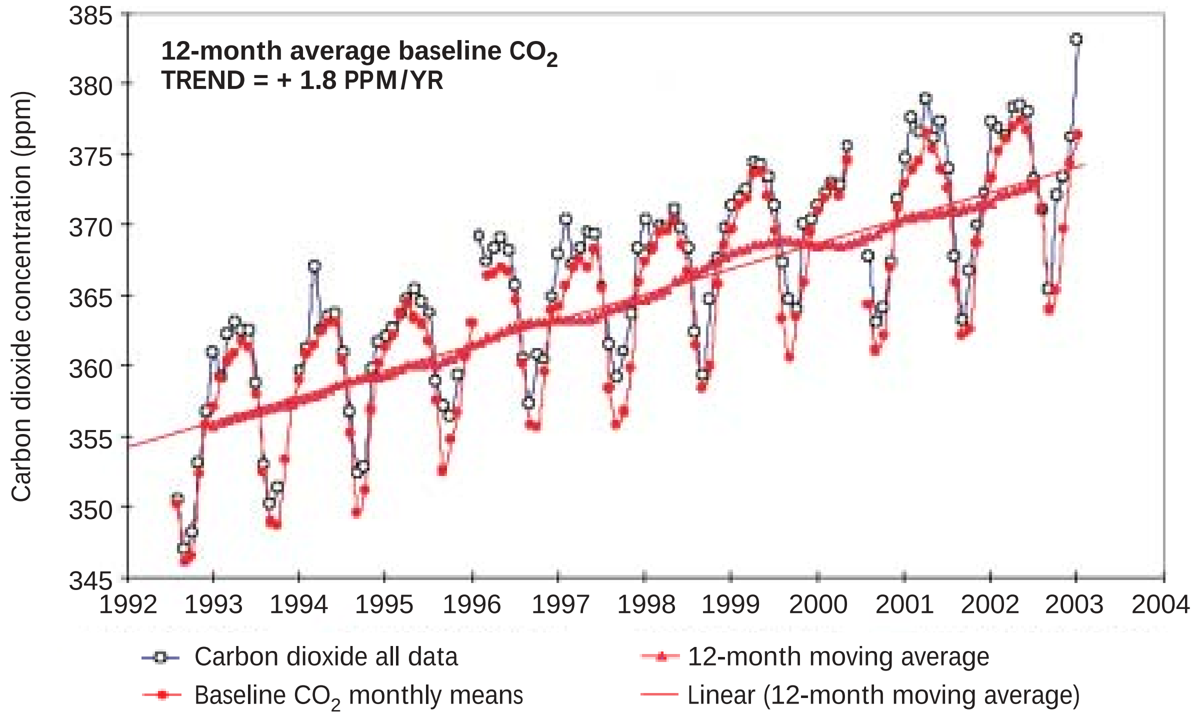


Figure 5.5: Trend in carbon dioxide baseline concentrations 1992–2002.



Box 5.3: Atmospheric chemistry

The gases shown in **Table 5.2** have direct and indirect radiative effects, and atmospheric interactions between them are complex. For example, whilst ozone is a potent greenhouse gas, it also helps to remove methane from the atmosphere. Ozone is not directly emitted by human activity, but other anthropogenic pollutants can react in the atmosphere to create it. One of these ozone-precursor gases is carbon monoxide, which tends to increase the atmospheric concentration of methane. Hydrogen is seen as a potential clean fuel, but it does have an indirect radiative impact and its presence in the atmosphere is mostly due to natural sources. Hydrogen is destroyed naturally, although increases in atmospheric methane concentrations have slowed this process and concentrations of hydrogen are rising. The mechanism for this effect is that both hydrogen and methane are destroyed when they react in the atmosphere with the hydroxyl radical OH and increasing amounts of methane are reducing the quantity of OH available to act as a hydrogen sink.

Table 5.2: Baseline concentrations in parts per billion (ppb) of the radiatively-active trace gases in the GAGE/AGAGE observations for Mace Head for the period 1987-2002.

Year	Carbon Dioxide (ppm)	Methane	Nitrous oxide	Ozone	Carbon monoxide	Hydrogen
1987		1736.9	305.1			
1988		1781.6	305.7			
1989		1790.3	307.5			
1990		1766.9	308.0	34.3	123.1	
1991		1794.6	308.5	35.1	134.4	
1992	351.6	1786.7	309.9	34.0	125.7	
1993	356.6	1795.4	309.3	32.1	112.8	
1994	358.6	1802.6	310.1	34.2	133.0	496.9
1995	359.3	1801.5	312.2	36.8	123.1	498.6
1996	362.7	1803.8	313.2	37.9	109.6	503.3
1997	364.0	1801.6	313.9	37.3	118.3	494.3
1998	367.3	1815.4	314.6	41.8	147.2	505.4
1999	369.9	1820.4	315.2	42.7	125.8	506.0
2000	369.2	1820.4	316.3	41.8	112.2	495.7
2001	370.2	1817.9	317.0	39.6	105.0	491.8
2002	375.2	1822.1	317.6	42.1	123.4	500.3

Data shown in blue indicate peak concentrations in the recent record

The atmospheric measurements of radiatively active trace gases are used in conjunction with the Met Office's NAME model – a Lagrangian dispersion model – to predict the trajectories of pollutants from their sources. The model uses sophisticated techniques to trace back along the path that the pollution has followed – known as inverse modelling – to identify the source of the emission and attribute it to a region or country. The aim of this process is to provide an accurate source attribution for each of the measurements made at Mace Head and to examine compliance with internationally binding commitments across Europe. The model also provides an independent method of verifying the estimates of greenhouse gas emissions produced for the UK inventory.

The NAME inverse modelling emission results for UK and Europe have been compared against emission inventories supplied to the UNFCCC where available (see **Table 5.3**). The inverse modelling results for each species for both the UK and Europe are all well within a factor of 2 of the UNFCCC estimates. The UK NAME totals are systematically lower than the UK's inventory estimates submitted to the UNFCCC. This is because the inversion technique has no knowledge of land-sea boundaries and due to errors in modelling the meteorology and transport, the emissions can be marginally displaced into the sea and therefore not included. When a zero sea emission assumption is enforced (as shown in the nitrous oxide table) the UK NAME totals move closer to the UNFCCC estimates. The European totals are not directly comparable since the UNFCCC total is the summation of the emission estimates from 12 European countries (UK, Ireland, France, Germany, Denmark, Sweden, Belgium, The Netherlands, Luxembourg, Spain, Portugal and Italy), whereas the model estimates are for all of the European region.

Table 5.3: Comparison of NAME and UNFCCC emission estimates in Gg yr^{-1} for methane and nitrous oxide (zero sea assumption).

Methane		1995-1997	1996-1998	1997-1999	1998-2000	1999-2001	2000-2002
UK	NAME	2020	1790	1940	1720	2270	1990
	UNFCCC	2962	2837	2676	2505	2341	-
Europe	NAME	18700	19500	24500	19400	21200	20100
(EU12)	UNFCCC	16147	15833	15471	15121	14787	-

Nitrous oxide		1995-1997	1996-1998	1997-1999	1998-2000	1999-2001	2000-2002
UK	NAME	140	120	120	100	130	130
	UNFCCC	190	191	176	159	142	-
Europe	NAME	1000	1100	1400	900	900	1200
(EU12)	UNFCCC	1190	1170	1122	1074	1046	-

Emissions projections

The UK is required periodically to report to the UNFCCC a National Communication, summarising the policies and measures the UK has implemented and planned, aimed at reducing national greenhouse gas emissions in order to achieve targets agreed within the Kyoto Protocol. In order to do this, projections for all gases need to be made by economic sector and reported in the National Communications and the UK's Climate Change Programme.

Carbon dioxide projections

Domestic & non-domestic building stock

The Building Research Establishment (BRE) provides estimates for the UK domestic and non-domestic building stock, of energy consumption and CO_2 emission savings potentials, as well as an assessment of policy effectiveness, disaggregated by sector, fuel type and end use.

Domestic sector work between April 2002 and March 2003 has consisted of two main activities:

- A paper has been prepared summarising the key conclusions of the extensive report that was published in December 2001[3], and focusing on the prospects for achieving the Climate Change Programme savings for the domestic sector. This paper[4] was presented at the 3rd European Conference on Energy Performance and Indoor Climate in Buildings in October 2002. The results show cost-effective carbon savings of between 5MtC and 20MtC in 2000, and between 2MtC and 12MtC in 2010, for a range of energy efficiency measures

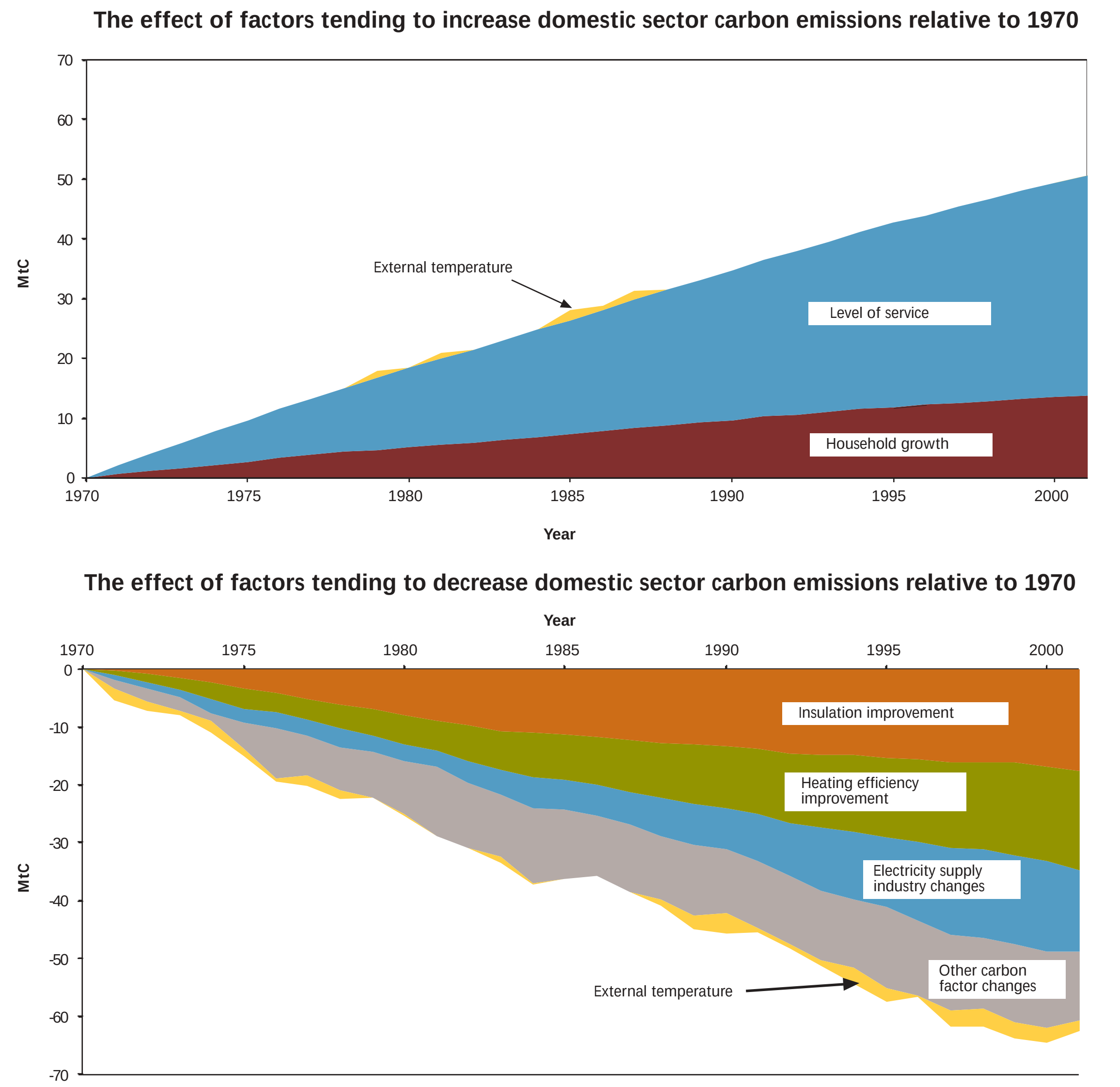
3 Carbon emission reductions from energy efficiency improvements to the UK housing stock. L D Shorrock, J Henderson, J I Utley and G A Walters. BRE Report BR435. December 2001.

4 UK Climate Change Programme and domestic sector end-use efficiency. L D Shorrock and J I Utley. Published in the proceedings of the 3rd European Conference on Energy Performance and Indoor Climate in Buildings. October 2002.

and energy efficient products. The cost effective measures include first time loft insulation, hot water tank insulation, cavity wall insulation, condensing boilers and low energy light bulbs. In contrast, solar water heating appears not to be cost-effective at the present time and solid wall insulation at best marginally so, despite the potentially large carbon savings; and

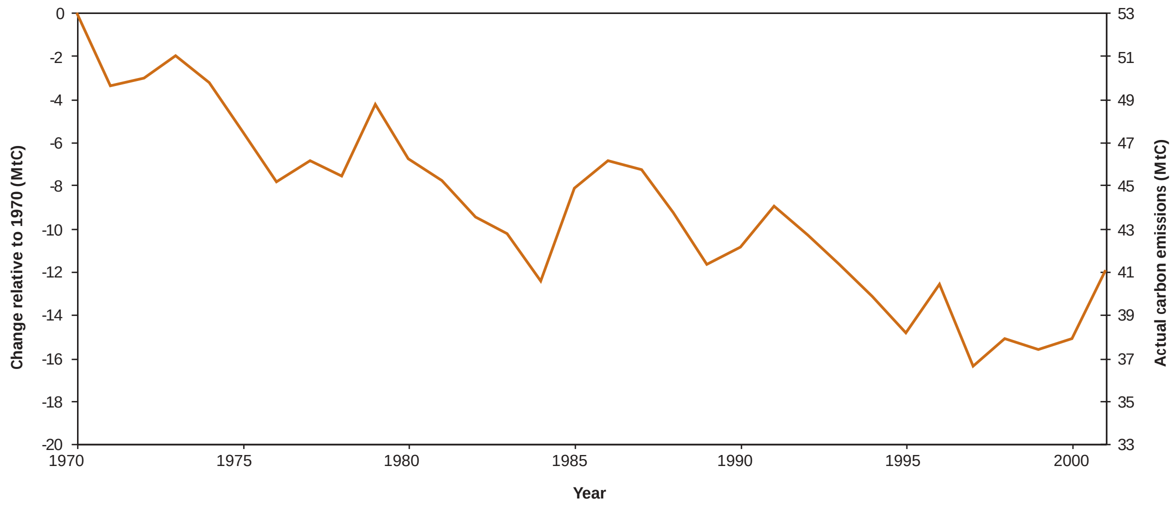
- A paper[5] on the decomposition of the changes in domestic sector carbon emissions from 1970 to 2001. identifies the effect of seven key factors that have influenced carbon emission changes (see **Figure 5.6**). The paper shows that energy efficiency improvements have been critical to reducing carbon emissions from the domestic sector over the last 30 years.

Figure 5.6: Domestic sector carbon emission changes and the factors contributing to these from 1970 to 2001 (expressed in million tonnes carbon MtC).



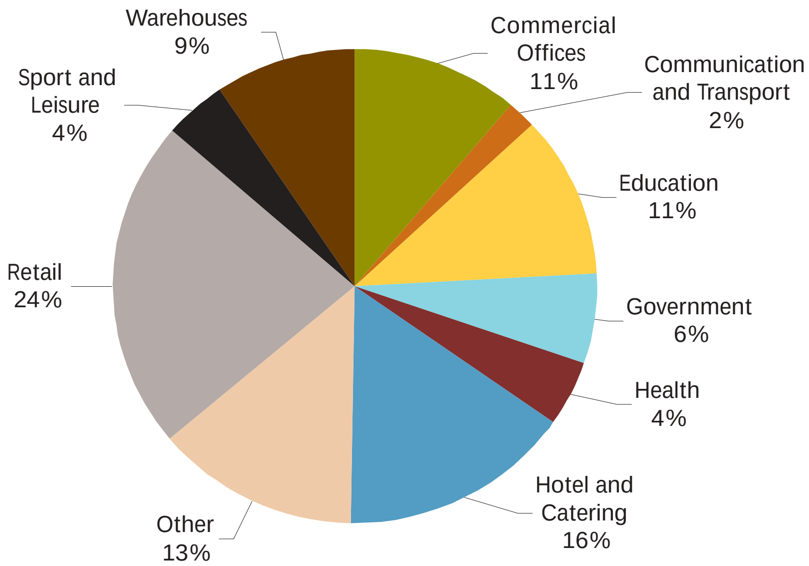
5 A detailed analysis of the historical role of energy efficiency in reducing carbon emissions from the UK housing stock. L D Shorrock. To be published in the proceedings of the ECEEE Summer Study. June 2003.

Overall change in domestic sector carbon emissions relative to 1970.



Between April 2002 and March 2003, BRE has continued to develop the Non-Domestic Energy and Emissions Model (N-DEEM) and to build upon the model and analyses described in a detailed report which was published in March 2002[6].

Figure 5.7: Carbon emissions by building activity type, indicates that the two sectors contributing most to UK carbon emissions are retail and hotels and catering.



6 Carbon dioxide emissions from non-domestic buildings: 2000 and beyond. C H Pout, F MacKenzie and R Bettle. BRE Report BR 442. March 2002.

Industrial sector CO_2

Energy-related CO_2 emissions from the manufacturing industry represent a quarter of total UK carbon dioxide emissions. The UK Climate Change Programme includes a number of policies and measures designed to curb emissions from this sector including the climate change levy (a business energy tax), and its associated agreements, business rate exemption on Combined Heat and Power (CHP) plant, and the UK's emissions trading scheme. Entec UK Ltd and Cambridge Econometrics have updated the estimates of carbon savings from these policies and measures using a combination of a technology-based bottom-up industrial energy end-use simulation model originally produced by the Energy Technology Support Unit (ETSU) at AEA Technology and a top-down model of the UK economy with fully integrated energy-environment sub-models. The results of this work are shown in the table below.

Table 5.4: Simulated policy contributions to carbon reductions from business as usual by 2010 (MtC).

Policy measure	Carbon reduction from policy simulation (mtC)
Climate Change Levy (CCL) plus Climate Change Agreements (CCA)	>3.4
CCL package, predominantly Enhanced Capital Allowances (ECAs)	0.6
Business rate exemption on Combined Heat and Power (CHP)	0.1
Emissions Trading Scheme (ETS)	>0.5
Interaction effects of CHP policies	-0.1
Total	**4.5**

Non-CO_2 projections

Although the contribution of the five non-CO_2 greenhouse gases – methane, nitrous oxide, HFCs, PFCs and SF_6 – to global warming is small compared to overall greenhouse gas emissions, they are significant with respect to the achievement of the UK's Kyoto target.

Landfill methane

Two projects were carried out in parallel during 2002/2003. Their aims were:

- To produce new estimates of national emissions of methane from landfill sites and new forecasts under a number of waste management scenarios; and
- To examine the wider effects and impacts of waste-related policies on emissions of greenhouse gases and ammonia arising from the life cycle of waste management systems.

The first project carried out by Land Quality Management (LQM) concluded that the generation of methane in landfill gas is likely to be much higher than had been previously reported. However, the emissions of methane from UK landfills are forecast to be similar to previous estimates. Flaring, utilisation, and methane oxidation play important roles in mitigating emissions from landfill. All the municipal solid waste (MSW) management strategies considered showed benefits in methane emissions reduction compared with the BAU base case, but the effects were not as significant as the impact on emissions reduction due to flaring or utilisation.

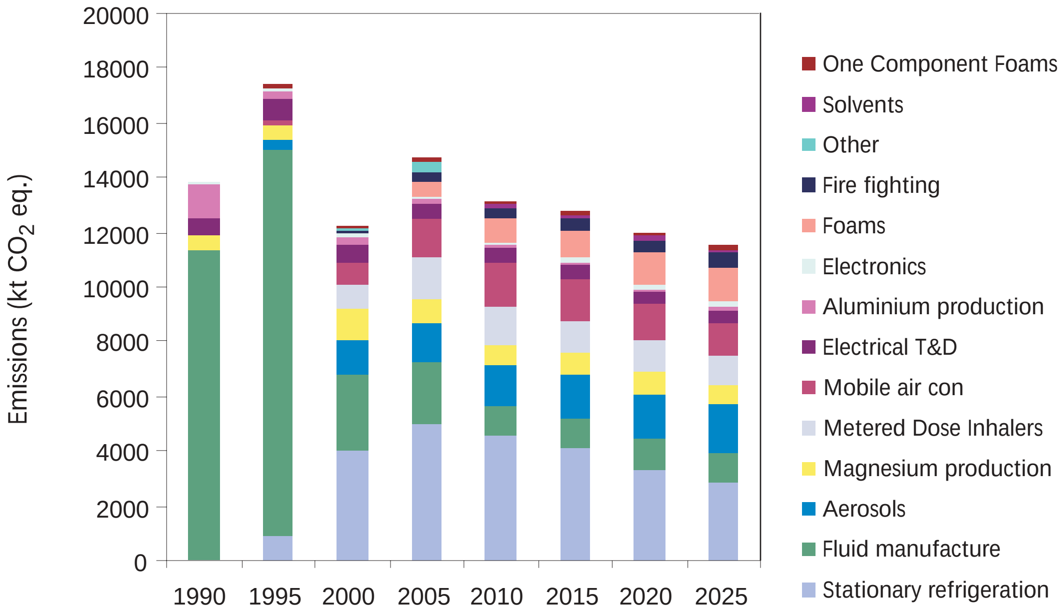
The second project carried out by Environmental Resource Management (ERM) developed a number of scenarios to examine the impact of different policies on emissions from MSW and commercial, industrial and other (CIO) wastes. The policies considered included the EU Landfill Directive and targets set out in Waste Strategy 2000, the national strategy for England and Wales. The scenarios varied in the type and proportion of materials recycled, the rate of energy recovery through combustion, and the extent of composting and anaerobic digestion of degradable wastes. The annual rate of growth in the quantity of wastes produced was also varied in some scenarios. A final report setting out the results of the ERM project will be published in 2003/4.

Fluorinated gases

Defra has recently funded work to update annual UK and constituent country emissions and projections of the fluorinated gases (HFCs, PFCs and SF_6) for the period 1990 to 2025. The work also assessed additional options for reducing future emissions of HFCs, PFCs and SF_6, and quantified the effects on future emissions and related cost implications of any additional measures to reduce emissions. In addition, the work provided emission estimates and projections for nitrogen trifluoride (NF3), which is a greenhouse gas that is not included in the Kyoto basket. The work involved extensive stakeholder interaction, with over 90 experts contributing through personal communication and participation at stakeholder workshops in September 2002 and March 2003. The final report was published in September 2003.

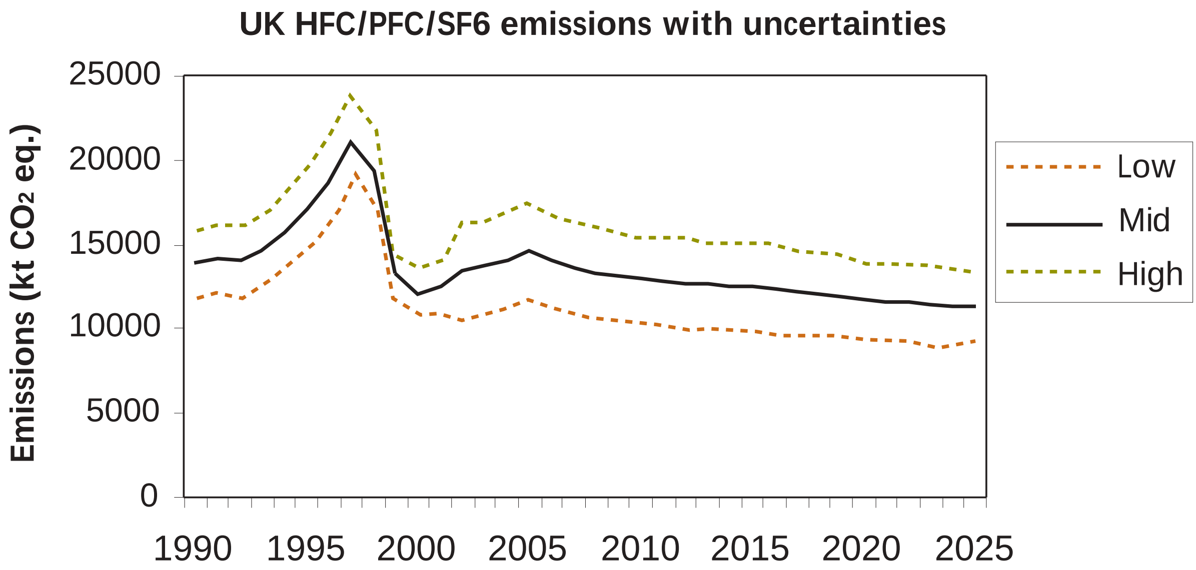
Figure 5.8 below summarises projected trends in UK emissions by sector, showing the GWP-weighted aggregated HFC, PFC and SF_6 emissions. Emissions arise from a wide range of manufacturing sectors and end-use applications.

Figure 5.8: HFC, PFC and SF6 emissions for the UK by sector 1990-2025 (ktonnes CO_2 equiv).



Based on best estimates, total UK GWP-weighted emissions of HFC, PFC and SF6 fell from about 4.7 MtC equivalent (eq.) in 1995 to about 3 MtC eq. in 2000. Emissions are expected to increase again to about 4 MtC eq. by 2005, largely due to increased use of HFCs for stationary refrigeration, mobile air conditioning, metered dose inhalers and foam blowing as replacements for CFCs and HCFCs, and then steadily decrease back down to about 3 MtC by 2025. There is expected to be a 25% emissions reduction in 2010 compared with the 1995 baseline. These overall trends and the associated uncertainties in emissions and projections are shown in **Figure 5.9** below.

Figure 5.9: HFC, PFC and SF6 emissions for the UK (ktonnes CO_2 equiv).



Montreal Protocol

The Antarctic ozone hole was discovered in the mid 1980s and its cause has been unambiguously identified as the increasing atmospheric concentration of man-made halocarbons, particularly chlorofluorocarbons (CFCs) and halons. International concern about low ozone levels and associated high levels of ultra-violet (UV) radiation, resulted in the Montreal Protocol, an international agreement aimed at the reduction of production and consumption of ozone depleting substances (ODS). The Protocol, agreed in 1987, has resulted in the phasing-out of use of such chemicals.

Although emissions of many ozone-depleting substances have dropped considerably, the large build-up of these chemicals in the atmosphere will not decrease for some time, due to their long atmospheric residence time, which can be anything up to thousands of years. Full compliance with the Protocol should ensure recovery of the ozone layer within the next fifty years. Climate change can also affect ozone levels by changing atmospheric conditions so that they do not favour ozone production, thus potentially delaying recovery.

GA continues to monitor ozone levels above the UK and to assess whether recovery is taking place as expected. Measurements of ozone depleting substances have been made at Mace Head, Ireland and North Norfolk, helping to verify compliance with the Montreal Protocol. Additionally, UV radiation is monitored to ensure that the measurements are consistent with ozone data, and to establish the levels of human and environmental exposure to UV.

Polar ozone loss

The Antarctic ozone hole reached a record 28 million km^2 in 2000 and decreased slightly to 26 million km^2 in 2001. There was a relatively small ozone hole in 2002, but the 2003 hole nearly reached the record of 28 million km^2 in late September. Yearly variations are a result of different meteorological conditions, but we should start to see a slow decline in the average size of the ozone hole in the next decade as levels of ODS fall in response to the Montreal Protocol. As demonstrated by the large 2003 ozone hole, compared to 2002, we should not be misled by short-term improvements due to natural meteorological variability.

Ozone depletion also occurs in the Arctic but tends to be less severe, due to the more disturbed meteorological conditions present there. The Arctic stratosphere is generally less cold and the formation of Polar Stratospheric Clouds (PSCs) is less common, so ozone destruction, catalysed by reactions on the surface of these clouds, is less likely to take place.

Ozone depleting substances

The implementation of the Montreal Protocol has reduced the emissions of ozone depleting substances (ODS) to the atmosphere but continued monitoring is required to ensure compliance with the Protocol and to identify the build up of new ODS. This is of particular importance over the next few decades, while the halogen loading of the stratosphere is at a maximum and the stratosphere is cooling as a result of climate change (in contrast to the surface, which is warming).

The Universities of Bristol and East Anglia measure a wide range of ozone depleting substances and their replacements, at Mace Head in Ireland, and have also carried out monitoring at Weybourne in the UK and Cape Grim in Tasmania. The UK Met Office has analysed the Mace Head data and identified trends in concentrations of ODS.

Table 6.1 shows that the concentrations of two of the principal ozone-depleting CFCs – CFC-11 and CFC-113 – are declining having peaked in the early 1990s. Conversely, CFC-12 concentrations continue to increase, albeit more slowly. Methyl chloroform (CH_3CCl_3) and carbon tetrachloride (CCl_4) are both decreasing and the amount of these two substances in polluted European air is almost indistinguishable from "clean" air coming from the Atlantic. This provides a clear indication that the phase-out of substances under the terms of the Montreal Protocol is taking effect. There is, however, sustained growth in the concentrations of the HFCs and HCFCs both potent greenhouse gases that have replaced CFCs in some applications, which is contrary to the aims of the Climate Convention.

Table 6.2 shows calculated emissions from Europe, based on the modelling of concentrations in different air masses. It shows that European emissions of CFC-11 and CFC-12 appear to have levelled out, having dropped to a level of approximately one twentieth of their historical emissions. Continuing emissions are likely to originate from the 'bank' of foams, refrigerators, freezers and other equipment either still in use or recently scrapped.

Table 6.1: Baseline concentrations in ppt of the major man-made halocarbons in the GAGE/AGAGE observations for Mace Head for the period 1987-2002.

Year	CFC-11	CFC-12	CH_3CCl_3	CCl_4	CFC-113	$CHCl_3$
1987	242.1	440.3	133.3	101.6	56.4	
1988	252.2	462.8	143.1	106.1	64.1	
1989	258.4	480.8	145.7	108.9	69.4	
1990	262.8	490.5	152.8	109.5	72.4	
1991	265.8	503.2	152.4	106.5	80.9	
1992	269.1	514.1	150.5	104.1	84.4	
1993	268.2	520.4	138.4	104.3	84.8	
1994	266.9	526.6	125.3	103.2	84.0	
1995	268.8	533.5	113.3	102.6	84.3	12.4
1996	267.2	537.9	94.8	101.2	83.8	12.5
1997	265.8	540.2	79.8	100.3	83.3	12.0
1998	264.4	542.5	66.1	99.0	82.9	12.1
1999	262.8	544.0	55.4	97.8	82.3	11.5
2000	261.7	545.9	46.5	97.1	81.8	11.0
2001	259.7	546.3	37.9	96.0	80.9	10.9
2002	258.1	546.5	33.5	95.4	80.5	10.9

Data shown in blue indicate peak concentrations in the recent record

Table 6.2: Modelled Estimates from Mace Head data of European source strengths in thousand tonnes yr^{-1} of the major man-made halocarbons from 1995-2002 (three year averages).

Year	CFC-11	CFC-12	CH_3CCl_3	CCl_4	CFC-113	$CHCl_3$
1995-1997	6.5	12.3	19.5	4.6	3.6	11.4
1996-1998	7.4	12.6	13.5	4.7	2.5	13.8
1997-1999	9.3	15.6	6.9	4.9	2.2	18.5
1998-2000	7.3	11.7	1.6	4.3	1.0	10.1
1999-2001	5.7	8.5	1.2	4.3	0.7	8.1
2000-2002	6.7	7.5	1.0	3.2	0.7	5.7

Data shown in blue indicate peak concentrations in the recent record

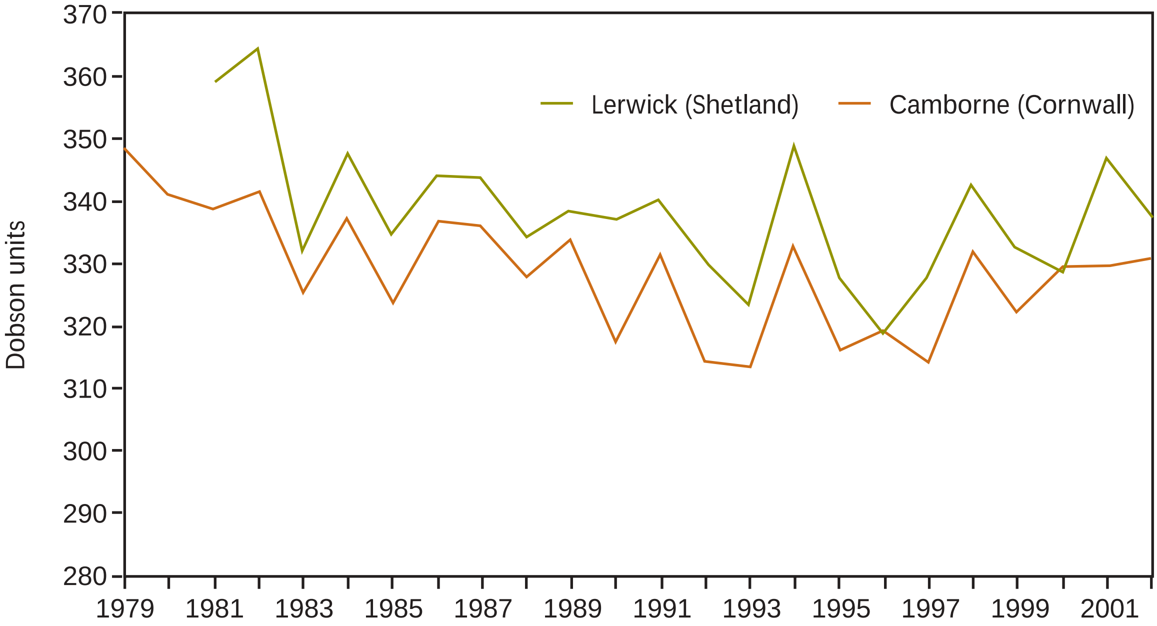
Bromine levels in the atmosphere have recently been increasing but recent results from the University of East Anglia (UEA) show that concentrations of methyl bromide, which is a major contributor to this burden, are now decreasing. Input for modelling studies was obtained by analysing firn air data (essentially very old air bubbles, trapped in ice cores), to give some indication of pre-industrial concentrations, and Cape Grim data, to inform understanding of coastal sources. The studies suggest that methyl bromide may live for longer in the atmosphere than previously thought. If this is the case, the expected decrease in atmospheric bromine concentrations will not take place until a greater period has elapsed after the phase out of methyl bromide (due in 2005 for developed countries, and in 2015 for developing countries).

Partly funded by the EU CARIBIC and EXPORT campaigns, UEA has also gathered upper-atmosphere data through the use of aircraft. Aircraft flying over Europe, for example, have collected atmospheric data that has identified some new ODS in the atmosphere (e.g. n-propyl bromide (NPB) and hexachlorobutadiene (HCBD)). Europe appears to be a significant source of NPB, which is being considered for phase-out under the Montreal Protocol. In addition, some aircraft data have indicated that there may not be full compliance with the phase-out programmes for some of the ODS already identified, so this will need to be monitored carefully.

UK ozone

Ozone monitoring over the UK, by the Met Office and AEA Technology, provides the data (**www.aeat.co.uk/ozone/**) that are used to assess long-term trends in ozone concentration. **Figure 6.1** shows the annual variation in ozone at Lerwick and Camborne, which has been calculated as a ten-year monthly mean. Daily values sometimes deviate from the long-term mean value by a large enough amount to be classified as ‘low’ or ‘high’ ozone events. Low ozone events in summer are relatively common and give greater cause for concern than winter low ozone events, as summer radiation is stronger and human exposure tends to be higher at this time of year. Column ozone measurements in the UK have fluctuated but total ozone values at Lerwick and Camborne have generally decreased during the 1980s and 1990s at an underlying rate of about 3% per decade, although it now appears that the trends are levelling out.

Figure 6.1: Column ozone levels at Lerwick and at Camborne: 1979-2002.



Source: Meteorological Office

Predicting ozone depletion

Coupled climate-chemistry modelling studies of the evolution of the ozone layer have been performed by the University of Cambridge and the Met. Office. Stratospheric chemistry is affected by climate, and reduced temperatures in the stratosphere will affect the production of ozone. Low ozone values will themselves affect future ozone concentrations; ozone absorbs heat and warms the stratosphere so lower levels result in a colder stratosphere, which could contribute to ozone destruction by enhancing the development of Polar Stratospheric Clouds (PSCs). Coupled climate-chemistry models are therefore essential, to show how the ozone layer and climate interact, and how this will affect the recovery of the ozone layer and progress of climate change in the future.

The modelling studies have been used to simulate past trends and have shown that a realistic simulation of ozone behaviour can be obtained when climate scenarios are included. Although the ozone hole has reached record size in recent years this has been partly due to meteorological factors, and is consistent with the expected recovery of the ozone layer, following the implementation of the Montreal Protocol. Other results show that Arctic ozone depletion will continue at a gradual rate over the next two decades, but additionally that there is no indication of Arctic depletion ever reaching the kind of levels experienced in the Antarctic. Furthermore, the model predicts that strong ozone recovery in the Antarctic is unlikely to occur during the next two decades, and in general that a delay in the recovery of the ozone layer will result from the effects of climate change.

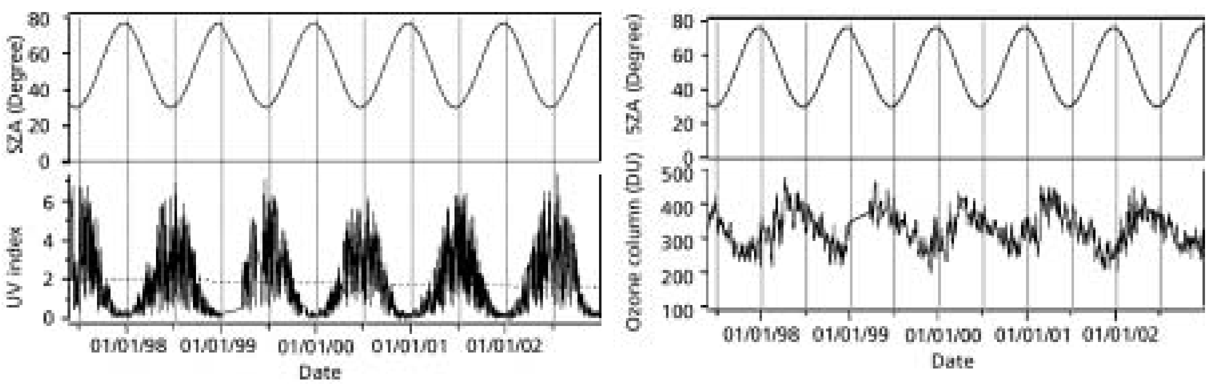
Consequences of decreasing ozone – UV monitoring in the UK

An increase in ultraviolet B (UVB) radiation in the biosphere could cause many detrimental biological and chemical effects including increased cancer incidence in humans. UVB is likely to increase as stratospheric ozone decreases, but the effect of local ozone depletion will be modified by local weather in the short-term, and any other climate changes in the long-term. Measurement of UV radiation enables its daily and seasonal ranges at a site to be established, under the prevailing weather conditions of the location.

Within the GA Research Programme, UV measurements are taken at two UK locations (Manchester and Reading) and analysed at the University of Manchester Institute of Science and Technology (UMIST). Comparisons with ozone data show a reciprocal relationship (i.e. UV is low when ozone is high, and vice versa). Measurements continue and, as the data record becomes longer, an analysis of the longer-term trends and changing UV climatology will be possible. In the UK, there is great variability in UV radiation on all time scales since cloud, which can substantially reduce UV radiation passing through the troposphere, is so changeable from day-to-day and year-to-year. Potential long-term trends in the UV climatology should only be therefore identifiable within a data record of sufficient length. Additionally, the spectral measurements being taken will allow exploration of possible causes of any identified trends

The time series of data from the Manchester site is too short to enable any meaningful analysis yet, but it can be used to illustrate the way in which atmospheric variables other than ozone affect UV. The graphs in **Figure 6.2** show the ozone and UV radiation measured each day at noon for the years 1997 to 2003. There are clear annual cycles in both data sets, with year to year variations. Analyses of both data sets (which should not be extended to infer long term trends) show a slight decrease in both ozone (-1.9%) and UV over the measurement period. One would expect that a decrease in ozone would give a corresponding increase in UV radiation. UV radiation is also reduced by cloud and aerosol in the atmosphere, however.

Figure 6.2: UV Index at noon (bottom left) and column ozone (bottom right) as measured at Manchester. The top panels are the annual solar zenith angle cycle, a major determinant of radiation at the surface.



This section describes research plans from April 2003. Research carried out during the financial year 2003/2004 will be summarised in the Global Atmosphere Research Programme Report 2003/2004, planned for publication November 2004.

Research on ozone and climate issues will continue to be needed to underpin and advise UK policy with respect to the Montreal Protocol and the Framework Convention on Climate Change. The programme is expected to continue to contribute to the international scientific assessments of the IPCC and the WMO/UNEP Ozone Assessment.

Stratospheric ozone depletion

The concentration of ozone depleting chemicals in the upper atmosphere have largely started to slowly decline. The risks to the stratosphere will remain for many years and the overall state of the stratosphere will need to be monitored to track expected slow improvements and also to monitor the influence of climate change. The capability to predict stratospheric change will need to be available to support the assessment of policy options and provide advice on potential public health impacts. Until ozone levels return to near normal, it will be important to continue to maintain UV levels and to increase our understanding of the effects of UVB radiation.

Climate change

Climate Change will continue to receive most of the attention as a major policy area. In anticipation of the entry into force of the Kyoto Protocol a number of technical details on emissions will need to be resolved, particularly with regard to international bunkers, wood products and sinks of greenhouse gases. Domestically the longer term (post 2020) options for reducing greenhouse gases will need to be further quantified in terms of cost and size, requiring considerable underpinning data.

Climate science

Our ability to assess current and predicted future impacts of greenhouse gases on the climate will continue to develop, with considerable effort being put into modelling of the ocean and an increasing range of physical, chemical and biological processes. Major model improvements already being implemented are expected to make significant improvements to the predictions and their scientific robustness and credibility. Continued analysis of climate data will remain an important priority particularly with respect to detection and attribution of human influences.

Plans for future work aim to maintain the Hadley Centre's leading position amongst climate modelling centres by continually improving the model's ability to represent past and current climate and to address policy relevant questions concerning future climate. New work will address whether probabilities can be assigned to future climate change regimes. Work will continue in the important areas of detection and attribution, and in developing a finer resolution to improve regional climate predictions, which are necessary for impact studies. In addition a portable regional climate model will be developed to enable other countries to assess their vulnerability to potential climate change. Work will also continue to assess key climate processes such as cloud radiative feedback to reduce uncertainties. Finally, it is aimed to link some impact models directly to the climate model.

Box 7.1: Probability, uncertainty and risk

All climate predictions involve an element of uncertainty. Policy makers and other stakeholders require the uncertainties to be clearly defined in order to make sound decisions. The Hadley Centre aims to quantify the uncertainty in climate change predictions, and the risk of occurrence of different outcomes, by estimating the probability distribution of future climate changes using large ensembles of different model simulations. A "climate prediction index" that will measure the ability of models to simulate the present day climate is being developed, and will ultimately help to identify which models are best suited to making predictions of future climate change. Work has already started on estimating the probability distribution of global temperature and other climate variables associated with a doubling of CO_2 in the atmosphere.

GA's programme of earth observations will continue. The AATSR satellite instrument (launched in late February 2002) is in orbit and efforts will concentrate on developing data handling and analysis capabilities.

Impacts and adaptation

Priority will be given to the assessment of the impacts of climate change both in the UK and globally, and development of a long term international response:

- GA is establishing a shared funding programme to undertake more detailed quantitative assessments that will inform decision making on regional adaptation options. A pilot phase has been introduced first and a later main phase is planned;
- Consideration will be given to addressing the question of dangerous levels of climate change and the associated long-term targets for greenhouse gas concentrations and the long-term strategy for emission reductions research; and
- We will continue the UK commitment to the IPCC by providing support to the co-chair of Working Group II.

Mitigation

The UK is committed to carrying out a formal review of the UK Climate Change Programme in 2004, and this work will feed into the development of the UK's Fourth National Communication to the UNFCCC. Concurrently, the UK will be required to submit a report on demonstrable progress under the Kyoto Protocol, and the international deadline for both reports is end of 2005.

Work will continue to update the UK's emissions inventories and to provide the underpinning assessments of the options available to reduce emissions and to make use of sinks.

Box 7.2: Enhancements to climate science and impacts research

Under the SR2002 review of resources, additional funding was successfully obtained to cover enhanced supercomputing requirements at the Hadley Centre to improve high resolution regional climate predictions, to allow a full assessment of the uncertainties in global and regional predictions, and to improve the assessment of changes to extreme weather events. This work was prompted by the autumn 2000 flooding event, and more recent floods at the end of 2002 suggest this work has even greater urgency. It will be taken forward during the next 3 financial years (2003-2006).

Science strategy

As part of a Defra-wide initiative, GA has set out its strategy for scientific research covering the period 2003–2006. To view Defra's Science and Innovation Strategy and GA's contribution to it, please visit the science pages at:
www.defra.gov.uk/science/S_IS/default.asp

Summary

The focus of GA's research programme in the future will be to:

- quantify and reduce uncertainties in the human and natural influences on climate, in particular to understand and characterize important unresolved processes and feedbacks in the climate system;
- improve regional climate predictions for impact and adaptation policies, including through development of a finer resolution model;
- further develop a portable regional model to enable other countries to assess their vulnerability to climate change, in conjunction with DFID and UNDP;
- develop a national framework to increase awareness of climate change impacts and stimulate action on adaptation (via UKCIP) and establish a shared funding programme to quantify impacts and inform decision making on regional adaptation options;
- undertake detailed assessment of the potential effects of climate change on extreme weather events and their impacts;
- continue to meet our annual international greenhouse gas inventory reporting commitments under the Convention and develop inventory coverage and quality in preparation for reporting under the Kyoto Protocol;

- update projections of greenhouse gases for the review of the UK Climate Change Programme and the UK's Fourth National Communication to the United Nations Framework Convention on Climate Change;
- develop options to reduce emissions in the longer term, and increase uptake by sinks, and to further quantify these in terms of cost and size;
- develop assessments of the emission pathways needed to achieve different levels of atmospheric stabilisation including technological options and costs;
- continue long term measurements of the ocean and atmosphere, contributing to international programmes in this area (AATSR, ARGO and ALE/GAGE); and
- continue long term measurements of stratospheric ozone and ultra-violet B levels over the UK, and support modelling of stratospheric change.

Information on projects intended to be commissioned during the financial year April 2003 to March 2004 and on how to register interest can be found in the Environmental Protection Group Newsletter at **www.defra.gov.uk/environment/research/index.htm**

The Department commissions research to inform policy development and operates a devolved system of procurement and management in which the research is contracted directly by policy Directorates. Global Atmosphere Division is part of the Environment Protection Group, and the Divisional research programme cycle operates on an annual basis within the wider Departmental framework.

The Global Atmosphere (GA) Division Programme Manager directs the overall research programme, whilst responsibility for the letting, management and evaluation of individual research contracts resides with GA's scientific Nominated Officers (NOs), or their deputies. Each NO manages contracts covering specific areas of research and is also responsible for liaising with policy customers to ensure maximum benefit is gained from the research commissioned by the Division.

The strategic development of the programme is carried out in the first instance in consultation with policy branches to ensure that it meets their needs and, in the second instance, in consultation with the scientific community through various fora- including the Department's own review bodies. This two-fold approach ensures that the Department's policy needs are identified and that the appropriate scientific approach is taken in meeting these needs. It also ensures that the Department takes due recognition of research developments elsewhere and issues not yet being addressed in the policy fora.

Departmental procurement and accounting practice requires contracts to be let on a competitive basis wherever possible, to ensure value for money and fairness to potential contractors. The annual Environment Protection Group Newsletter – which is available on the web at: **www.defra.gov.uk/environment/research/index.htm** – seeks to inform potential contractors of future areas of work, including those relating to the GA research programme, and requests that expressions of interest be submitted by interested research organisations. Using this and other sources of information, organisations capable of carrying out specific research are identified by the NOs and invited to tender in response to a detailed work specification. An internal tender board is convened to choose the successful tenderer prior to letting a contract.

Each NO is responsible for monitoring the progress of work against the schedule and ensuring that contract deliverables and invoices are received and processed in a timely manner. On completion of the contract, an evaluation of the work is undertaken which includes an assessment of the value and relevance of the research and an explanation of how the results are to be used and disseminated.

The utilisation of research results for policy purposes is the priority output for research. The results of all research are also disseminated externally where possible to:

- ensure that the results reach the widest possible range of potential users;
- make available soundly based information relating to issues of concern to the Department;
- encourage good practice and the application of research results by external agencies, and
- avoid duplication of research effort.

In 2002/2003, Global Atmosphere Division supported 35 research contracts in 21 different establishments at a total of £12 million (ex VAT).

Title	Contractor	Contract Value 2002/03
1. Ozone Layer – Prediction and Detection		
Measurement and Analysis of Ozone Levels Over the U.K.	Meteorological Office	82,861
Analysis of Ozone Levels over the UK: Phase III	AEA Technology	60,731
Sub-total		**143,592**
2. Ozone layer – Impacts		
Ultraviolet Measurements and their Analysis	University of Manchester Institute of Science & Technolgy (UMIST)	25,182
Sub-total		**25,182**
3. Climate Change – Prediction and Detection		
Climate Prediction Programme	Meteorological Office (Hadley Centre)	8,441,000
IPCC Working Group 1: Technical Support Unit	Meteorological Office	67,600
Climate Observations (ARGO)	Meteorological Office	448,710
Sub-total		**8,957,310**
4. Climate Change – Earth Observation		
AATSR – Management Information System	Vega Group Plc	35,711
AATSR – Prime Industrial	EADS Astrium	376,236
AATSR – Post Launch Flight Operations Support	Rutherford Appleton Laboratory	294,242
AATSR – Validation Activities	University of Leicester	111,053
AATSR – Principal Investigator	University of Leicester	5,608
Sub-total		**822,850**
5. Climate Change – Trace Gases and Radiative Forcing		
Long-term Monitoring of Trace Gases at Mace Head	International Science Consultants	124,953
Interpretation of Long-term Measurements of Ozone-Depleting Substances Phase III	Meteorological Office	60,820
Sub-total		**185,773**

Title	Contractor	Contract Value 2002/03
6. Climate Change – Impacts		
Climate Impacts LINK Project	University of East Anglia	95,841
Review of UK Impacts Indicators	Centre for Ecology and Hydrology	7,500
UKCIP 2002 Programme	University of Oxford	517,942
Global Impacts of Climate Change on Human Health	London School of Hygiene and Tropical Medicine	10,190
Global Impacts of Climate Change on Water Resources	University of Southampton	5,850
Global Impacts of Sea-level Rise as a Result of Climate Change	Middlesex University	9,400
Global Impacts of Climate Change on Food Security	Parry Associates	64,020
Global Impacts of Climate Change on Natural Vegetation	Centre for Ecology and Hydrology	14,043
INDO-UK Programme on Impacts of Climate Change in India	Environmental Resources Management	260,316
Agricultural Impacts in China	AEA Technology	154,530
IPCC Working GroupII Technical Support Unit	Meteorological Office	96,906
2001 Climate Change Scenarios for UKCIP	University of East Anglia	64,771
Sub-total		**1,301,309**
7. Climate Change – Response strategies		
CO_2 and Energy Use in UK Buildings	British Research Establishment Ltd	61,353
Industrial Sector CO_2 Emissions	Entec	57,892
UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities (LULUCF)	Centre for Ecology and Hydrology	168,215
UK GHG Inventory & Regional Inventories for England, NI, Scotland & Wales	AEA Technology	164,093
Emissions and Projections of Fluorinated Gases for the UK	AEA Technology	25,000
Baseline for CDM projects (LULUCF)	Edinburgh Centre for Carbon Management	2,537
Baseline for CDM projects (non-LULUCF)	ECO Securities	12,176
Estimation of Methane Emissions from Abandoned Coal Mines	IMC Group Consulting LTD	75,000
Methane Emissions from UK Landfill Sites and Impact on EU Landfill Directive and National Strategies on UK Greenhouse Gas Emissions	Land Quality Management and Environmental Resources Management	0
Sub-total		**566,266**
Research Programe Total		**12,002,282**

Figure 9.1: 2002/2003 annual contract value (£m) by topic.

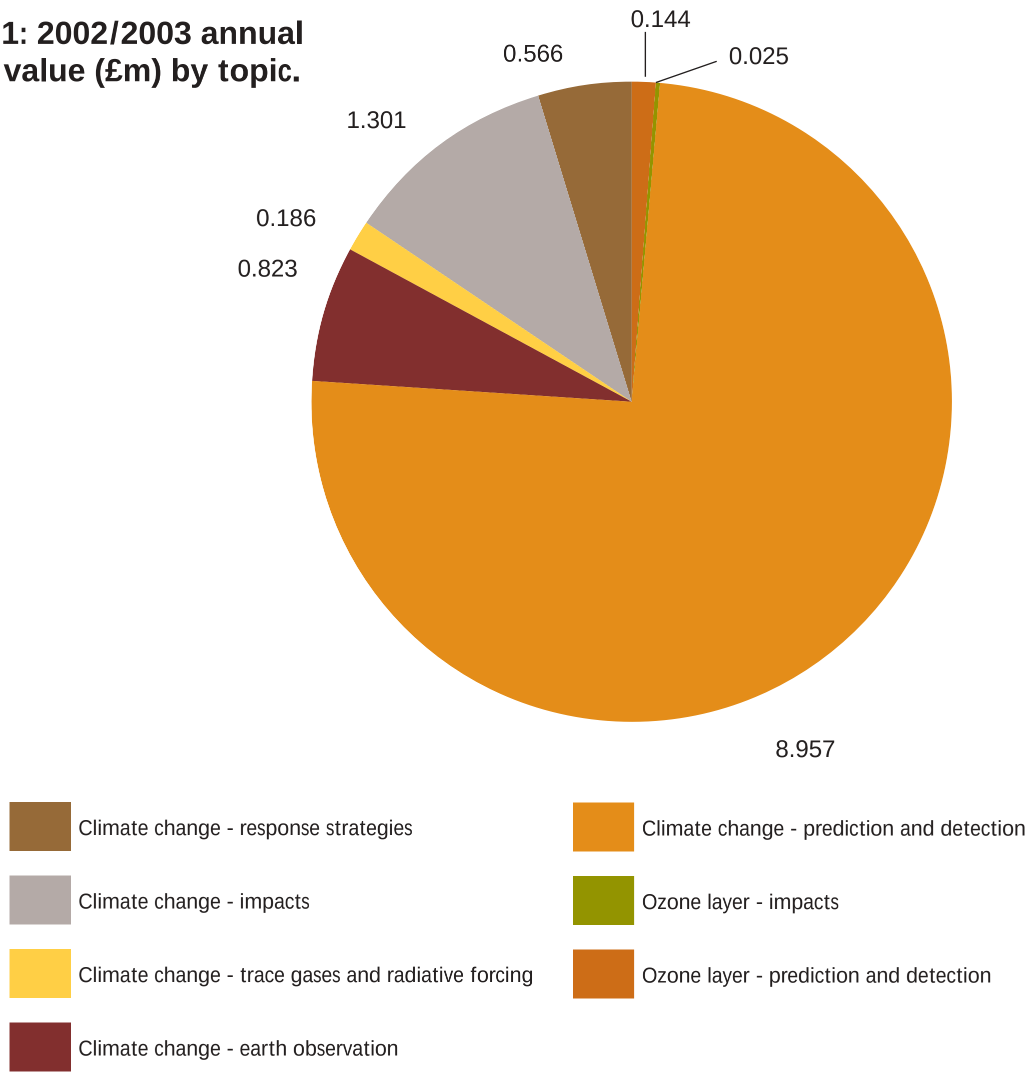
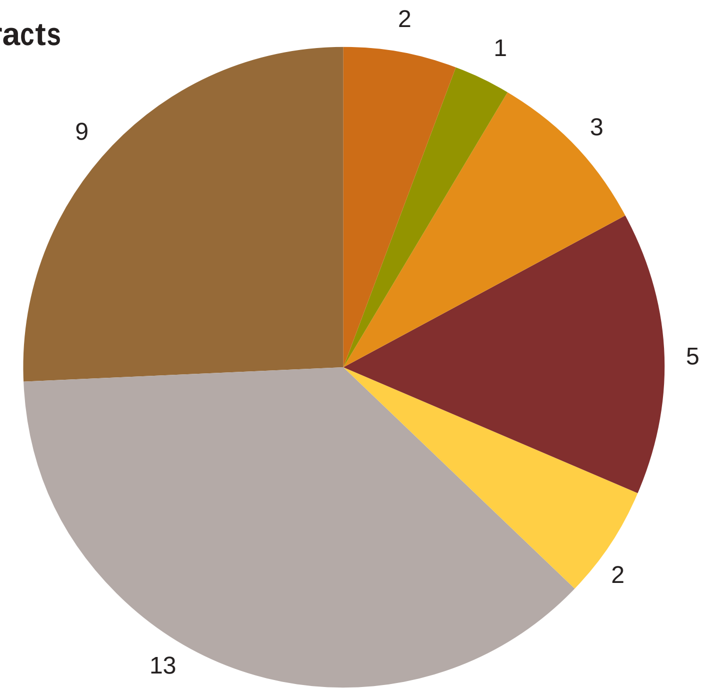


Figure 9.2: Number of contracts by topic 2002/2003.



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Enquiries on the technical aspects of the programme should be addressed to the relevant Nominated Officer below.

If you want to make contact with the Nominated Officers by email; firstname.lastname@defra.gsi.gov.uk. Telephone numbers are 020 7082 + extension

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Climate change	Impacts	Diana Wilkins	(x8163)
Climate change	Response strategies	Jim Penman	(x8152)

Further copies of this Report can be obtained from the Defra distribution centre at Defra Publications, Admail 6000, LONDON, SW1A 2XX Tel.: 08459 556000 (e-mail: defra@iforcegroup.com).

Alternatively copies may be downloaded from the climate change pages of the Defra website at: **www.defra.gov.uk/environment/climatechange**

A more detailed summary of GA's research results for 2002/2003 is given in Global Atmosphere research programme annual report 2002/2003 – Research Results, available in electronic format only on the climate change pages of the Defra web-site at: **www.defra.gov.uk/environment/climatechange/index.htm**

The annual Environment Protection (EP) Group Research Newsletter contains further information on research objectives and titles of proposed new projects. Copies can be obtained from: **www.defra.gov.uk/environment/research/index.htm**