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These information sheets were written by Roberto Acosta, Myles Allen, Anilla Cherian, Sarah Granich, Irving Mintzer, Alevino Suarez, and David von Hippel, and edited by Michael Williams. Each sheet was reviewed by at least two experts.

Foreword

The most profound global threat facing humanity today is the prospect that our economic activities will result in global warming, with serious consequences for the earth's entire ecosystem and for the way of life in rich and poor societies alike.

The expected consequences – rising sea levels, depleted agriculture, reduced water flows, increased health hazards, turbulent weather, social strains – suggest that both developed and developing countries have good reason to worry about climate change.

Many scientists suspect that recent temperature increases and changes in climate variability in various parts of the world may be the first signals of such global climate change.

The stakes are high. We cannot allow damage to the systems that support human life to become irreversible knowing that the cost of implementing future adaptive measures will be prohibitive.

In this regard, the Kyoto Protocol to the Climate Change Convention goes beyond mere calls for action. It relies on legally binding commitments to arrest and then reverse the upward surge in emissions that started in the industrialized countries 150 years ago.

Now it is up to policymakers everywhere to refine and launch the many "win-win" solutions available to them. Abandoning counterproductive incentives and subsidies, removing barriers to market efficiency, and promoting investments in energy efficiency can limit emissions while benefiting the national economy.

Economists have much to offer policymakers by analyzing win-win policies, market mechanisms, and other solutions. The Kyoto Protocol is the first instance where governments have agreed to use economic instruments to implement their commitments. Developing these instruments will give stake-holders more opportunities for achieving cost efficiencies.

One of the most important tasks facing policymakers will be to engage the energies of business, local government, and civil society. Industry leaders must be convinced to adjust their investment and marketing strategies and to develop more energy-efficient vehicles, consumer goods, and production processes. At the local government and community level, the Protocol should be seen as a harbinger of increased pressure to make urban transport systems, public buildings, and town planning more energy efficient and environmentally friendly.

Most importantly, individual households must contribute to emissions reduction through their power of consumer choice and their personal lifestyle decisions.

For its part, the United Nations Environment Programme is fully committed to strengthening its support to the Intergovernmental Panel on Climate Change and its contribution to Convention-related activities, including public information services. Only by working together in this way can the international community effectively address the global challenge of climate change.

Klaus Töpfer
Executive Director
United Nations Environment Programme (UNEP)

An introduction to climate change

◆ **Human activities are releasing greenhouse gases into the atmosphere.** Carbon dioxide is produced when fossil fuels are used to generate energy and when forests are cut down and burned. Methane and nitrous oxide are emitted from agricultural activities, changes in land use, and other sources. Artificial chemicals called halocarbons (CFCs, HFCs, PFCs) and other long-lived gases such as sulphur hexafluoride (SF6) are released by industrial processes. Ozone in the lower atmosphere is generated indirectly by automobile exhaust fumes.

◆ **Rising levels of greenhouse gases are expected to cause climate change.** By absorbing infrared radiation, these gases control the way natural energy flows through the climate system. In response to humanity's emissions, the climate will somehow have to adjust to a "thicker blanket" of greenhouse gases in order to maintain the balance between energy arriving from the sun and energy escaping back into space.

◆ **Climate models predict that the global temperature will rise by about 1-3.5°C by the year 2100.** This projected change is larger than any climate change experienced over the last 10,000 years. It is based on current emissions trends and assumes that no efforts are made to limit greenhouse gas emissions. There are many uncertainties about the scale and impacts of climate change, particularly at the regional level. Because of the delaying effect of the oceans, surface temperatures do not respond immediately to greenhouse gas emissions, so climate change will continue for many decades after atmospheric concentrations have stabilized. Meanwhile, the balance of the evidence suggests that the climate may have already started responding to past emissions.

◆ **Climate change is likely to have a significant impact on the global environment.** In general, the faster the climate changes, the greater will be the risk of damage. The mean sea level is expected to rise 15-95 cm by the year 2100, causing flooding of low-lying areas and other damage. Climatic zones (and thus ecosystems and agricultural zones) could shift towards the poles by 150-550 km in the mid-latitude regions. Forests, deserts, rangelands, and other unmanaged ecosystems would face new climatic stresses. As a result, many will decline or fragment, and individual species will become extinct.

◆ **Human society will face new risks and pressures.** Food security is unlikely to be threatened at the global level, but some regions are likely to experience food shortages and hunger. Water resources will be affected as precipitation and evaporation patterns change around the world. Physical infrastructure will be damaged, particularly by sea-level rise and by extreme weather events. Economic activities, human settlements, and human health will experience many direct and indirect effects. The poor and disadvantaged are the most vulnerable to the negative consequences of climate change.

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◆ **People and ecosystems will need to adapt to future climatic regimes.** Past and current emissions have already committed the earth to some degree of climate change in the 21st century. Adapting to these effects will require a good understanding of socio-economic and natural systems, their sensitivity to climate change, and their inherent ability to adapt. Many strategies are available for adapting to the expected effects of climate change.

◆ **Stabilizing atmospheric concentrations of greenhouse gases will demand a major effort.** Based on current trends, the total climatic impact of rising greenhouse gas levels will be equal to that caused by a doubling of pre-industrial CO_2 concentrations by 2030, and a trebling or more by 2100. Freezing global CO_2 emissions at their current levels would postpone CO_2-doubling to 2100; emissions would eventually have to fall to about 30% of their current levels for concentrations to stabilize at doubled-CO_2 levels sometime in the future. Given an expanding world economy and growing populations, this would require dramatic improvements in energy efficiency and fundamental changes in other economic sectors.

◆ **The international community is tackling this challenge through the Climate Change Convention.** Adopted in 1992 and now boasting over 175 members, the Convention seeks to stabilize atmospheric concentrations of greenhouse gases at safe levels. It commits developed countries to take measures aimed at returning their emissions to 1990 levels by the year 2000. It further requires all countries to limit their emissions, gather relevant information, develop strategies for adapting to climate change, and cooperate on research and technology.

◆ **The 1997 Kyoto Protocol will require stronger action in the post-2000 period.** The Parties to the Convention have agreed by consensus that developed countries will have a legally binding commitment to reduce their collective emissions of six greenhouse gases by at least 5% compared to 1990 levels by the period 2008-2012. The Protocol also establishes an emissions trading regime and a "clean development mechanism".

◆ **Many options for limiting emissions are available in the short- and medium-term.** Policymakers can encourage energy efficiency and other climate-friendly trends in both the supply and consumption of energy. Key consumers of energy include industries, homes, offices, vehicles, and farms. Efficiency can be improved in large part by providing an appropriate economic and regulatory framework for consumers and investors. This framework should promote cost-effective actions, the best current and future technologies, and "no regrets" solutions that make economic and environmental sense irrespective of climate change. Taxes, regulatory standards, tradable emissions permits, information programmes, voluntary programmes, and the phase-out of counterproductive subsidies can all play a role. Changes in practices and lifestyles, from better urban transport planning to personal habits such as turning out the lights, are also important.

◆ **Energy efficiency gains of 10-30% above baseline trends can be realized over the next 20-30 years at no net cost.** Some researchers believe that much greater gains are also feasible during this period and beyond. Improvements over the baseline can be achieved in all major economic sectors with current knowledge and with today's best technologies. In the longer term, it will be possible to move close to a zero-emissions industrial economy – with the innumerable environmental and economic benefits that this implies.

◆ **Reducing uncertainties about climate change, its impacts, and the costs of various response options is vital.** In the meantime, it will be necessary to balance concerns about risks and damages with concerns about economic development. The prudent response to climate change, therefore, is to adopt a portfolio of actions aimed at controlling emissions, adapting to impacts, and encouraging scientific, technological, and socio-economic research.

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The greenhouse effect

◆ **The earth's climate is driven by a continuous flow of energy from the sun.** This energy arrives mainly in the form of visible light. About 30% is immediately scattered back into space, but most of the 70% that is absorbed passes down through the atmosphere to warm the earth's surface.

◆ **The earth must send this energy back out into space in the form of infrared radiation.** Being much cooler than the sun, the earth does not emit energy as visible light. Instead, it emits infrared, or thermal radiation. This is the heat thrown off by an electric fire or grill before the bars begin to glow red.

◆ **"Greenhouse gases" in the atmosphere block infrared radiation from escaping directly from the surface to space.** Infrared radiation cannot pass straight through the air like visible light. Instead, most departing energy is carried away from the surface by air currents and clouds, eventually escaping to space from altitudes above the thickest layers of the greenhouse gas blanket.

◆ **The main greenhouse gases are water vapour, carbon dioxide, ozone, methane, nitrous oxide, and the chlorofluorocarbons (CFCs).** Apart from CFCs all of these gases occur naturally. Together, they make up less than 1% of the atmosphere. This is enough to produce a "natural greenhouse effect" that keeps the planet some 30°C warmer than it would otherwise be - essential for life as we know it.

◆ **Levels of all key greenhouse gases (with the possible exception of water vapour) are rising as a direct result of human activity.** Emissions of carbon dioxide (mainly from burning coal, oil, and natural gas), methane and nitrous oxide (due to agriculture and changes in land use), ozone (generated by the fumes in automobile exhausts) and CFCs (manufactured by industry) are changing how the atmosphere absorbs energy. Water vapour levels may also be rising because of a "positive feedback". This is all happening at an unprecedented speed. The result is known as the "enhanced greenhouse effect".

◆ **The climate system must adjust to rising greenhouse gas levels to keep the global "energy budget" in balance.** In the long term, the earth must get rid of energy at the same rate at which it receives energy from the sun. Since a thicker blanket of greenhouse gases helps to reduce energy loss to space, the climate must change somehow to restore the balance between incoming and outgoing energy.

◆ **This adjustment will include a "global warming" of the earth's surface and lower atmosphere.** But this is only part of the story. Warming up is the simplest way for the climate to get rid of the extra energy. But even a small rise in temperature will be accompanied by many other changes: in cloud cover and wind

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patterns, for example. Some of these changes may act to enhance the warming (positive feedbacks), others to counteract it (negative feedbacks).

◆ **Meanwhile, industrially-generated "sulphate aerosols" may have a local cooling effect.** Sulphur emissions from coal- and oil-fired power stations produce clouds of microscopic particles that reflect sunlight back out into space. This partly compensates for greenhouse warming. These sulphate aerosols, however, remain in the atmosphere for a relatively short time compared to the long-lived greenhouse gases. They also cause problems, such as acid rain. This means we should not rely on sulphate aerosols to keep the climate cool indefinitely.

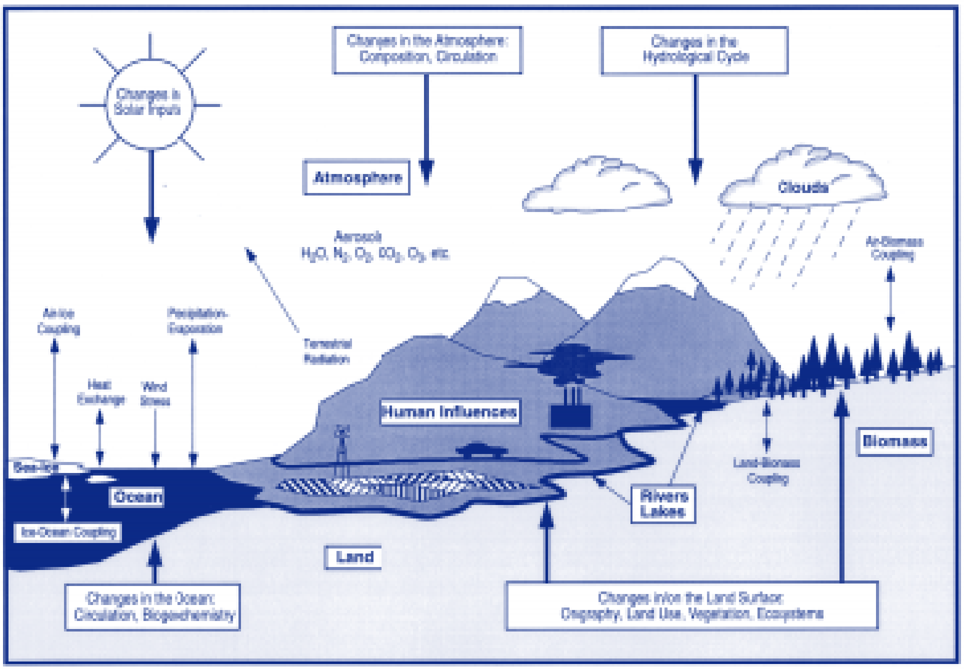
◆ **Climate models predict that the global average temperature will rise by about 2°C (3.6°F) by the year 2100 if current emission trends continue.** This projection uses 1990 as a baseline. It also takes into account climate feedbacks and the effects of sulphate aerosols as they are presently understood. Because there are still many uncertainties, current estimates of how much it will warm during the 21st century range from 1 to 3.5°C.

◆ **Past emissions have already committed us to some climate change.** The climate does not respond immediately to emissions. It will therefore continue to change for many years even if greenhouse gas emissions are reduced and atmospheric levels stop rising. Some important impacts of climate change, such as a predicted rise in sea level, will take even longer to be fully realized.

◆ **There is evidence that climate change has already begun.** The climate varies naturally, making it difficult to identify the effects of rising greenhouse gases. But the pattern of temperature trends over the past few decades does resemble the pattern of greenhouse warming predicted by models. These trends are unlikely to be due entirely to known sources of natural variability. While many uncertainties remain, scientists believe that "the balance of the evidence suggests a discernible human influence on global climate."

◆ **It is still too early to predict the size and timing of climate change in specific regions.** Current climate models are only able to predict patterns of change for the continental scale. Predicting how climate change will affect the weather in a particular region is much more difficult. Thus the practical consequences of "global warming" for individual countries or regions remain very uncertain.

A schematic illustration of the climate system



Source: IPCC 1995.

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Greenhouse gases and aerosols

◆ **Greenhouse gases (GHGs) control energy flows in the atmosphere by absorbing infra-red radiation.** These trace gases comprise less than 1% of the atmosphere. Their levels are determined by a balance between "sources" and "sinks". Sources are processes that generate greenhouse gases; sinks are processes that destroy or remove them. Humans affect greenhouse gas levels by introducing new sources or by interfering with natural sinks.

◆ **The largest contributor to the natural greenhouse effect is water vapour.** Its presence in the atmosphere is not directly affected by human activity. Nevertheless, water vapour matters for climate change because of an important "positive feedback". Warmer air can hold more moisture, and models predict that a small global warming would lead to a rise in global water vapour levels, further adding to the enhanced greenhouse effect. On the other hand, it is possible that some regions may become drier. Because modelling climate processes involving clouds and rainfall is particularly difficult, the exact size of this crucial feedback remains unknown.

◆ **Carbon dioxide is currently responsible for over 60% of the "enhanced" greenhouse effect, which is responsible for climate change.** This gas occurs naturally in the atmosphere, but burning coal, oil, and natural gas is releasing the carbon stored in these "fossil fuels" at an unprecedented rate. Likewise, deforestation releases carbon stored in trees. Current annual emissions amount to over 7 billion tonnes of carbon, or almost 1% of the total mass of carbon dioxide in the atmosphere.

◆ **Carbon dioxide produced by human activity enters the natural carbon cycle.** Many billions of tonnes of carbon are exchanged naturally each year between the atmosphere, the oceans, and land vegetation. The exchanges in this massive and complex natural system are precisely balanced; carbon dioxide levels appear to have varied by less than 10% during the 10,000 years before industrialization. In the 200 years since 1800, however, levels have risen by almost 30%. Even with half of humanity's carbon dioxide emissions being absorbed by the oceans and land vegetation, atmospheric levels continue to rise by over 10% every 20 years.

◆ **A second important human influence on climate is aerosols.** These clouds of microscopic particles are *not* a greenhouse gas. In addition to various natural sources, they are produced from sulphur dioxide emitted mainly by power stations, and by the smoke from deforestation and the burning of crop wastes. Aerosols settle out of the air after only a few days, but they are emitted in such massive quantities that they have a substantial impact on climate.

◆ **Aerosols cool the climate locally by scattering sunlight back into space.** Aerosol particles block sunlight directly and also provide "seeds" for clouds to form, and often these clouds also have a cooling effect. Over heavily industrialized regions, aerosol cooling may counteract nearly all of the warming effect of greenhouse gas increases to date.

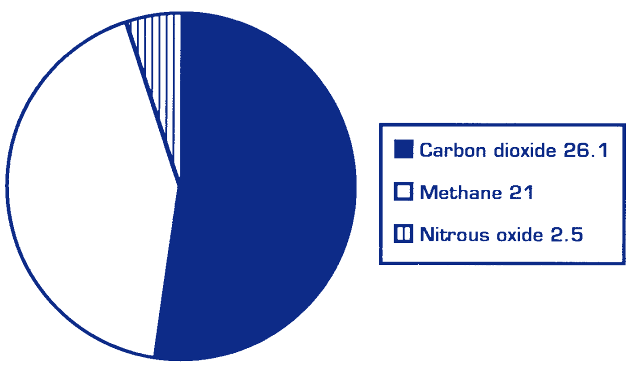
◆ **Methane is a powerful greenhouse gas whose levels have already doubled.** The main "new" sources of methane are agricultural, notably flooded rice paddies and expanding herds of cattle. Emissions from waste dumps and leaks from coal mining and natural gas production also contribute. The main sink for methane is chemical reactions in the atmosphere, which are very difficult to model and predict.

◆ **Methane from past emissions currently contributes 15-20% of the enhanced greenhouse effect.** The rapid rise in methane started more recently than the rise in carbon dioxide, but methane's contribution has been catching up fast. However, methane has an effective atmospheric lifetime of only 12 years, whereas carbon dioxide survives much longer. This means that the relative importance of methane versus carbon dioxide emissions depends on the "time horizon". For example, methane emitted during the 1980s is expected to have about 80% of the impact of that decade's carbon dioxide emissions over the 20-year period 1990-2010, but only 30% over the 100-year period 1990-2090 (see figure).

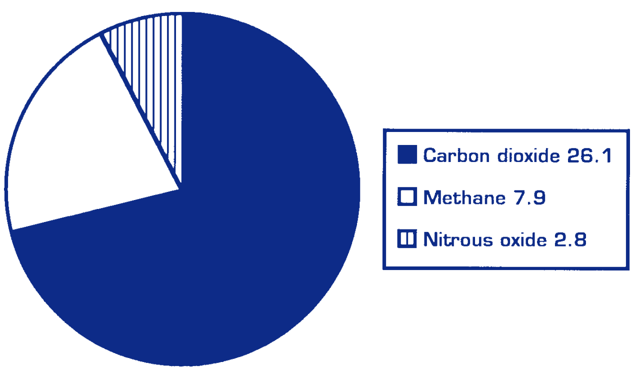
◆ **Nitrous oxide, chlorofluorocarbons (CFCs), and ozone contribute the remaining 20% of the enhanced greenhouse effect.** Nitrous oxide levels have risen by 15%, mainly due to more intensive agriculture. CFCs increased rapidly until the early 1990s, but levels of key CFCs have since stabilised due to tough emission controls introduced under the Montreal Protocol to protect the stratospheric ozone layer. Ozone is another naturally-occurring greenhouse gas whose levels are rising in some regions in the lower atmosphere due to air pollution, even as they decline in the stratosphere.

◆ **Humanity's greenhouse gas emissions have already disturbed the global energy budget by about 2.5 Watts per square metre.** This equals about one percent of the net incoming solar energy that drives the climate system. One percent may not sound like much, but added up over the earth's entire surface, it amounts to the energy content of 1.8 million tonnes of oil every minute, or over 100 times the world's current rate of commercial energy consumption. Since greenhouse gases are only a by-product of energy consumption, it is ironic that the amount of energy humanity actually uses is tiny compared to the impact of greenhouse gases on natural energy flows in the climate system.

20-year time-horizon



100-year time-horizon



Relative impact of carbon dioxide, methane and nitrous oxide emitted during the 1980s, considering their cumulative impact on the earth's radiation budget over a 20-year and 100-year time-horizon. Methane has an atmospheric lifetime of only about 12 years, so it's relative impact declines as we look over longer timescales. Ozone and CFCs are omitted because current rates are uncertain or changing rapidly.
Source: IPCC94 with updated GWPs from IPCC95. Methane impact includes indirect.

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How will greenhouse gas levels change in the future ?

◆ **Future greenhouse gas emissions will depend on global population, economic, technological, and social trends.** The link to population is clearest: the more people there are, the higher emissions are likely to be. The link to economic development is less clear. Rich countries generally emit more per person than do poor countries. However, countries of similar wealth can have very different emission rates depending on their geographical circumstances, their sources of energy, and the efficiency with which they use energy and other natural resources.

◆ **As a guide to policymakers, economists produce "scenarios" of future emissions.** A scenario is not a prediction. Rather it is a way of investigating the implications of particular assumptions about future trends, including policies on greenhouse gases. Depending on the assumptions, a scenario can project growing, stable, or declining emissions.

◆ **Most scenarios suggest that future growth in emission rates will be dominated by what happens in developing countries.** The bulk of emissions to date have come from industrialized countries. However, most future growth is likely to come from emerging economies where economic and population growth is fastest - and for which projections are most uncertain.

◆ **In a typical "non-intervention" scenario, carbon dioxide emissions rise from 7 billion tonnes of carbon per year in 1990 to 20 billion in 2100.** "Non-intervention" means that no new policies are adopted to reduce emissions in response to the threat of climate change. It does not mean that nothing else changes: in this particular scenario (known as IS92a), world population doubles by 2100 while economic growth continues at 2-3% per year. (Remember that scenarios are based on assumptions, which may be quite wrong.)

◆ **This scenario leads to the equivalent of a doubling of pre-industrial CO_2 concentrations by 2030, and a trebling by 2100.** This includes the effects of other greenhouse gas emissions, translated into their carbon-dioxide equivalents. Even a doubling of pre-industrial carbon dioxide would take levels of long-lived greenhouse gases higher than they have been for several million years.

◆ **Different assumptions about sources and sinks give very different results.** Future emissions are uncertain, and they have to be translated into future atmospheric concentrations using models of the carbon cycle and atmospheric chemistry. This introduces more uncertainty, since it is unclear how key sinks (processes that absorb or destroy greenhouse gases) will respond to a changing climate. Rising carbon dioxide levels, for example, cause plants to grow faster (the "CO_2-fertilisation effect") and absorb more carbon dioxide through photosynthesis. CO_2 fertilisation, together with forest re-growth in northern countries, may be absorbing up to 25% of the carbon dioxide currently produced by human activity.

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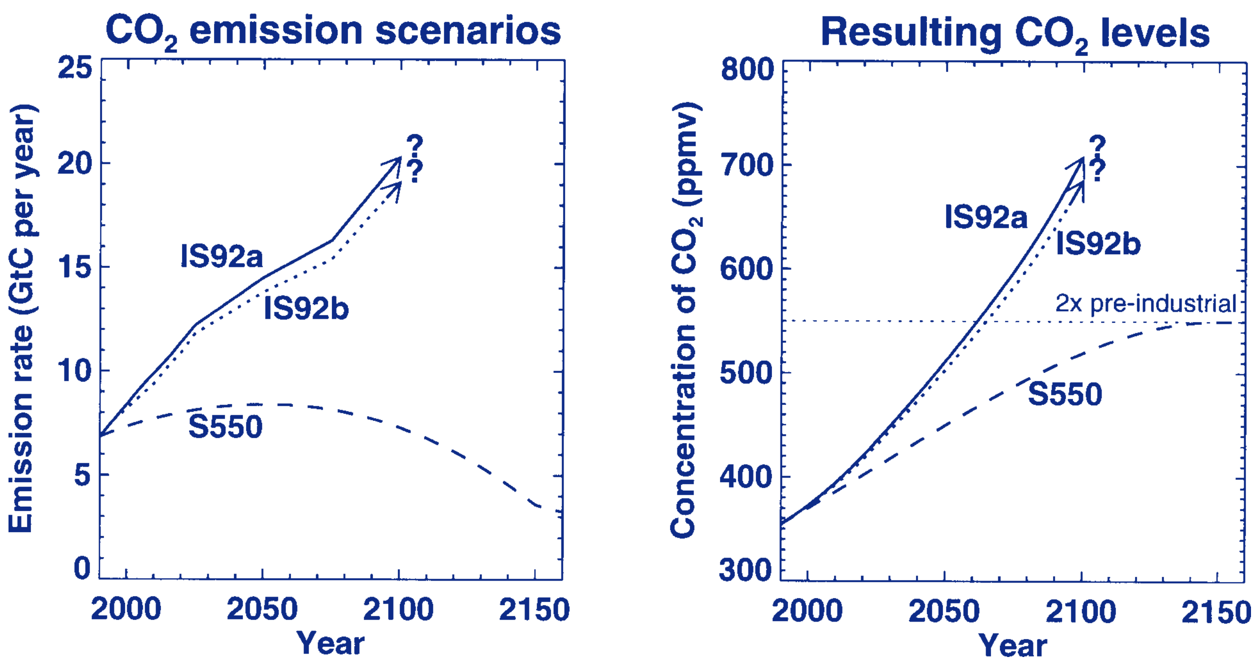
No-one knows how this sink will behave in the future: if more land is required for food production, the trend may reverse.

◆ **"Intervention" scenarios are designed to examine the impact of efforts to reduce greenhouse gas emissions.** They depend not only on assumptions about population and economic growth, but also about how future societies will respond to the introduction of policies such as taxes on carbon-rich fossil fuels.

◆ **Existing international commitments could slightly reduce the rate of growth in emissions through the 21st century.** Under the Climate Change Convention, developed countries are trying to return their greenhouse gas emissions to 1990 levels by the year 2000. If they were to succeed, the date of CO_2 doubling would be postponed by less than five years. A goal of making more substantial reductions in atmospheric concentrations would clearly require all countries to make dramatically stronger cuts in their emissions.

◆ **Freezing global emissions at current levels would postpone CO_2-doubling to 2100.** While such a scenario is far beyond any proposals now being considered, it still would not be enough to prevent greenhouse gas concentrations from continuing to rise far beyond the year 2100. Stabilising carbon dioxide at double its pre-industrial concentration sometime in the 22nd century would require emissions to fall eventually to less than 30% of their current levels, despite growing populations and an expanding world economy.

◆ **Reducing uncertainties about climate change impacts and the costs of various response options is vital for policymakers.** Stabilising or reducing emissions world-wide would have an impact on almost every human activity. To decide if it is worthwhile, we need to know how much it would cost, and how bad things will get if we let emissions grow. There are tough moral questions too: how much are we prepared to pay for the climate of the 22nd century, which only our children's children will see?



Future carbon dioxide emissions (left panel) for a range of policy scenarios and the resulting atmospheric carbon dioxide concentrations (right panel) estimated from a carbon cycle model. The IS92a scenario assumes that world population grows to 11.3 billion by 2100, economic growth continues at 2.3-2.9% per annum, and no active steps are taken to reduce CO_2 emissions. IS92b makes the same assumptions about population and growth, but assumes commitments by many OECD countries to stabilize or reduce emissions. S550 illustrates a pattern of emissions that would stabilize CO_2 at approximately double its pre-industrial level shortly after 2100. GtC is one billion tonnes of carbon; ppmv is parts per million by volume. Source: IPCC 1995; data provided by the Hadley Centre for Climate Prediction and Research, UK.

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How will the climate change ?

◆ **If nothing is done to reduce emissions, current climate models predict a global warming of about 2°C between 1990 and 2100.** This projection takes into account the effects of aerosols and the delaying effect of the oceans. This oceanic inertia means that the earth's surface and lower atmosphere would continue to warm by a further 1-2°C even if greenhouse gas concentrations stopped rising in 2100.

◆ **The range of uncertainty in this projection is 1°C to 3.5°C. Even a 1°C rise would be larger than any century-time-scale trend for the past 10,000 years.** Uncertainties about future emissions, climate feedbacks, and the size of the ocean delay all contribute to this uncertainty range.

◆ **The earth's average sea level is predicted to rise by about 50 cm by 2100.** The uncertainty range is large - 15 to 95 cm - and changing ocean currents could cause local and regional sea levels to rise much more or much less than the global average. The main cause of this rise is the thermal expansion of the upper layers of the ocean as they warm, with some contribution from melting glaciers. Slightly faster melting of the Greenland and Antarctica ice sheets is likely to be balanced by increased snowfall in both regions. As the warming penetrates deeper into the oceans and ice continues to melt, sea level will continue rising well after surface temperatures have levelled off.

◆ **Regional and seasonal warming predictions are much more uncertain.** Although most areas are expected to warm, some will warm much more than others. The largest warming is predicted for cold northern regions in winter. The reason is that snow and ice reflect sunlight, so less snow means more heat is absorbed from the sun, which enhances any warming: a strong positive feedback effect. By the year 2100, parts of northern Canada and Siberia are predicted to warm by up to 10°C in winter, but less than 2°C in summer.

◆ **Inland regions are projected to warm faster than oceans and coastal zones.** The reason is simply the ocean delay, which prevents the sea surface from warming as fast as the land. The size of this delay depends on how deep any warming penetrates into the oceans. Over most of the oceans, the uppermost few hundred metres do not mix with the water beneath them. These upper layers will warm within just a few years, while the deep ocean stays cold. Water mixes down into the ocean depths in only a few very cold regions, such as the Atlantic south of Greenland and the Southern Ocean near Antarctica. In these regions, warming will be delayed because much more water needs to be warmed up to get the same temperature change at the surface.

◆ **Aerosols may counteract some of the effects of greenhouse warming in the vicinity of major industrialised regions.** Clouds of superfine sulphate particles

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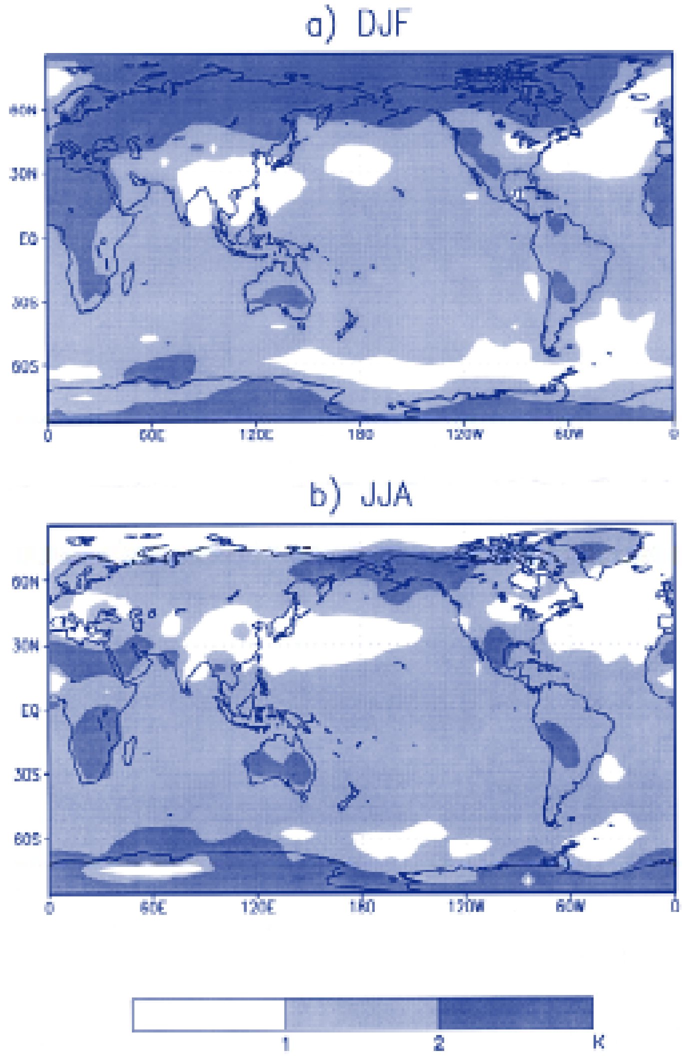
from burning coal and oil should counteract greenhouse warming over much of the Eastern USA, Eastern Europe, and parts of China. But since some action is likely to reduce sulphur emissions because of acid rain, the size of this effect is unpredictable.

◆ **Total precipitation is predicted to increase, but at the local level trends are much less certain.** Wintertime precipitation in the far north is likely to rise, but what happens in mid-latitudes and in the tropics depends very much on the details of the particular climate model and the emissions scenario. Including the effects of aerosols, for example, significantly weakens the Asian summer monsoon in the two models which have so far run this experiment.

◆ **More rain and snow will mean wetter soil conditions in high-latitude winters, but higher temperatures may mean drier soils in summer.** Local changes in soil moisture are clearly important for agriculture, but models still find it difficult to simulate them. Even the sign of the global change in summertime soil moisture - whether there will be an increase or a decrease - is uncertain.

◆ **The frequency and intensity of extreme weather events such as storms and hurricanes may change.** However, models still cannot predict how. The models used to simulate climate change cannot themselves simulate these extreme weather events, so the evidence is indirect. There is some concern that patterns of extreme weather may change because the models predict changes in ocean surface temperatures and other factors that are known to affect storm and hurricane development. However, it will be many years before scientists can predict whether individual regions will become more or less stormy.

◆ **Rapid and unexpected climate transitions cannot be ruled out.** The most dramatic such change, the collapse of the West Antarctic ice sheet, which would lead to a catastrophic rise in sea level, is now considered unlikely in the next 100 years. There is evidence that changes in ocean circulation which have a significant impact on regional climate (such as a weakening of the Gulf Stream that warms Europe) can take place in only a few decades, but it is unknown whether or not greenhouse warming could trigger any such change. External factors, such as a series of volcanic eruptions or a change in the power output of the sun, could also have a major impact, but the consensus is that climate change over the 21st century as a whole is likely to be dominated by the effects of greenhouse gas emissions.



Predicted surface-temperature change in a climate model forced with the effects of changing greenhouse gas levels and sulphate aerosols. The maps show the difference between the decade 2040-2049 and the period 1950-1979 during a) the December-January-February period and b) June-July-August. White indicates warming less than 1°C, light shading 1-2°C, and heavy shading greater than 2°C. Notice how there is more warming over land than over sea, and that the strongest warming is at high latitudes in winter.
Source; Deutsches Klimarechenzentrum.

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Has climate change already begun ?

◆ **The earth's climate is already adjusting to past greenhouse gas emissions.** The climate system must adjust to changing greenhouse gas concentrations in order to keep the global energy budget balanced. This means that the climate is changing and will continue to change as long as greenhouse gas levels keep rising. But this is not very useful. The real question is how large the change is likely to be relative to the natural climate fluctuations that human societies and natural ecosystems have learned to adapt to.

◆ **Measurement records indicate a warming of 0.3°-0.6°C in global average temperature since 1860.** This is in line with model projections of the size of warming to date, particularly when the cooling effect of sulphur emissions is included. But observations are sparse before 1900 and much of the warming occurred between 1910 and 1940, before the largest rise in greenhouse gases. There is clearly more going on than a simple, direct response to emissions. This is to be expected as the climate is a complicated and chaotic system.

◆ **Mean sea level has risen by 10 to 25 cm and mountain glaciers have retreated.** As the upper layers of the oceans warm, water expands and sea level rises. Models suggest that a 0.3°-0.6°C warming should indeed result in a 10 to 25 cm sea-level rise. But other, harder-to-predict, changes also affect the real and apparent sea level, notably snowfall and ice-melt in Greenland and Antarctica and the slow "rebound" of northern continents freed from the weight of ice age glaciers. Almost all recorded mountain glaciers show a retreat over the past century but, as with sea level, this is unlikely to be only a response to changes in greenhouse gases.

◆ **The observed global warming trend is larger than the trends that models indicate could be due to natural variability.** A key problem in climate change research is that scientists have no direct way of observing what would have happened if humanity had left the climate alone. There is no direct way of comparing the greenhouse "signal" with the background "noise" of natural climate variability. Instead, this background variability can be estimated by running climate change computer models with constant greenhouse gas levels. The results indicate that the warming trend of 0.3°-0.6°C per century is unlikely to be a chance fluctuation. However, indirect evidence from past climates suggests that these models underestimate the size of natural climate variability, so they may be overestimating the significance of the signal.

◆ **Climate models omit many sources of variability that could also cause apparent long-term trends.** Current model-based estimates of natural variability do not include the effects of volcanic eruptions, which can cool the global climate temporarily by several tenths of a degree. They are also only beginning to include the effects of long-term changes in the power output of the sun. The sun may have been responsible for relatively cool periods during the 16th, 17th, and 19th centuries (the so-called "Little Ice Age") when the northern hemisphere may have

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been about 0.5°C colder than it is today. Some of the warming over the past century (about 20-30% of it, according to some recent model results) may still be a recovery from that time.

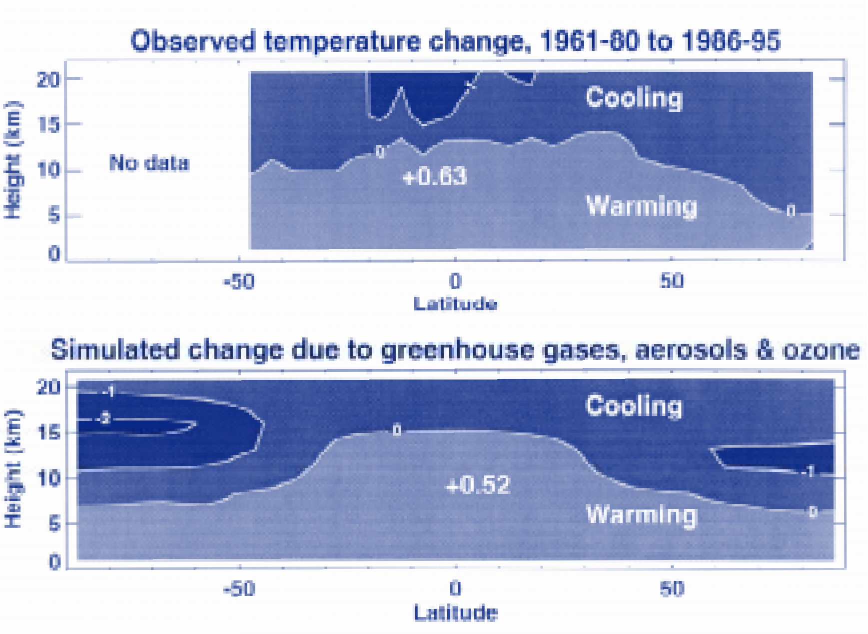
◆ **Models can also be used to predict the overall pattern of climate change.** Because so many unknown factors may affect the global average temperature, scientists are reluctant to conclude that greenhouse warming has arrived on the evidence of that one number alone. Instead, they look for similarities between the pattern of change emerging in the observations and the pattern projected by climate models.

◆ **Several studies have reported increasingly close agreement between model-predicted and observed patterns of temperature change.** Studies of surface temperature records show some evidence that the land is warming faster than the oceans. They also show reduced warming in areas affected by sulphate aerosols and in those ocean regions where surface water mixes down, distributing any warming to the ocean depths - all features of the model-predicted pattern. But coverage is incomplete, and observations in different regions (e.g. land vs. sea) are made in different ways. A more consistent, but much shorter, record is provided by air temperatures from meteorological stations. These show a pattern of cooling in the stratosphere (above about 10 km) and warming in the troposphere (lower atmosphere), which is also predicted by climate models (see figure).

◆ **The satellite record is still too short to reveal significant trends.** The climate has to be observed over several decades before any climate change signal can be distinguished from natural variability. The longest satellite records are still well under 20 years. Models predict that it should not be possible to detect anything in such a short period, so all that can be said about the satellite data for the moment is that they are consistent with climate model projections and with evidence from conventional observations. Satellite data do provide global coverage, which helps to validate models and reduce uncertainties.

◆ **The evidence suggests that recent changes are unlikely to be entirely due to known sources of natural variability.** The pattern of change seems to point to some human influence on climate similar to that projected by climate models and larger than expected from natural fluctuations. This point is not yet settled, however, mainly because of uncertainty over the ability of current models to simulate natural variability realistically. Nevertheless, it is reassuring for many modelers because it suggests that the models are pointing in roughly the right direction.

◆ **Uncertainty about the ability of models to simulate natural climate variability remains a significant problem.** As with trends in global mean temperature, scientists must use climate model simulations to assess the probability of getting a certain level of agreement purely by chance between the model and the observed patterns of change. There are many sources of natural variability that these models simulate poorly or not at all, and one of these might be associated with a pattern similar to the greenhouse warming pattern. Thus there is still a wide range of uncertainty about the size and origin of the present signal and about the size of future changes.



Top: Vertical pattern of temperature change in a north-south section through the atmosphere, averaged over all longitudes, as observed over the past 35 years. Bottom: Same section as predicated by a climate model simulation of the same period including changes in greenhouse gas levels, sulphate aerosols, and stratosphere ozone. The vertical axis shows height above the surface, the horizontal axis shows latitude. The pattern of warming (lightest shade) below 7-12 km and of cooling (darker shades) above that level is the same in both figures. The model appears to predict the strength of the pattern approximately correctly, although clear differences remain. Source: Tett, Mitchell, Parker and Allen, Science, vol. 247, pp. 1170-1173, 1998, figures provided by the Hadley Centre for Climatic Prediction and Research and the Space Science Department of the Rutherford Appleton Laboratory, UK.

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The evidence from climate models

◆ **The climate system is extremely complex.** Consequently, there is no simple way of determining how much the climate will change in response to rising greenhouse gas levels. If the only changes were air and surface temperatures, it would be easy to predict a 1-1.5°C warming by 2100 assuming that current emissions trends continue. But this "direct response" figure (which is less than the current "best guess" of future warming) is almost meaningless because it is physically impossible for the climate system to warm up by over 1°C without any other changes.

◆ **Complex computer simulations are therefore essential for understanding climate change.** Computers allow scientists to model the many interactions between different components of the climate system. The most detailed projections are based on coupled atmosphere-ocean general circulation models (AOGCMs). These are similar to the models used to predict the weather, in which the physical laws governing the motion of the atmosphere are reduced to systems of equations to be solved on supercomputers. However, climate models must also include equations representing the behaviour of the oceans, land vegetation, and the cryosphere (sea ice, glaciers, and ice caps).

◆ **"Positive feedbacks" involving water vapour, snow, and ice may amplify the direct response to greenhouse gas emissions by a factor of two to three.** Snow and ice reflect sunlight very effectively. If a small warming melts snow earlier in the year, more energy will be absorbed by the ground exposed underneath it, in turn causing more warming. This is the main reason wintertime northern regions are expected to warm the most. The water vapour feedback is even more important: water vapour is itself a powerful greenhouse gas, and models project that global warming will raise water vapour levels in the lower atmosphere.

◆ **Changes in cloud cover, ocean currents, and chemistry and biology, may either amplify or reduce the response.** Models generally predict that cloudiness will change in a warmer world, but depending on the type and location of the clouds, this could have various effects. Clouds reflect sunlight, implying that more clouds would have a cooling effect. But most clouds, particularly those at high altitudes, also have an insulating effect: being very cold, they shed energy to space relatively ineffectively, thus helping to keep the planet warm. So the net cloud feedback could go either way. Clouds are the main reason for the large uncertainty about the size of warming under any given emissions scenario.

◆ **The speed and timing of climate change strongly depends on how the oceans respond.** The uppermost layers of the oceans interact with the atmosphere every year and so are expected to warm along with the earth's surface. But it takes over 40 times as much energy to warm the top 100 m of the ocean as to warm the entire atmosphere by the same amount. With ocean depths reaching several

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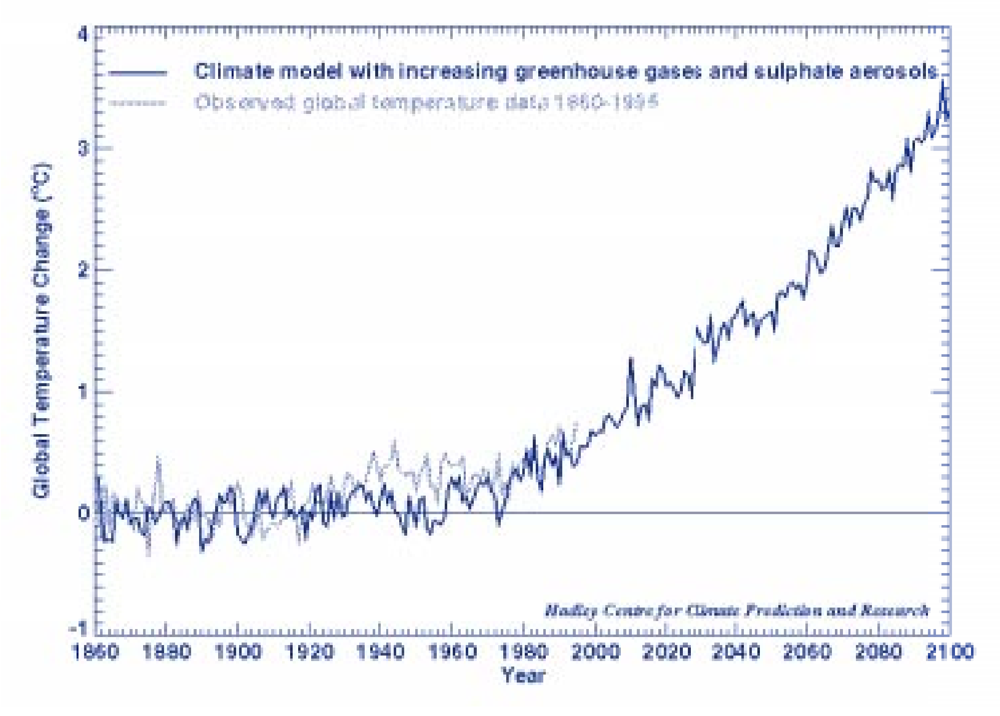
kilometres, the oceans will therefore slow down any atmospheric warming. How much they slow it down depends on how deeply the warming penetrates. The latest climate models are only just beginning to represent the processes which exchange energy between the atmosphere and ocean depths, so this remains an important source of uncertainty.

◆ **Climate projections must begin from a stable and realistic simulation of the present-day climate, which is not easy to obtain.** Ideally, scientists would like to allow a model to settle down with pre-industrial levels of greenhouse gases and then increase greenhouse gas levels to examine the response. But the inevitable approximations mean that the model generally starts to drift away from the present climate at a rate comparable to, or even larger than, the warming expected due to changing greenhouse gas levels. There are various ways of correcting for this "climate drift" to obtain a stable model climate before starting a climate change experiment. None of these correction schemes is very satisfactory, since they are covering up model errors that might be important for climate change. The size of these corrections is diminishing as models improve, however, which suggests that it may be possible to eliminate them altogether in the relatively near future.

◆ **Scientists' ability to verify model projections is often limited by incomplete knowledge of the real climate.** The processes that matter for climate change are those that operate on time-scales of decades or more. Detailed observations only exist for a few decades, but scientists can attempt to extend the record back using indirect evidence. This record suggests that model simulations of past climates and natural year-to-year climate fluctuations are improving, although they still have significant shortcomings.

◆ **Climate models are scientific tools, not crystal balls.** Large climate modelling experiments consume enormous computing resources and are so expensive that each year only a handful of such experiments can be performed world-wide. Then the work involved in interpreting the results of a computer simulation is often greater than the work needed to perform the experiment in the first place. All of this work and expense can give models the aura of truth. But even the most sophisticated models are approximate representations of a very complex system, so they will never be an infallible guide to the future. This said, the level of uncertainty in climate models should not be exaggerated; it is no greater than the uncertainty in the economic models on which many other far-reaching decisions must be based. So think of climate models as sophisticated tools for extending our knowledge of present and past climate into an unexplored future. Since climate change will only happen once, they are the best tool we have.



Global average near-surface temperature change from 1860 to 2100 as predicted by a climate model (black line). Changes in greenhouse gases and sulphate aerosols are prescribed following the observed changes up to 1990, and following a scenario (IS92a) under which no new policies are adopted to combat climate changes from 1990-2100. The grey line shows observed global average temperature changes since 1860. Data provided by the Hadley Centre for Climate Prediction and Research, UK.

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The evidence from past climates

◆ **The earth's climate varies naturally.** Each component of this complex system evolves on a different timescale. The atmosphere changes in hours, and its detailed behaviour is impossible to predict beyond a few days. The upper layers of the oceans adjust in the course of a few seasons, while changes in the deep oceans can take centuries. The animal and plant life of the biosphere (which influences rainfall and temperature) normally varies over decades. The cryosphere (snow and ice) is slower still: changes in thick ice sheets take centuries. The geosphere (the solid earth itself) varies slowest of all - mountain-building and continental drift (which influence winds and ocean currents) take place over millions of years.

◆ **Past natural climate changes offer vital insights into human-induced climate change.** Studies of past climates ("paleoclimatology") give a sense of the scale of future changes projected by climate models. They also provide a crucial check on scientists' understanding of key climate processes and their ability to model them.

◆ **Systematic global temperature records are available only since 1860.** These include land-based air temperature measurements and sea-surface temperature measurements. Such data need to be checked carefully for any biases that may be introduced by changes in observation methods or sites. For example, many meteorological stations have been located in or near cities. As cities grow, they can have a significant warming effect on the local climate. Such effects must be - and are - taken into account in estimating recent changes in global temperature.

◆ **Studies of earlier climates are based on indirect evidence.** Changing lake levels, for example, can reveal the past balance between rainfall and evaporation. Tree-rings, coral, ice-caps, or ocean sediments can all preserve information about the past. Using a combination of measurements, models, and "detective work", scientists convert the quantities they can measure (such as the chemical composition of an ice-core sample) into the physical variables they wish to investigate (such as the Antarctic temperature of 100,000 years ago).

◆ **The earth's climate has been dominated by ice ages for the past few million years.** Ice ages are almost certainly triggered by slow "wobbles" in the earth's axis and its orbit around the sun. These wobbles affect the total amount of energy the planet receives from the sun and in particular its geographic distribution. During an ice age, global temperatures fall by 5°C and ice-sheets advance over much of Europe and North America. Ice ages are separated by warmer "interglacial" periods.

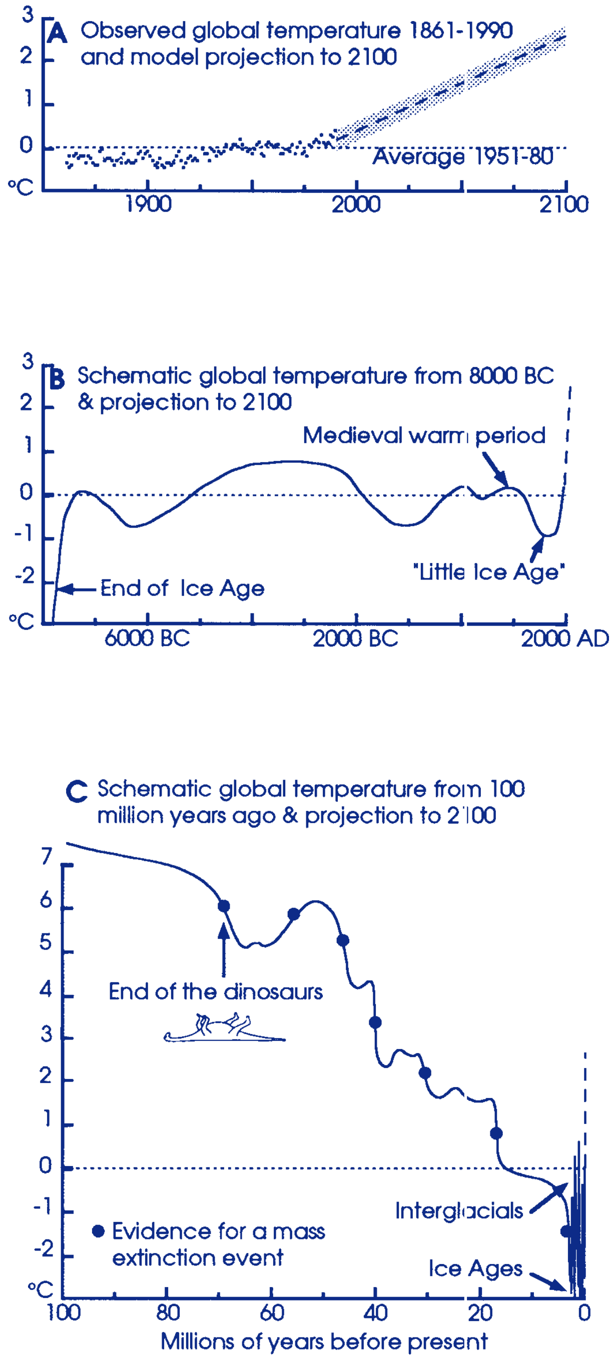
◆ **Changes in greenhouse gas concentrations may have helped to amplify ice-age cycles.** The small fluctuations in energy arriving from the sun due to the earth's orbital wobbles are not large enough to account for the size of global temperature changes during the ice age cycles. Ice-core samples show that greenhouse gas levels also varied significantly and may have played an important role in amplifying temperature fluctuations.

◆ **Reconstructions of past climates can be used as a check on climate model projections.** Comparing a model "prediction" of ice-age climate with the evidence from paleoclimatology provides a crucial check on the model's representation of processes relevant for future climate change. But the paleoclimatic evidence can be ambiguous: some sources suggest that, compared with today, tropical seas were some 5°C colder at the peak of the last ice age, while others suggest only 1-2°C. As a result, separating model errors from uncertainties in the evidence can be difficult.

◆ **The climate seems to have been remarkably stable since the last ice age ended 10,000 years ago.** As far as scientists can tell, global temperatures have varied by less than one degree since the dawn of human civilisation. Against the apparently extreme and sometimes rapid climate fluctuations of the preceding 100,000 years, this stands out as a relatively peaceful interglacial period.

◆ **Models predict that the climate could be warmer by the end of the 21st century than it was during any previous inter-glacial period.** In a period between two ice ages about 125,000 years ago, much of Europe and Asia appear to have been about 2°C warmer than they are today. However, models are predicting that temperatures could rise by more than 4°C over much of this region during the 21st century if greenhouse gas emissions continue as projected.

◆ **Abrupt climate variations in the distant past appear to have been traumatic for life on earth.** The earth's biological history is punctuated by so-called "mass extinction events" during which a large fraction of the world's species are wiped out. There are many possible reasons for mass extinctions, but the records suggest that some of these events coincided with relatively abrupt changes in climate - similar in magnitude to the kind of change now forecast for the 21st century. Over the next 100 years we may experience conditions unknown since before the ice ages began many millions of years ago.



Sources: A) Schematic of global average temperature compiled from ice-core records from IPCC 1990. B) Schematic of global temperature estimated from geological records adapted from T.J. Crowley and G.R. North, Science, Vol. 240, pp. 996-1002, 1988, scaled for global temperature following T.J. Crowley in A. Berger et. al. (eds.), "Climate and the Geo-Sciences", pp. 179-207, Kluwer, 1989. Dinosaur by David Catling.

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Adapting to the impacts of climate change

◆ **Even an immediate and dramatic cut in global greenhouse gas emissions would not fully prevent climate change impacts.** The climate system responds to changes in greenhouse gas levels with a time lag, in part because of the oceans' thermal inertia. Past and present emissions have already committed the earth to at least some climate change in the 21st century. Natural ecosystems and human societies will be sensitive to both the magnitude and the rate of this change. Therefore, while controlling emissions is vital, it must be combined with efforts to minimize damage through adaptation.

◆ **The most vulnerable ecological and socio-economic systems are those with the greatest sensitivity to climate change and the least ability to adapt.** ***Sensitivity*** is the degree to which a system will respond to a given change in climate; it measures, for example, how much the composition, structure, and functioning of an ecosystem will respond to a given temperature rise. ***Adaptability*** is the degree to which systems can adjust in response to, or in anticipation of, changed conditions. ***Vulnerability*** defines the extent to which climate change may damage or harm a system; this depends not only on the system's sensitivity, but on its ability to adapt.

◆ **Ecosystems that are already under stress are particularly vulnerable.** Most ecosystems are sensitive to humanity's unsustainable management practices and increasing demands for resources. For example, human activities can fragment lightly managed and unmanaged ecosystems, limiting their potential for adapting naturally to climate change. Fragmentation of ecosystems will also complicate human efforts to assist adaptation, for example by creating migration corridors.

◆ **Socio-economic systems tend to be more vulnerable in developing countries with weaker economies and institutions.** People who live in arid or semi-arid lands, low-lying coastal areas, flood-prone areas, or on small islands are at particular risk. Greater population densities have made some sensitive areas more vulnerable to hazards such as storms, floods, and droughts.

◆ **Adapting to climate change can be a spontaneous or planned act.** Individuals, businesses, governments, and nature itself will often adapt to climate change impacts without any external help. In many cases, however, people will need to plan how to minimize negative impacts or benefit from positive ones. Planned adaptation can be launched prior to, during, or after the onset of the actual consequences.

◆ **Six general strategies are available for adapting to climate change.** Measures can be taken in advance to ***prevent losses***, for example by building barriers against sea-level rise. It may be possible to ***reduce losses*** to a tolerable level; this could include redesigning crop mixes to ensure a guaranteed minimum yield under even the worst conditions. The burden on those directly affected by climate change can be eased by ***spreading or sharing losses***, perhaps through government disaster relief. Communities can also ***change a use or activity*** that is no longer viable, or ***change the location*** of an activity, for example by re-siting a hydro-electric power utility in a place where there is more water. Sometimes it may be best to ***restore a site***, such as an historical monument newly vulnerable to flood damage.

◆ **Successful strategies will draw on ideas and advances in law, finance, economics, technology, public education, and training and research**. Technological advances often create new options for managed systems such as agriculture and water supply. However, many regions of the world currently have limited access to new technologies and to information. Technology transfer is essential, as is the availability of financial resources. Cultural, educational, managerial, institutional, legal, and regulatory practices are also important to effective adaptation, at both the national and international levels. For example, the ability to incorporate climate change concerns into development plans can help ensure that new investments in infrastructure reflect likely future conditions.

◆ **Many adaptation policies would make good sense even without climate change.** Present-day climatic variability, including extreme climatic events such as droughts and floods, already causes a great deal of destruction. Greater efforts to adapt to these events could help to reduce damage in the short term, regardless of any longer-term changes in climate.

◆ **Crafting adaptation strategies is complicated by uncertainty.** It is still not possible to quantify future impacts on any particular system at any particular location. This is because climate change predictions at the regional level are uncertain, current understanding of natural and socio-economic processes is often limited, and most systems are subject to many different interacting stresses.

◆ **Detecting early impacts will be difficult, and unexpected changes cannot be ruled out**. The unambiguous detection of climate-induced changes in most ecological and socio-economic systems will prove extremely difficult in the coming decades. Knowledge has increased dramatically in recent years, but research and monitoring remain essential for gaining a better understanding of potential impacts and the adaptation strategies needed to deal with them.

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Agriculture and food security

◆ **Some agricultural regions will be threatened by climate change, while others may benefit.** The impact on crop yields and productivity will vary considerably. Added heat stress, shifting monsoons, and drier soils may reduce yields in the tropics and subtropics, whereas longer growing seasons may boost yields in northern Canada and Europe. Projections of regional climate change and the resulting agricultural impacts, however, are still full of uncertainties (as illustrated by the table below).

◆ **Climate and agricultural zones are likely to shift towards the poles.** Because average temperatures are expected to rise more near the north and south poles than near the equator, the shift in climate zones will be more pronounced at higher latitudes. In the mid-latitude regions (45° to 60°), present temperature zones could shift by 150-550 km. Since each of today's latitudinal climate belts is optimal for particular crops, such shifts could strongly affect agricultural and livestock production. Efforts to shift crops poleward in response could be limited by the inability of soil types in the new climate zones to support intensive agriculture as practiced today in the main producer countries.

◆ **Soil moisture will be affected by changing precipitation patterns.** Based on a global warming of 1-3.5°C over the next 100 years, climate models project that both evaporation and precipitation will increase, as will the frequency of intense rainfalls. While some regions may become wetter, in others the net effect of an intensified hydrological cycle will be a loss of soil moisture. Some regions that are already drought-prone may suffer longer and more severe dry spells. The models also project seasonal shifts in precipitation patterns: soil moisture will decline in some mid-latitude continental regions during the summer, while rain and snow will probably increase at high latitudes during the winter.

◆ **Higher temperatures will influence production patterns**. Plant growth and health may benefit from fewer freezes and chills, but some crops may be damaged by higher temperatures, particularly if combined with water shortages. Certain weeds may expand their range into higher-latitude habitats. There is also some evidence that the poleward expansion of insects and plant diseases will add to the risk of crop loss.

◆ **More carbon dioxide in the atmosphere could boost productivity.** In principle, higher levels of CO_2 should stimulate photosynthesis in certain plants. This is particularly true for so-called C3 plants because increased carbon dioxide tends to suppress their photo-respiration, making them more water efficient. C3 plants make up the majority of species globally, especially in cooler and wetter habitats, and include most crop species, such as wheat, rice, barley, cassava and potato. The response of C4 plants would not be as dramatic. C4 plants include such tropical crops as maize, sugar cane, sorghum and millet, which are important for the food

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security of many developing countries, as well as pasturage and forage grasses. Experiments based on a doubling of CO_2 concentrations have confirmed that "CO_2 fertilization" can increase mean yields of C3 crops by 30%. This effect could be enhanced or reduced, however, by accompanying changes in temperature, precipitation, pests, and the availability of nutrients.

◆ **The productivity of rangelands and pastures would also be affected.** For example, livestock would become costlier if agricultural disruption leads to higher grain prices. In general, it seems that intensively managed livestock systems will more easily adapt to climate change than will crop systems. This may not be the case for pastoral systems, however, where communities tend to adopt new methods and technologies more slowly.

◆ **The global yield from marine fisheries should remain unchanged by global warming.** The principal effects will be felt at the national and local levels as the mix of species changes and people respond by relocating fisheries. These possible local effects could threaten the food security of countries that are highly dependent on fish. In general, some of the positive effects of climate change could include longer growing seasons, lower natural winter mortality, and faster growth rates at higher latitudes. The negative ones could include upsets in established reproductive patterns, migration routes, and ecosystem relationships.

◆ **Food security risks are primarily local and national.** Studies suggest that global agricultural production could be maintained relative to the expected baseline levels over the next 100 years. However, regional effects would vary widely, and some countries may experience reduced output even if they take measures to adapt. This conclusion takes into account the beneficial effects of CO_2 fertilization but not other possible effects of climate change, including changes in agricultural pests and soils.

◆ **The most vulnerable people are the landless, poor, and isolated**. Poor terms of trade, weak infrastructure, lack of access to technology and information, and armed conflict will make it more difficult for these people to cope with the agricultural consequences of climate change. Many of the world's poorest areas, dependent on isolated agricultural systems in semi-arid and arid regions, face the greatest risk. Many of these at-risk populations live in sub-Saharan Africa; South, East and Southeast Asia; tropical areas of Latin America; and some Pacific island nations.

◆ **Effective policies can help to improve food security.** The negative effects of climate change can be limited by changes in crops and crop varieties, improved water-management and irrigation systems, adapted planting schedules and tillage practices, and better watershed management and land-use planning. In addition to addressing the physiological response of plants and animals, policies can seek to improve how production and distribution systems cope with fluctuations in yields.

Selected crop studies of future climate change

Region	Impact on yields (%)	
	Maize	Wheat
Latin America	-61 to an increase	-50 to -5
Former Soviet Union	-	-19 to +41
Europe	-30 to an increase	increase or decrease
North America	-55 to +62	-100 to +234
Africa	-65 to +6	-
South Asia	-65 to -10	-61 to +67
Other Asia and Pacific Rim	-	-41 to +65

Note: Based on double CO_2-equivalent equilibrium scenarios from global climate models.
Source: Intergovernmental Panel on Climate Change, "Summary for Policymakers: Scientific-Technical Analysis of Impacts, Adaptations, and Mitigation of Climate Change", p. 10, in "Climate Change 1995", Vol. 2, Cambridge University Press.

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Sea levels, oceans, and coastal areas

◆ **The global average sea level has risen by 10 to 25 cm over the past 100 years.** It is likely that much of this rise is related to an increase of 0.3-0.6°C in the lower atmosphere's global average temperature since 1860.

◆ **Models project that sea levels will rise another 15 to 95 cm by the year 2100 (with a "best estimate" of 50 cm).** This will occur due to the thermal expansion of ocean water and an influx of freshwater from melting glaciers and ice. The projected rise is two to five times faster than the rise experienced over the past 100 years. The rate, magnitude, and direction of sea-level change will vary locally and regionally in response to coastline features, changes in ocean currents, differences in tidal patterns and sea-water density, and vertical movements of the land itself. Sea levels are expected to continue rising for hundreds of years after atmospheric temperatures stabilize.

◆ **Coastal zones and small islands are extremely vulnerable.** Coasts have been modified and intensively developed in recent decades and thus made even more vulnerable to higher sea levels. Developing countries with their weaker economies and institutions face the gravest risks, but the low-lying coastal zones of developed countries could also be seriously affected. Given the present degree of protection, a sea-level rise of one metre would cause estimated land losses of 0.05% in Uruguay, 1% in Egypt, 6% in the Netherlands, 17.5% in Bangladesh, and up to about 80% for Atoll Majuro in the Marshall Islands.

◆ **Flooding and coastal erosion would worsen.** Salt-water intrusion will reduce the quality and quantity of freshwater supplies. Higher sea levels could also cause extreme events such as high tides, storm surges, and seismic sea waves (tsunami) to reap more destruction. Flooding due to storm surges already affects some 46 million people in an average year, most of them in developing countries. Studies suggest that this figure could increase to 92 million with a 50 cm sea-level rise, and to 118 million with a one-metre rise.

◆ **Sea-level rise could damage key economic sectors** . . . A great deal of food is produced in coastal areas, making fisheries, aquaculture, and agriculture particularly vulnerable. Other sectors most at risk are tourism, human settlements, and insurance (which has already suffered record losses recently due to extreme climate events). The expected sea-level rise would inundate much of the world's lowlands, damaging coastal cropland and displacing millions of people from coastal and small-island communities.

◆ . . . **and threaten human health.** The displacement of flooded communities, particularly those with limited resources, would increase the risk of various infectious, psychological, and other illnesses. Insects and other transmitters of disease could spread to new areas. The disruption of systems for sanitation, storm-water drainage, and sewage disposal would also have health implications.

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◆ **Valuable coastal ecosystems will be at serious risk.** Coastal areas contain some of the world's most diverse and productive ecosystems, including mangrove forests, coral reefs, and sea grasses. Low-lying deltas and coral atolls and reefs are particularly sensitive to changes in the frequency and intensity of rainfall and storms. Coral will generally grow fast enough to keep pace with sea-level rise but may be damaged by warmer sea temperatures.

◆ **Ocean ecosystems may also be affected.** In addition to higher sea levels, climate change could reduce sea-ice cover and alter ocean circulation patterns, the vertical mixing of waters, and wave patterns. This could have an impact on biological productivity, the availability of nutrients, and the ecological structure and functions of marine ecosystems. Changing temperatures could also cause geographical shifts in biodiversity, particularly in high-latitude regions, where the growing period should increase (assuming light and nutrients remain constant). People would be more affected by changes in fish and other biotic resources, and less by impacts on transport (due to changed currents) and physical resources such as oil and gravel. Finally, any changes in plankton activity could affect the oceans' ability to absorb and store carbon. This could "feedback" into the climate system and moderate or boost climate change.

◆ **Various natural forces will influence the impact that higher sea levels will have.** Coastal areas are dynamic systems. Sedimentation, physical or biotic defenses (such as coral reefs), and other local conditions will interact with rising sea-water. For example, freshwater supplies in coastal zones will be more or less vulnerable depending on changes in freshwater inflows and the size of the freshwater body. The survival of salt marshes and mangrove forests will depend in part on whether the rate of sedimentation is greater than or less than the rate of local sea-level rise. Sedimentation is more likely to exceed sea-level rise in sediment-rich regions such as Australia, where strong tidal currents redistribute sediments, than in sediment-starved environments such as the Caribbean.

◆ **Human activities will also play a role.** Roads, buildings, and other infrastructure could limit or affect the natural response of coastal ecosystems to sea-level rise. Pollution, sediment deposits, and land development will influence how coastal waters respond to, and compensate for, climate change impacts.

◆ **Many policy options are available for adapting to sea-level rise.** Sensitive environmental, economic, social, and cultural values are at stake, and trade-offs may be unavoidable. Until recently, the assessment of possible response strategies focused mainly on protection, and studies have shown that protecting low-lying islands and large delta areas with sea walls and other barriers is likely to be costly. A fuller range of options would include protection (dikes, dune restoration, wetland creation), accommodation (new building codes, protection of threatened ecosystems), and planned retreat (regulations against new coastal development). Other specific examples are dredging ports, strengthening fisheries management, and improving design standards for offshore structures. "Integrated coastal zone management" can offer a portfolio of possible responses from which to choose, including social, cultural, legal, structural, financial, economic, and institutional measures.

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Biological diversity and ecosystems

◆ **Biological diversity - the source of enormous environmental, economic, and cultural value - will be threatened by rapid climate change.** A warming of 1-3.5°C over the next 100 years would shift current climate zones poleward by approximately 150-550 km - and vertically by 150-550 m - in mid-latitude regions. The composition and geographic distribution of unmanaged ecosystems will change as individual species respond to new conditions. At the same time, habits will be degraded and fragmented by the combination of climate change, deforestation, and other environmental pressures. Species that cannot adapt quickly enough may become extinct - an irreversible loss.

◆ **Forests adapt slowly to changing conditions.** Observations, experiments, and models demonstrate that a sustained increase of just 1°C in the global average temperature would affect the functioning and composition of forests. A typical climate change scenario for the 21st century shows a major impact on the species composition of one third of the world's existing forests (varying by region from one seventh to two thirds). Entire forest types may disappear, while new combinations of species, and hence new ecosystems, may be established. Other stresses caused by warming may include more pests, pathogens, and fires. Because higher latitudes are expected to warm more than equatorial ones, boreal forests will be more affected than temperate and tropical forests.

◆ **Forests play an important role in the climate system.** They are a major reservoir of carbon, containing some 80% of all the carbon stored in land vegetation, and about 40% of the carbon residing in soils. Large quantities of carbon may be emitted into the atmosphere during transitions from one forest type to another because mortality releases carbon faster than growth absorbs it. Forests also directly affect climate on the local, regional, and continental scales by influencing ground temperature, evapo-transpiration, surface roughness, albedo (or reflectivity), cloud formation, and precipitation.

◆ **Deserts and arid and semi-arid ecosystems may become more extreme.** With few exceptions, deserts are projected to become hotter but not significantly wetter. Higher temperatures could threaten organisms that now exist near their heat-tolerance limits.

◆ **Rangelands may experience altered growing seasons.** Grasslands support approximately 50% of the world's livestock and are also grazed by wildlife. Shifts in temperatures and precipitation may reshape the boundaries between grasslands, shrublands, forests, and other ecosystems. In tropical regions such changes in the evapo-transpiration cycle could strongly affect productivity and the mix of species.

◆ **Mountain regions are already under considerable stress from human activities.** The projected declines in mountain glaciers, permafrost, and snow cover will further affect soil stability and hydrological systems (most major river systems start in the mountains). As species and ecosystems are forced to migrate uphill, those whose climatic ranges are already limited to mountain tops may have nowhere to go and become extinct. Agriculture, tourism, hydropower, logging, and other economic activities will also be affected. The food and fuel resources of indigenous populations in many developing countries may be disrupted.

◆ **The cryosphere will shrink.** Representing nearly 80% of all freshwater, the cryosphere encompasses all of the earth's snow, ice, and permafrost. Frozen water is, of course, highly sensitive to temperature change (a fact that researchers have used for studying past climate changes). Climate models project that mountain glaciers could be reduced by one third to one half over the next 100 years. This in turn will affect nearby ecosystems and communities as well as seasonal river flows and water supplies - which in turn would affect hydropower and agriculture. The landscapes of many high mountain ranges and polar regions would change dramatically. The melting of permafrost could destabilize infrastructure and release additional carbon and methane into the atmosphere. Reduced sea-ice would open certain rivers and coastal areas to navigation for longer seasons. Despite these many striking effects, the Greenland and Antarctic ice sheets are not expected to change much over the next 50-100 years.

◆ **Non-tidal wetlands will also be reduced.** These open-water and waterlogged areas provide refuge and breeding grounds for many species. They also help to improve water quality and control floods and droughts. Studies from several countries suggest that a warmer climate will contribute to the decline of wetlands through higher evaporation. By altering their hydrological regimes, climate change will influence the biological, biogeochemical, and hydrological functions of these ecosystems, as well as their geographical distribution.

◆ **Human actions can help natural ecosystems adapt to climate change.** Creating natural migration corridors and assisting particular species to migrate could benefit forest ecosystems. Reforestation and the "integrated management" of fires, pests, and diseases can also contribute. Rangelands could be supported through the active selection of plant species, controls on animal stocking, and new grazing strategies. Wetlands can be restored and even created. Desertified lands may adapt better if drought-tolerant species and better soil conservation practices are encouraged.

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Water resources

◆ **Climate change will lead to more precipitation - but also to more evaporation.** In general, this acceleration of the hydrological cycle will result in a wetter world. The question is, how much of this wetness will end up where it is needed?

◆ **Precipitation will probably increase in some areas and decline in others.** Climate models are still unable to make precise regional predictions. In addition, the hydrological cycle is extremely complex: a change in precipitation may affect surface wetness, reflectivity, and vegetation, which then affect evapo-transpiration and cloud formation, which in turn affect precipitation. Meanwhile, the hydrological system is also responding to other human activities such as deforestation, urbanization, and the over-use of water supplies.

◆ **Changing precipitation patterns will affect how much water can be captured.** Several models suggest that downpours will become more intense. This would increase floods and runoff while reducing the ability of water to infiltrate the soil. Changes in seasonal patterns may affect the regional distribution of both ground and surface water supplies.

◆ **The drier the climate, the more sensitive is the local hydrology.** Relatively small changes in temperature and precipitation could cause relatively large changes in runoff. Arid and semi-arid regions will therefore be particularly sensitive to reduced rainfall and to increased evaporation and plant transpiration.

◆ **High-latitude regions may see more runoff due to greater precipitation.** Runoff would also be affected by a reduction in snowfall, deep snow, and glacier ice, particularly in the spring and summertime when it is traditionally used for hydroelectricity and agriculture. All climate change models show increased wintertime soil moisture in the high northern latitudes, with a reduction of moisture in some areas. Most models produce less soil moisture in summer in northern mid latitudes, including some important grain producing areas; these projections are more consistent for Europe than for North America.

◆ **The effects on the tropics are harder to predict.** Different climate models produce different results for the future intensity and distribution of tropical rainfall.

◆ **Reservoirs and wells would be affected.** Changes at the surface would influence the recharging of groundwater supplies and, in the longer term, aquifers. Water quality may also respond to changes in the amount and timing of precipitation.

◆ **New patterns of runoff and evaporation will also affect natural ecosystems.** Freshwater ecosystems will respond to altered flood regimes and water levels. Changes in water temperatures and in the thermal structure of fresh waters could affect the survival and growth of certain organisms, and the diversity and productivity of ecosystems. Changes in runoff, groundwater flows, and precipitation directly over lakes and streams would affect nutrients and dissolved organic oxygen, and therefore the quality and clarity of the water.

◆ **Rising seas could invade coastal freshwater supplies.** Coastal aquifers may be damaged by saline intrusion as salty groundwater rises. The movement of the salt-front up estuaries would affect freshwater pumping plants upriver.

◆ **Reduced water supplies would place additional stress on people, agriculture, and the environment.** Regional water supplies, particularly in developing countries, will come under many stresses in the 21st century. Climate change will exacerbate the stresses caused by pollution and by growing populations and economies. The most vulnerable regions are arid and semi-arid areas, some low-lying coasts, deltas, and small islands.

◆ **Conflicts could be sparked by the additional pressures.** The links among climate change, water availability, food production, population growth, and economic growth are many and complex. But climate change is likely to add to economic and political tensions, particularly in regions that already have scarce water resources. A number of important water systems are shared by two or more nations, and in several cases there have already been international conflicts.

◆ **Improved water resource management can help to reduce vulnerabilities.** New supplies must be developed and existing supplies used more efficiently. Long-term management strategies should include: regulations and technologies for directly controlling land and water use, incentives and taxes for indirectly affecting behavior, the construction of new reservoirs and pipelines to boost supplies, and improvements in water-management operations and institutions. Other adaptation measures can include removing levees to maintain flood plains, protecting waterside vegetation, restoring river channels to their natural form, and reducing water pollution.

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Human health

◆ **Climate change is expected to have wide-ranging consequences for human health.** Public health depends on sufficient food, safe drinking water, secure shelter, good social conditions, and a suitable environmental and social setting for controlling infectious diseases. All of these factors can be affected by climate.

◆ **Any increase in the frequency or intensity of extreme weather events would pose a threat.** Heat waves, flooding, storms, and drought can cause deaths and injuries, famine, the displacement of populations, disease outbreaks, and psychological disorders. While scientists are uncertain how climate change will affect storm frequency, they do project that certain regions will experience increased flooding or drought. In addition, coastal flooding is expected to worsen due to sea-level rise unless sea defences are upgraded.

◆ **Heat waves are linked to cardiovascular, respiratory, and other diseases.** Illness and deaths from these causes could be expected to increase, especially for the elderly. A greater frequency of warm or hot weather and of thermal inversions (a meteorological phenomenon that can delay the dispersal of pollutants) may worsen air quality in many cities. On the other hand, milder winters in temperate climates would probably reduce cold-related deaths in some countries.

◆ **By reducing fresh water supplies, climate change may affect water resources and sanitation.** This in turn could reduce the water available for drinking and washing. It could also lower the efficiency of local sewer systems, leading to increased concentrations of bacteria and other micro-organisms in raw water supplies. Water scarcity may force people to use poorer quality sources of fresh water, such as rivers, which are often contaminated. All of these factors could result in an increased incidence of diarrhoeal diseases.

◆ **Food security may be undermined in vulnerable regions.** Local declines in food production would lead to more malnutrition and hunger, with long-term health consequences, particularly for children.

◆ **The geographical distribution of species that transmit disease may be altered.** In a warmer world, mosquitoes, ticks, and rodents could expand their range to higher latitudes and higher altitudes. Approximately 45% of the world's human population presently live in regions suitable for malaria transmission. Climate change impacts models suggest that the largest changes in the potential for disease transmission will occur at the fringes — in terms of both latitude and altitude — of the current malaria risk areas. Generally, people in these border areas will not have developed immunity to the disease. The seasonal transmission and distribution of many other diseases that are transmitted by mosquitoes (dengue, yellow fever) and by ticks (Lyme disease, hantavirus pulmonary syndrome, tick-borne encephalitis) may also be affected by climate change.

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◆ **There is a long list of other potential health effects.** Asthma, allergic disorders, and cardio-respiratory diseases could result from climate-induced changes in the formation and persistence of pollens, spores, and certain pollutants. Changes in the production of both aquatic pathogens and biotoxins may jeopardize the safety of seafood.

◆ **People will have to adapt or intervene to minimize these enhanced health risks.** Many effective measures are available. The most important, urgent, and cost-effective is to rebuild the public health infrastructure in countries where it has deteriorated in recent years. Many diseases and public health problems that may be exacerbated by climate change can be effectively prevented with adequate financial and human resources. Adaptation strategies can include infectious disease surveillance, sanitation programmes, disaster preparedness, improved water and pollution control, public education directed at personal behaviour, training of researchers and health professionals, and the introduction of protective technologies (such as housing improvements, air conditioning, water purification, and vaccination).

◆ **Assessing the potential health effects of climate change involves many uncertainties.** Researchers must consider not only future scenarios of climate change but many non-climate factors as well. For example, trends in socio-economic conditions can have a major affect on a population's vulnerability. Clearly, poorer communities will be more vulnerable to the health impacts of climate change than rich ones.

Source: "Climate change and human health", WHO/WMO/UNEP, 1996.

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Infrastructure, industry, and human settlements

◆ **Climate change will have some negative effects on humanity's physical assets.** Some of the most valuable infrastructure includes industrial plants and products; equipment for producing and distributing energy; roads, ports, and other transportation facilities; residential and commercial properties; and coastal embankments. While climate change may have important consequences for infrastructure, they are likely to be smaller than those resulting from demographic, technological, and market changes, in good part because of the many opportunities for adaptation.

◆ **Industrial, energy, and transport infrastructure may be damaged.** Changes in temperature, precipitation, or extreme events can destroy exposed infrastructure or affect productive output. Among the extreme events that may become more frequent or intense in some regions are coastal storm surges, floods, and landslides induced by local downpours, windstorms, rapid snow-melt, tropical cyclones and hurricanes, and drought-induced forest and bush fires.

◆ **Some economic activities are particularly vulnerable.** In general, the climate sensitivity of the industry, energy, and transportation sectors is relatively low compared to that of agriculture and natural ecosystems. Most susceptible to surprises, sudden changes, and extreme events are agro-industry; the production of hydroelectricity, biomass, and other forms of renewable energy; energy use; construction; some transportation activities; and infrastructure located in coastal zones, on permafrost, or other vulnerable areas.

◆ **Rising sea levels could have the most dramatic and direct consequences.** Many coastlines are highly developed and contain human settlements, industry, ports, and other infrastructure. Among the most vulnerable are some small island nations, developing countries, and densely populated coasts that currently lack extensive sea and coastal defense systems. Sea-level rise, storm surges, and flooding could force populations to migrate, with additional consequences for infrastructure further in-land.

◆ **The property insurance sector is particularly vulnerable to extreme climate events.** A greater risk of extreme events due to climate change could lead to higher insurance premiums or the withdrawal of insurance coverage in some vulnerable areas. Changes in climate variability and the risk of extreme events may be hard to detect or predict, making it difficult for insurance companies to adjust their premiums correctly. If such problems lead these firms to insolvency, they may not be able to honor outstanding insurance contracts. This in turn could weaken other economic sectors, such as banking.

◆ **Industry would experience many indirect effects . . .** Because economic activities are so interconnected, an impact on one sector can affect the entire economy. Industry, energy, and transportation are likely to feel knock-on effects via climate-sensitive resource sectors such as agro-industry and biomass production. Climate-sensitive markets will also send signals, such as a changing energy demand for heating or cooling buildings. The result will be an aggregation of many individual impacts.

◆ **. . . as would human settlements.** For example, a decline in the productivity of natural resources in rural areas may accelerate rural-to-urban migration, especially in the developing world. Migration in response to chronic crop failures, regional flooding, or drought would put pressure on existing housing, water, food, and health systems.

◆ **Settlements stressed by population growth, poverty, industrialization, and environmental degradation are the most vulnerable.** Also at risk are large primary coastal cities, squatter camps located in flood plains and on steep hillsides, settlements in forested areas vulnerable to increased seasonal wildfires, and communities that depend on subsistence agriculture or on commercial fishing. In all cases, the poorest people will be the most affected.

◆ **Human infrastructure can be protected through well-chosen policies and management strategies.** The life cycles for planning and investing in infrastructure are often short enough to allow managers to anticipate future climate change. They could adapt to climate change by replacing capital at the normal pace with more appropriate designs and locations. However, it cannot be assumed that people and organizations will always adopt such adaptation strategies automatically. Governments may need to set policy and regulatory frameworks to encourage private action. They may also need to take direct action to protect certain vulnerable infrastructure. The message, then, is clear: future risks can be reduced if climate change is incorporated into all current planning.

◆ **Diversifying the economy can offer additional protection.** Developing countries that rely on a limited number of crops or other resources are economically vulnerable to climate change. When combined with improved management practices such as "integrated coastal management", economic diversification can be an important precautionary response. However, these strategies will often encounter resistance. Some of the possible constraints are technological advancement, human resources, finances, cultural and social sensitivities, and political and legal obstacles. The lack of financial and human resources is especially acute for developing countries.

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Climate disasters and extreme events

◆ **The climate varies naturally on all time-scales.** Variations can be caused by external forces such as volcanic eruptions or changes in the sun's energy output. They can also result from the internal interactions of the climate system's various components - the atmosphere, oceans, biosphere, ice cover, and land surface. These internal interactions can cause fairly regular fluctuations, such as the El Nino/ Southern Oscillation (ENSO) phenomenon, or apparently random changes in climate.

◆ **Natural variability often leads to climate extremes and disasters.** On time-scales of days, months, and years, weather and climate variability can produce heat waves, frosts, floods, droughts, severe storms, and other extremes. A climate extreme is a significant departure from the normal state of the climate system, irrespective of its actual impact on life or the earth's ecology. When a climate extreme has a major adverse impact on human welfare, it is called a climatic disaster. In some parts of the world climatic disasters occur so frequently that they may be considered part of the norm. It is possible that greenhouse gas-induced climate change will alter the frequency, magnitude, and character of both climate extremes and climatic disasters.

◆ **Every region of the world experiences record-breaking climate extremes from time to time.** In 1995, for example, summer heat-waves affected both the US Midwest and the Indian sub-continent. More than 700 people died from heat stress in the US; 500 died in northern India when June temperatures soared to 50 degrees Celsius. Earlier that year, river flooding in the Netherlands caused the evacuation of over 200,000 people and almost half a million livestock. It was the worst flooding since the Dutch sea dikes failed in 1953. In the first decades of this century, a trend towards increased drought in the North American Midwest culminated in the "Dust Bowl" decade of the 1930s, after which conditions eased. More recently, annual rainfall over the Sahel zone of northern Africa during nine of the years since 1970 has dropped more than 20% below the average prevailing during this century's first seven decades; those previous 70 years saw only one extreme of this magnitude.

◆ **Do today's frequent reports of record-breaking events mean that climate extremes are becoming more common?** According to the Intergovernmental Panel on Climate Change, "there are inadequate data to determine whether consistent changes in climate variability or weather extremes have occurred over the 20th century". There have been some regional trends but "some of these changes have been toward greater variability; some have been toward lower variability". It may simply be that people are much more aware of extreme events because the communications revolution has made news and information so much more widely available than ever before.

◆ **Increased human vulnerability is transforming extreme events into more climatic disasters.** People in many parts of the world are being forced to live in

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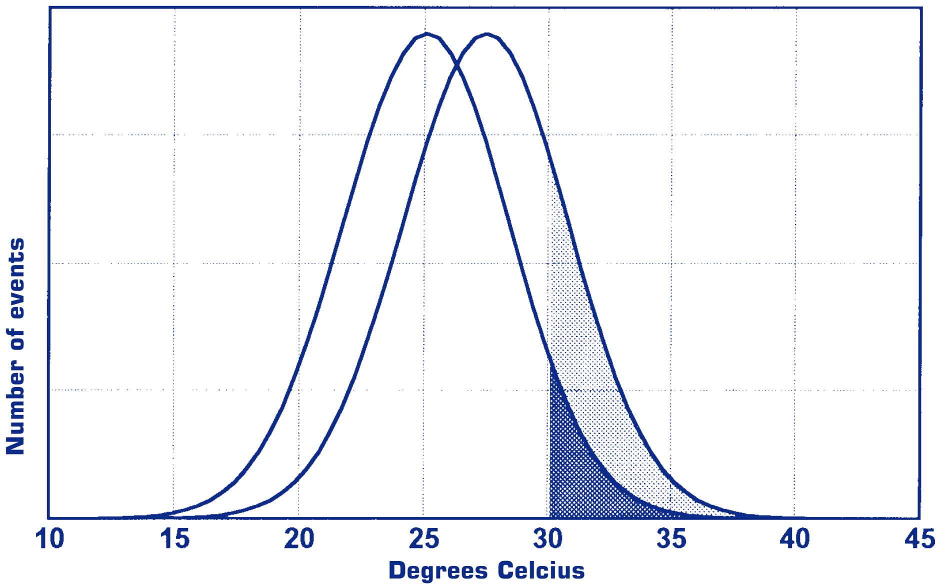
more exposed and marginal areas. Elsewhere, high-value property is being developed in high-risk zones. This has been reflected in the severe pounding that the insurance industry has received from a series of "billion dollar" storms since 1987.

◆ **In the future, global climate change may significantly affect the frequency, magnitude, and location of extreme events.** Any shift in mean climate will almost inevitably affect the frequency of extreme events (see figure). In general, more heat-waves and fewer frosts could be expected, and more intense rainfalls may lead to increased flooding in some regions. However, extreme events last for a relatively short time and are usually a local experience, making it difficult for scientists to predict how these events might respond to climate change. For example, a warming of the tropical oceans would by itself be expected to increase the frequency, and perhaps the severity, of tropical cyclones. But other factors, such as changing winds or storm tracks, might offset this effect at the local level. In any case, growing human vulnerability to climate extremes, combined with the uncertainties of climate change, clearly offers cause for concern.

◆ **While extreme events are inherently abrupt and random, the risks they pose can be reduced.** Improved preparedness planning is urgently needed in many parts of the world, with or without climate change. Better information, stronger institutions, and new technologies can minimize human and material losses. For example, new buildings can be designed and located in ways that minimize damage from floods and tropical cyclones, while sophisticated irrigation techniques can protect farmers and their crops from droughts.

◆ **Scientists cannot state that today's extreme events result from climate change.** They simply do not understand the climate system and the effects of greenhouse gas emissions well enough to conclude that particular events are linked to the general problem. (It is possible that in future decades they may look back and realise with the benefit of hindsight that certain events indeed were linked.) Nevertheless, monitoring and studying extreme events, and learning how to predict and cope with them, must be a priority. Of all the effects of climate variability in the decades to come, extreme events are likely to be of greatest consequence for human well-being.

The frequency distribution of monthly temperature before and after a change in mean climate in this hypothetical example, temperature rises by 2.5°C from a present mean given as 25°C. Without any other changes in the character of the local climate, this doubles the frequency of cases in which the temperature exceeds 30°C. The probability of temperature extremes greater than 30°C in the present is indicated by the darker areas while the lighter shaded area indicates the effect of increasing the mean temperature by 2.5°C. The frequency of low temperature extremes decreases correspondingly. Source: Climatic Research Unit, University of East Anglia.



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The international response to climate change

◆ **The First World Climate Conference recognized climate change as a serious problem in 1979.** This scientific gathering explored how climate change might affect human activities. It issued a declaration calling on the world's governments "to foresee and prevent potential man-made changes in climate that might be adverse to the well-being of humanity". It also endorsed plans to establish a World Climate Programme (WCP) under the joint responsibility of the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), and the International Council of Scientific Unions (ICSU).

◆ **A number of intergovernmental conferences focusing on climate change were held in the late 1980s and early 1990s**. Together with increasing scientific evidence, these conferences helped to raise international concern about the issue. Participants included government policy-makers, scientists, and environmentalists. The meetings addressed both scientific and policy issues and called for global action. The key events were the Villach Conference (October 1985), the Toronto Conference (June 1988), the Ottawa Conference (February 1989), the Tata Conference (February 1989), the Hague Conference and Declaration (March 1989), the Noordwijk Ministerial Conference (November 1989), the Cairo Compact (December 1989), the Bergen Conference (May 1990), and the Second World Climate Conference (November 1990).

◆ **The Intergovernmental Panel on Climate Change (IPCC) released its First Assessment Report in 1990.** Established in 1988 by UNEP and WMO, the Panel was given a mandate to assess the state of existing knowledge about the climate system and climate change; the environmental, economic, and social impacts of climate change; and the possible response strategies. Approved after a painstaking peer review process, the Report 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.

◆ **In December 1990, the UN General Assembly approved the start of treaty negotiations.** The Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (INC/FCCC) met for five sessions between February 1991 and May 1992. Facing a strict deadline – the June 1992 Rio "Earth Summit" – negotiators from 150 countries finalized the Convention in just 15 months. It was adopted in New York on 9 May 1992.

◆ **The 1992 UN Framework Convention on Climate Change was signed by 154 states (plus the EC) at Rio de Janeiro.** Twenty years after the 1972 Stockholm Declaration first laid the foundations of contemporary environmental policy, the Earth Summit became the largest-ever gathering of Heads of State. Other agreements adopted at Rio were the Rio Declaration, Agenda 21, the Convention on Biological Diversity, and Forest Principles.

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◆ **The Convention entered into force on 21 March 1994.** This was 90 days after the receipt of the 50th instrument of ratification (after signing a convention a state must also ratify). The next critical date was 21 September when developed country Parties started submitting national communications describing their climate change strategies. Meanwhile, the INC continued its preparatory work, meeting for another six sessions to discuss matters relating to commitments, arrangements for the financial mechanism, technical and financial support to developing countries, and procedural and institutional matters. The INC was dissolved after its 11th and final session in February 1995, and the Conference of the Parties (COP) became the Convention's ultimate authority.

◆ **The Conference of the Parties held its first session in Berlin from 28 March - 7 April 1995.** Delegates from 117 Parties and 53 Observer States participated in COP-1, as did over 2,000 observers and journalists. They agreed that the commitments contained in the Convention for developed countries were inadequate and launched the "Berlin Mandate" talks on additional commitments. They also reviewed the first round of national communications and finalized much of the institutional and financial machinery needed to support action under the Convention in the years to come. COP-2 was held at the Palais des Nations in Geneva from 8-19 June 1996.

◆ **The IPCC adopted its Second Assessment Report in December 1995.** Published in time for COP-2, the Second Assessment Report was written and reviewed by some 2,000 scientists and experts world-wide. It was soon widely known for concluding that "the balance of evidence suggests that there is a discernible human influence on global climate." However, the Report did much more, for example confirming the availability of so-called no-regrets options and other cost-effective strategies for combating climate change. The IPCC will produce a series of technical papers and special reports before publishing its Third Assessment Report in 2001.

◆ **The Kyoto Protocol was adopted at COP-3 in December 1997.** Some 10,000 delegates, observers, and journalists participated in this high-profile event from 1 - 11 December. Under the Protocol, which was adopted by consensus, industrialized countries have a legally binding commitment to reduce their collective greenhouses gas emissions by at least 5% compared to 1990 levels by the period 2008-2012. The Protocol will enter into force 90 days after it has been ratified by at least 55 Parties to the Convention, including developed countries representing at least 55% of this group's total 1990 CO_2 emissions.

◆ **The 1998 Buenos Aires conference adopted a two-year Plan of Action.** Held from 2-13 November, COP-4 set deadlines for finalizing the outstanding details of the Kyoto Protocol so that the agreement will be fully operational when it enters into force sometime after the year 2000. In addition to the Protocol's "mechanisms", the Plan of Action addresses work on compliance issues and on policies and measures. COP-5 will be held from 25 October - 5 November in Bonn, and COP-6 will be held in late 2000.

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The Climate Change Convention

◆ **The United Nations Framework Convention on Climate Convention is the foundation of global efforts to combat global warming.** Opened for signature in 1992 at the Rio Earth Summit, its ultimate objective is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic [human-induced] interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

◆ **The Convention sets out some guiding principles.** The precautionary principle says that the lack of full scientific certainty should not be used as an excuse to postpone action when there is a threat of serious or irreversible damage. The principle of the "common but differentiated responsibilities" of states assigns the lead in combating climate change to developed countries. Other principles deal with the special needs of developing countries and the importance of promoting sustainable development.

◆ **Both developed and developing countries accept a number of general commitments.** All Parties will develop and submit "national communications" containing inventories of greenhouse gas emissions by source and greenhouse gas removals by "sinks". They will adopt national programmes for mitigating climate change and develop strategies for adapting to its impacts. They will also promote technology transfer and the sustainable management, conservation, and enhancement of greenhouse gas sinks and "reservoirs" (such as forests and oceans). In addition, the Parties will take climate change into account in their relevant social, economic, and environmental policies; cooperate in scientific, technical, and educational matters; and promote education, public awareness, and the exchange of information related to climate change.

◆ **Industrialized countries undertake several specific commitments.** Most members of the Organization for Economic Cooperation and Development (OECD) plus the states of Central and Eastern Europe – known collectively as Annex I countries – are committed to adopting policies and measures aimed at returning their greenhouse gas emissions to 1990 levels by the year 2000. They must also submit national communications on a regular basis detailing their climate change strategies. Several states may together adopt a joint emissions target. The countries in transition to a market economy are granted a certain degree of flexibility in implementing their commitments.

◆ **The richest countries shall provide "new and additional financial resources" and facilitate technology transfer.** These so-called Annex II countries (essentially the OECD) will fund the "agreed full cost" incurred by developing countries for submitting their national communications. These funds must be "new and additional" rather than redirected from existing development aid funds. Annex II Parties will also help finance certain other Convention-related projects, and they will promote and finance the transfer of, or access to, environmentally sound technologies, particularly for developing country Parties. The Convention recognizes that the extent to which developing country Parties implement their commitments will depend on financial and technical assistance from the developed countries.

◆ **The supreme body of the Convention is the Conference of the Parties (COP).** The COP comprises all the states that have ratified or acceded to the Convention (over 175 by May 1999). It held its first meeting (COP-1) in Berlin in 1995 and will continue to meet on a yearly basis unless the Parties decide otherwise. The COP's role is to promote and review the implementation of the Convention. It will periodically review existing commitments in light of the Convention's objective, new scientific findings, and the effectiveness of national climate change programmes. The COP can adopt new commitments through amendments and protocols to the Convention; in December 1997 it adopted the Kyoto Protocol containing stronger emissions-related commitments for developed countries in the post-2000 period.

◆ **The Convention also establishes two subsidiary bodies.** The Subsidiary Body for Scientific and Technological Advice (SBSTA) provides the COP with timely information and advice on scientific and technological matters relating to the Convention. The Subsidiary Body for Implementation (SBI) helps with the assessment and review of the Convention's implementation. Two additional bodies were established by COP-1: the Ad hoc Group on the Berlin Mandate (AGBM), which concluded its work in Kyoto in December 1997, and the Ad hoc Group on Article 13 (AG13), which concluded its work in June 1998.

◆ **A financial mechanism provides funds on a grant or concessional basis.** The Convention states that this mechanism shall be guided by, and be accountable to, the Conference of the Parties, which shall decide on its policies, programme priorities, and eligibility criteria. There should be an equitable and balanced representation of all Parties within a transparent system of governance. The operation of the financial mechanism may be entrusted to one or more international entities. The Convention assigns this role to the Global Environment Facility (GEF) on an interim basis; in 1999 the COP decided to entrust the GEF with this responsibility on an on-going basis and to review the financial mechanism every four years.

◆ **The COP and its subsidiary bodies are serviced by a secretariat.** The interim secretariat that functioned during the negotiation of the Convention became the permanent secretariat in January 1996. The secretariat arranges for sessions of the COP and its subsidiary bodies, drafts official documents, services meetings, compiles and transmits reports submitted to it, facilitates assistance to Parties for the compilation and communication of information, coordinates with secretariats of other relevant international bodies, and reports on its activities to the COP.

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The Conference of the Parties (COP)

◆ **The Conference of the Parties is the "supreme body" of the Climate Change Convention**. The vast majority of the world's states are members – over 175 as of May 1999. The Convention enters into force for a state 90 days after that state ratifies it. The COP held its first session in 1995 and will continue to meet annually unless decided otherwise. (The various subsidiary bodies that advise and support the COP meet more frequently.)

◆ **The COP must promote and review the Convention's implementation.** The Convention states that the COP must periodically examine the obligations of the Parties and the institutional arrangements under the Convention. It should do this in light of the Convention's objective, the experience gained in its implementation, and the current state of scientific knowledge.

◆ **Progress is reviewed largely through the exchange of information.** The COP assesses information about policies and emissions that the Parties share with each other through their "national communications." It also promotes and guides the development and periodic refinement of comparable methodologies, which are needed for quantifying net greenhouse gas emissions and evaluating the effectiveness of measures to limit them. Based on the information available, the COP assesses the Parties' efforts to meet their treaty commitments and adopts and publishes regular reports on the Convention's implementation.

◆ **Mobilizing financial resources is vital for helping developing countries carry out their obligations.** They need support so that they can submit their national communications, adapt to the adverse effects of climate change, and obtain environmentally sound technologies. The COP therefore oversees the provision of new and additional resources by developed countries.

◆ **The COP is also responsible for keeping the entire process on track.** In addition to the two subsidiary bodies established under the Convention – the Subsidiary Body for Implementation (SBI) and the Subsidiary Body for Scientific and Technological Advice (SBSTA) – the COP can establish new ones to help it with its work, as it did at its first session (see below). The COP reviews reports from these bodies and guides them. It must also agree and adopt, by consensus, rules of procedure and financial rules for itself and the subsidiary bodies (as of early 1999 the rules of procedures had not been adopted and, with the exception of the rule on voting, are being "applied").

◆ **The Conference of the Parties held its first session (known as COP-1) in Berlin.** From 28 March -7 April 1995, the historic city of Berlin was the site of the first global climate change meeting attended by ministers since the 1992 Rio "Earth Summit". The Convention required COP-1 to review whether the commitment by developed countries to take measures aimed at returning their emissions to

1990 levels by the year 2000 was adequate for meeting the Convention's objective. The Parties agreed that new commitments were indeed needed for the post-2000 period. They adopted the "Berlin Mandate" and established a new subsidiary body, the Ad hoc Group on the Berlin Mandate (AGBM), to draft "a protocol or another legal instrument" for adoption at COP-3 in 1997. The Berlin meeting also started the review process to consider the implementation of the Convention by discussing a compilation and synthesis of the first 15 national communications submitted by developed countries.

◆ **The second session of the COP took stock of progress on the Berlin Mandate.** Ministers stressed the need to accelerate talks on how to strengthen the Climate Change Convention. Their Geneva Declaration endorsed the 1995 Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) "as currently the most comprehensive and authoritative assessment of the science of climate change, its impacts and response options now available." Held at the Palais des Nations in Geneva from 8-19 July 1996, COP-2 also considered the review process for national communications and decided on the contents of the first national communications that developing countries were to start submitting in April 1997.

◆ **The third session of the Conference of the Parties adopted the Kyoto Protocol.** The Parties met in Kyoto, Japan from 1-11 December 1997 to conclude the Berlin Mandate process. The Protocol they crafted is a legally binding agreement under which industrialized countries are to reduce their collective emissions of six greenhouse gases by 5.2% by 2008-12, calculated as an average over these five years. To help Parties reduce emissions cost-effectively while promoting sustainable development, the Protocol includes three "mechanisms": the clean development mechanism, an emissions trading regime, and joint implementation. COP-3 also considered funding, technology transfer, and the review of information under the Convention.

◆ **COP-4 adopted a two-year Plan of Action to finalize the Protocol's outstanding details.** To ensure that the agreement will be fully operational when it enters into force sometime after the year 2000, governments agreed to a COP-6 deadline for deciding just how its "mechanisms" will function. The Plan also addresses compliance issues and policies and measures and Convention-related issues such as the transfer of climate-friendly technologies to developing countries and the special needs and concerns of countries affected by global warming and by the economic implications of response measures. COP-4 was held in Buenos Aires from 2 -13 November 1998. COP-5 will take place in Bonn from 25 October - 5 November 1999, and COP-6 will be held in late 2000 or early 2001.

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Sharing and reviewing national information

◆ **The sharing of information by governments is central to how the Climate Change Convention works.** The Convention requires its members to submit "national communications" to the Conference of the Parties (COP) on a regular basis. This information about national greenhouse gas emissions, international cooperation, and national activities is reviewed periodically so that the Parties can track the Convention's effectiveness and draw lessons for future national and global action.

◆ **National communications describe what a Party is doing to implement the Convention.** Relevant issues could include policies for limiting greenhouse gas emissions and adapting to climate change, climate research, monitoring of climate impacts on ecosystems and agriculture, voluntary action by industry, integration of climate change concerns into long-term planning, coastal-zone management, disaster preparedness, training, and public awareness.

◆ **"National inventories" of greenhouse gas emissions and removals are updated regularly.** This data details the sources of emissions for each gas, the "sinks" (such as forests) that remove greenhouse gases from the atmosphere, and the quantities involved. The information should be collected using agreed methodologies to ensure that national data are consistent and comparable and can be incorporated into global data sets.

◆ **Developed countries are providing additional details on their efforts to limit emissions.** These so-called Annex I Parties must describe the policies and measures they are adopting in an effort to return their greenhouse gas emissions to 1990 levels by the year 2000. They also provide projections through the year 2000 of how these policies will affect emissions and sinks. Developed countries were committed to making their first submissions no later than six months after becoming a Party. These initial communications were single documents, normally with annexes and a brief executive summary. The majority of developed countries have already submitted their second communications, which were due starting April 1997.

◆ **National communications from developed countries are subjected to a three-step review process.** The first step is to compile and synthesize the information contained in all the submissions. A team of experts from developed and developing countries and from international organizations is assembled by the Convention's secretariat for each review. The first review of the second national communications in late 1997 considered submissions from 18 Parties, while the second review in late 1998 was based on 26.

◆ **The second step is the in-depth review of individual communications.** Based in part on on-site visits, the experts conduct a comprehensive technical assessment of each submission. In addition to providing a more rigorous analysis, this approach has the benefit of building capacity in developing countries through the participation of their experts. Together with the information compiled in step one, the in-depth reviews are summed up in a "compilation and synthesis" report that is prepared for each session of the Conference of the Parties.

◆ **The process concludes with an overall review by the COP.** This third step focuses on the big picture of how the Convention is influencing international action on climate change.

◆ **The 1998 review revealed that greenhouse gas emissions in the richest (essentially OECD) countries have risen by 3.5% since 1990.** Meanwhile, emissions in the economies in transition (Central/Eastern Europe and the former Soviet Union) have declined by 28% due to economic restructuring. As a result, overall emissions from developed countries have declined by 4.6% since 1990. Comparing data from the 1990 inventories with projections for the years 2000 and 2010 suggests that emissions will be some 3% lower in 2000. They will rise by 8% by 2010 if additional control measures are not adopted. (For details on CO_2 see Table 4 on Sheet 30.)

◆ **Carbon dioxide accounted for 82% of total greenhouse gas emissions from developed countries in 1995.** The 1998 review confirmed that fuel combustion is the most important source of CO_2, accounting for 96% of 1995's emissions. Since the 36 Parties included in this review account for a major part of 1990 global carbon dioxide emissions, this seems to confirm carbon dioxide as the most important greenhouse gas resulting from human activities. Governments generally believe that their data on carbon dioxide have a high confidence level (with the exception of land-use change and the forestry sector).

◆ **Methane and nitrous oxide accounted for 12% and 4% of total emissions, respectively.** Confidence levels for data on these gases are medium to low, depending on the sector. For methane, all but five Parties project that their emissions will decline or stabilize. Nitrous oxide trends will also decline or stabilize in the majority of developed countries. These countries' combined emissions of HFCs, PFCs, and SF_6 represented 2% of the 1995 total.

◆ **Developed countries are exploring a wide range of climate change policies and measures.** The policies governments choose are generally dictated by national circumstances such as political structure and the overall economic situation. Many are "no regrets" measures that have environmental or economic benefits while responding to climate change concerns. In addition to regulatory and economic instruments, Parties are promoting voluntary agreements with industry and public authorities. Other measures involve research and development, and information and education.

◆ **Specific measures are being used for most of the major economic sectors.** Policies for the energy sector (the largest source of emissions for many countries) include switching to low-or no-carbon fuels, energy market liberalization, and removing subsidies on coal. Industry-related policies include voluntary arrangements, efficiency standards, financial incentives, and liberalized energy prices. The focus in the residential, commercial, and institutional sector is on energy-efficiency standards for new buildings, higher energy prices, and public information campaigns. Agricultural measures include reducing herd sizes and fertilizer use and improving waste management. While most governments project an expansion of the transportation sector, relatively few measures for controlling its emissions were reported.

◆ **Developing countries started making their initial submissions in 1997.** Their due date is 36 months after becoming a Party or having access to the necessary financial resources. Parties that are least developed countries may make their initial communications at their discretion. In 1996, the COP adopted the guidelines and format that developing countries should use for these initial communications. It has also emphasized to the Global Environmental Facility the need to expedite the approval and disbursement of financial resources so that developing countries can make their submissions on time.

◆ **The frequency of future communications by all Parties will be determined by the COP.** In 1998, the COP asked developed countries to submit their third national communications by 30 November 2001. The COP will also continue to work towards improving the quality and usefulness of the national communications. In particular, many methodological and practical problems concerning data collection and the calculation of inventories must still be resolved. The Intergovernmental Panel on Climate Change (IPCC) is therefore working to refine the methodologies used for national communications.

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The Kyoto Protocol

◆ **The Kyoto Protocol to the United Nations Framework Convention on Climate Change strengthens the international response to climate change.** Adopted by consensus at the third session of the Conference of the Parties (COP-3) in December 1997, it contains legally binding emissions targets for Annex I (developed) countries for the post-2000 period. By arresting and reversing the upward trend in greenhouse gas emissions that started in these countries 150 years ago, the Protocol promises to move the international community one step closer to achieving the Convention's ultimate objective of preventing "dangerous anthropogenic [man-made] interference with the climate system".

◆ **The developed countries commit themselves to reducing their collective emissions of six key greenhouse gases by at least 5%.** This group target will be achieved through cuts of 8% by Switzerland, most Central and East European states, and the European Union (the EU will meet its target by distributing different rates to its member states); 7% by the US; and 6% by Canada, Hungary, Japan, and Poland. Russia, New Zealand, and Ukraine are to stabilize their emissions, while Norway may increase emissions by up to 1%, Australia by up to 8%, and Iceland 10%. The six gases are to be combined in a "basket", with reductions in individual gases translated into "CO_2 equivalents" that are then added up to produce a single figure.

◆ **Each country's emissions target must be achieved by the period 2008-2012.** It will be calculated as an average over the five years. "Demonstrable progress" must be made by 2005. Cuts in the three most important gases – carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) - will be measured against a base year of 1990 (with exceptions for some countries with economies in transition). Cuts in three long-lived industrial gases – hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) - can be measured against either a 1990 or 1995 baseline. (A major group of industrial gases, chlorofluorocarbons, or CFCs, are dealt with under the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer.)

◆ **Actual emission reductions will be much larger than 5%.** Compared to emissions levels projected for the year 2000, the richest industrialized countries (OECD members) will need to reduce their collective output by about 10%. This is because many of these countries will not succeed in meeting their earlier non-binding aim of returning emissions to 1990 levels by the year 2000, and their emissions have in fact risen since 1990. While the countries with economies in transition have experienced falling emissions since 1990, this trend is now reversing. Therefore, for the developed countries as a whole, the 5% Protocol target represents an actual cut of around 20% when compared to the emissions levels that are projected for 2010 if no emissions-control measures are adopted.

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◆ **Countries will have a certain degree of flexibility in how they make and measure their emissions reductions.** In particular, an international "emissions trading" regime will be established allowing industrialized countries to buy and sell emissions credits amongst themselves. They will also be able to acquire "emission reduction units" by financing certain kinds of projects in other developed countries. In addition, a "clean development mechanism" for promoting sustainable development will enable industrialized countries to finance emissions-reduction projects in developing countries and to receive credit for doing so. The operational guidelines for these various schemes are being elaborated under a two-year Plan of Action that is to conclude by COP-6 in late 2000 or early 2001.

◆ **They will pursue emissions cuts in a wide range of economic sectors.** The Protocol encourages governments to cooperate with one another, improve energy efficiency, reform the energy and transportation sectors, promote renewable forms of energy, phase out inappropriate fiscal measures and market imperfections, limit methane emissions from waste management and energy systems, and protect forests and other carbon "sinks". The measurement of changes in net emissions (calculated as emissions minus removals of CO_2) from forests is methodologically complex and still needs to be clarified.

◆ **The Protocol will advance the implementation of existing commitments by all countries.** Under the Convention, both developed and developing countries agree to take measures to limit emissions and promote adaptation to future climate change impacts; submit information on their national climate change programmes and inventories; promote technology transfer; cooperate on scientific and technical research; and promote public awareness, education, and training. The Protocol also reiterates the need to provide "new and additional" financial resources to meet the "agreed full costs" incurred by developing countries in carrying out these commitments.

◆ **The Conference of the Parties (COP) of the Convention will also serve as the meeting of the Parties (MOP) for the Protocol.** This structure is expected to reduce costs and facilitate the management of the intergovernmental process. Parties to the Convention that are not Parties to the Protocol will be able to participate in Protocol-related meetings as observers.

◆ **The new agreement will be periodically reviewed.** The Parties will take "appropriate action" on the basis of the best available scientific, technical, and socio-economic information. The first review will take place at the second COP session serving the Protocol. Talks on commitments for the post-2012 period must start by 2005.

◆ **The Protocol was opened for signature for one year starting 16 March 1998.** It will enter into force 90 days after it has been ratified by at least 55 Parties to the Convention, including developed countries representing at least 55% of the total 1990 carbon dioxide emissions from this group. In the meantime, governments will continue to carry out their commitments under the Climate Change Convention. They will also work on many practical issues relating to the Protocol and its future implementation at their regular COP and subsidiary body meetings.

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How human activities produce greenhouse gases

◆ **Most important human activities emit greenhouse gases (GHGs).** Emissions started to rise dramatically in the 1800s due to the Industrial Revolution and changes in land use. Many greenhouse gas-emitting activities are now essential to the global economy and form a fundamental part of modern life.

◆ **Carbon dioxide from the burning of fossil fuels is the largest single source of greenhouse gas emissions from human activities.** The supply and use of fossil fuels accounts for about three quarters of mankind's carbon dioxide (CO_2) emissions (equal to some 5.9 billion metric tonnes of carbon in 1992), one-fifth of the methane (CH_4), and a significant quantity of nitrous oxide (N_2O). It also produces nitrogen oxides (NO_x), hydrocarbons (HCs), and carbon monoxide (CO), which, though not greenhouse gases themselves, influence chemical cycles in the atmosphere that create or destroy other greenhouse gases, such as tropospheric ozone. Meanwhile, fuel-related releases of sulphate aerosols are temporarily masking part of the warming effect of greenhouse gases.

◆ **Most emissions associated with energy use result when fossil fuels are burned.** Oil, natural gas, and coal (which emits the most carbon per unit of energy supplied) furnish most of the energy used to produce electricity, run automobiles, heat houses, and power factories. If fuel burned completely, the only by-product containing carbon would be carbon dioxide. But combustion is often incomplete, so carbon monoxide and other hydrocarbons are also produced. Nitrous oxide and other nitrogen oxides are produced because fuel combustion causes nitrogen in the fuel or air to combine with oxygen in the air. Sulphur oxides (SO_x) result when sulphur (primarily from coal and heavy fuel oil) combines with oxygen; the resulting sulphate aerosols have a cooling effect on the atmosphere.

◆ **Extracting, processing, transporting, and distributing fossil fuels also releases greenhouse gases.** These releases can be deliberate, as when natural gas is flared or vented from oil wells, emitting mostly carbon dioxide and methane, respectively. They can also result from accidents, poor maintenance, and small leaks in well heads, pipe fittings, and pipelines. Methane occurring naturally in coal seams as pockets of gas or "dissolved" in the coal itself is released when coal is mined or pulverized. Hydrocarbons enter the atmosphere as a result of oil spills from tanker ships or small losses during the routine fueling of motor vehicles.

◆ **Deforestation is the second largest source of carbon dioxide.** When forests are cleared for agriculture or development, most of the carbon in the burned or decomposing trees escapes to the atmosphere. However, when new forests are planted the growing trees absorb carbon dioxide, removing it from the atmosphere. Recent net deforestation has occurred mainly in the tropics. There is a great deal of scientific uncertainty about emissions from deforestation, but it is estimated that from 600 million to 2.6 billion tonnes of carbon are released globally every year.

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◆ **Producing lime (calcium oxide) to make cement accounts for 2.5% of CO_2 emissions from industrial sources.** Like the CO_2 emitted from fossil fuels, the carbon dioxide released during cement production is derived from limestone and is thus of fossil origin, primarily sea shells and other biomass buried in ancient ocean sediments.

◆ **Domesticated animals emit methane.** The second-most important greenhouse gas after carbon dioxide, methane is produced by cattle, dairy cows, buffalo, goats, sheep, camels, pigs, and horses. Most livestock-related methane emissions are produced by "enteric fermentation" of food by bacteria and other microbes in the animals' digestive tracts; another source is the decomposition of animal manure. Livestock account for about one-quarter of the methane emissions from human activities, totalling some 100 million tonnes a year.

◆ **Rice cultivation also releases methane . . .** "Wetland" or "paddy" rice farming produces roughly one-fifth to one-quarter of global methane emissions from human activities. Accounting for over 90 percent of all rice production, wetland rice is grown in fields that are flooded or irrigated for much of the growing season. Bacteria and other micro-organisms in the soil of the flooded rice paddy decompose organic matter and produce methane.

◆ **. . . as does the disposal and treatment of garbage and human wastes.** When garbage is buried in a landfill, it sooner or later undergoes anaerobic (oxygen-free) decomposition and emits methane (and some carbon dioxide). Unless the gas is captured and used as a fuel, the methane eventually escapes to the atmosphere. This source of methane is more common near cities, where garbage from many homes is brought to a central landfill, than in rural areas where garbage is typically burned or left to decompose in the open air. Methane is also emitted when human waste (sewage) is treated anaerobically, for example in anaerobic ponds or lagoons.

◆ **Fertilizer use increases nitrous oxide emissions.** The nitrogen contained in many fertilizers enhances the natural processes of nitrification and denitrification that are carried out by bacteria and other microbes in the soil. These processes convert some nitrogen into nitrous oxide. The amount of N_2O emitted for each unit of nitrogen applied to the soil depends on the type and amount of fertilizer, soil conditions, and climate - a complex equation that is not fully understood.

◆ **Industry has created a number of long-lived and potent greenhouse gases for specialized uses.** Developed in the 1920s, chlorofluorocarbons (CFCs) have been used as propellants in aerosol cans, in the manufacture of plastic foams for cushions and other products, in the cooling coils of refrigerators and air conditioners, as fire extinguishing materials, and as solvents for cleaning. Thanks to the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, atmospheric concentrations of many CFCs are stablizing and expected to decline over the coming decades. Other halocarbons that are being used as ozone-safe replacements for CFCs — notably hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) — contribute to global warming and so are targeted for reduction under the 1997 Kyoto Protocol. The Protocol also targets sulphur hexafluoride (SF_6), used as an electric insulator, heat conductor, and freezing agent; molecule for molecule, its global warming potential is thought to be 23,900 times greater than that of carbon dioxide

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Limiting emissions: The challenge for policymakers

◆ **Climate change will have economic consequences.** The damage it causes plus the measures people take to adapt to a new climate regime will impose quantifiable market costs as well as non-quantifiable, non-market costs. The fact that some important types of damages cannot be easily monetized makes current damage estimates highly uncertain.

◆ **Damages will be unevenly distributed and sometimes irreversible.** Although developed countries are responsible for more than two thirds of historical greenhouse gas emissions and approximately 75% of current annual emissions, their strong economies and institutions leave them better positioned than other countries to cope with changes in climate. The annual costs to developed countries of a world with twice the pre-industrial levels of carbon dioxide could equal 1-3% of their aggregate gross domestic product (GDP). The estimated costs for developing countries are 2-9% of GDP. Again, it must be emphasized that these estimates include only readily monetized damages and thus understate the likely costs. Some studies have created a "vulnerability index" showing that developing countries are, on average, about twice as vulnerable to the negative impacts of climate change as are developed countries; small island developing countries are about three times as vulnerable.

◆ **Policies for minimizing risks by reducing greenhouse gas emissions will also come with a price-tag.** Estimates of how much such policies will cost vary widely. For example, cost estimates for stabilizing emissions from the developed countries vary from -0.5% of GDP (that is, a net savings of US$ 60 billion) to +2% of GDP (equal to a net loss of US$ 240 billion). The costs (and potential benefits) of adaptation measures are less well understood. Nevertheless, it seems that for both emissions reduction and adaptation, policymakers can often seek to minimize climate change damage while actually benefiting their national economies.

◆ **While some damage from human-induced climate change seems inevitable, policymakers can try to limit the risks.** The earth's climate has periodically warmed and cooled during natural cycles that have lasted from decades to millennia. The climate will continue to vary due to these cycles and to the human-enhanced greenhouse effect. The risks posed by rapid climate change due to human action, however, are qualitatively different than those posed by the climate variations that humanity has experienced since the start of civilization. The Climate Change Convention does not seek to avoid all future human-induced climate change, but rather to minimize it and slow the rate of change to ensure that ecosystems and human societies can adapt.

◆ **Climate change policies should be viewed as an integral part of sustainable development.** Actions to address climate change can promote both socio-economic development and environmental protection (such as reduced urban smog). Climate change strategies should be integrated into national development plans for all economic sectors.

◆ **Early action to limit the risks of climate change can have multiple benefits.** Many researchers believe it will be possible to reduce climate change damages and adaptation costs while generating economic benefits, such as more cost-effective energy systems and greater technological innovation. Some climate change policies can also bring local and regional environmental benefits, such as reductions in air pollution and increased protection for forests and thus biodiversity. The scientific, technical, and socio-economic literature shows that such "no regrets" opportunities are available in most countries. It also suggests that the risk of net damage, a concern for risk aversion, and the precautionary principle together provide a rationale for actions that go beyond "no regrets" - that is, for actions to reduce emissions that do indeed have net costs beyond climate change benefits.

◆ **Policymakers should not overlook the importance of equity.** Choosing policies that are both cost-efficient and fair is not easy. Traditional economics rigorously explores how to formulate flexible and cost-effective policies; it has less to say about equity. Because countries differ considerably in their vulnerability to climate change, the costs of damage and adaptation will vary widely unless special efforts are made to redistribute them. Policymakers can pursue equitable solutions by promoting capacity building in poorer countries and reaching collective decisions in a credible and transparent manner. They could also develop financial and institutional mechanisms for sharing risks among countries.

◆ **The fact that some climate change impacts will not be felt for many decades also raises the issue of intergenerational equity.** Future generations are not able to influence directly the choice of policies made today. What's more, it might not be possible to compensate them for any negative effects on their well-being. This concern should be factored into current policies.

◆ **To be effective, policies will require support from the public and from key interest groups.** Governments cannot act alone to cut emissions - individuals, communities, and businesses must also cooperate. Education and public information is vital. For example, increased energy consciousness would encourage people to adopt any number of minor changes in their lifestyles, such as riding public transport, using more efficient lighting and appliances, and re-using materials to reduce the need for exploiting natural resources. Local authorities could start restructuring communities to minimize commuting distances by placing homes closer to shops and offices; they could also introduce standards that encourage building designs that take maximum advantage of sunlight and solar heating. Many other changes in the high-consumption lifestyles of the rich countries are also possible.

◆ **Cooperation is also essential at the international level.** There are different views on whether or not specific policies and measures should be coordinated globally, proponents arguing that coordination ensures fairness and a "level playing field" for business, opponents believing that national flexibility is more cost-effective. But the need for internationally-agreed targets and timetables for emissions reductions and for financial and technological cooperation is more universally accepted. Policymakers must therefore be sensitive to both national conditions and to international trends and concerns.

◆ **The prudent response to climate change is to adopt a portfolio of actions aimed at mitigation, adaptation, and research.** The economic literature suggests that the optimal policy mix will necessarily differ among countries and over time. The challenge is not for all countries to agree on what is the single best policy and to maintain it for the next 100 years. Rather, each country should select a prudent strategy and adjust it over time in light of new information and changing circumstances. By constructing a balanced portfolio of policy options aimed at reducing emissions, adapting to climate change, and improving the knowledge base, national policymakers can reduce the risks of rapid climate change while promoting sustainable development.

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Crafting policies that are cost-efficient

◆ **The costs of climate change policies can be minimized through "no regrets" strategies.** Such strategies make economic and environmental sense whether or not the world is moving towards rapid climate change. Despite their many differences, economists do broadly agree that energy efficiency gains of 10-30% above baseline trends can be achieved over the next two or three decades at zero net cost or even with net gains. A substantial range of technically feasible and cost-effective policies and measures for reducing emissions are available today. For example, raising energy efficiency not only reduces greenhouse gas emissions but can also make industries and countries more competitive in international markets. While no-regrets policies are certainly justified, the precautionary principle and the level of net damage expected from climate change justify adopting policies that go beyond no regrets.

◆ **Although immediate action may sometimes seem more expensive than waiting, delays could lead to greater risks and therefore greater long-term costs.** Governments can choose whether to phase-in emissions cuts slowly or rapidly. This choice must balance the economic costs of early actions (including the risk of prematurely retiring some still usable capital stock) against the corresponding costs of delay. One risk of delay is that it would "lock-in" the currently available models of high-emissions capital equipment for many years to come; if people then become convinced of the need for more rapid emissions reductions, these investments would have to be prematurely retired at a large cost. An earlier push to control emissions would increase the long-term flexibility of how humanity works toward stabilizing atmospheric concentrations of greenhouse gases.

◆ **Many variables need to be considered in the cost equation.** The internationally-agreed timetables and targets for emissions reductions, global population and economic trends, and the development of new technologies will all play a role. Policymakers must also heed the rate of capital replacement (which relates to the natural lifetime of equipment), the range of discount rates that economists use for putting a current value on future benefits (which affects investment decisions), and the possible actions of industry and consumers in response to climate change and related policies.

◆ **Many cost-effective policies involve sending the appropriate economic and regulatory signals to national markets.** Policies to reduce price distortions and subsidies can increase the efficiency of energy, transport, agricultural, and other markets. Consistent and appropriate signals will encourage research and give producers and consumers the information they need to adapt to future constraints on greenhouse gas emissions. For example, by adopting policies and measures early enough to allow enterprises to replace their capital stocks at the end of their natural economic lifetimes, the costs of adaptation and mitigation will be much lower than if companies are forced to prematurely retire their capital. Some

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of the greatest benefits of climate policies may be realized in developing countries that are experiencing rapid economic growth and in countries with economies in transition to a market economy.

◆ **Economic incentives can be used to influence investors and consumers.** If they are market-based, incentives can often be more flexible and efficient than regulatory policies alone. For example, deposit-refund systems can encourage people to trade-in their cars and appliances for more energy-efficient models. Technology and performance standards can reward manufacturers for selling climate-friendly goods, or penalize those who do not. Targeted subsidies, voluntary agreements linked to appropriate targets, and direct government investment can also be cost-effective in shaping the behavior of both consumers and producers.

◆ **Introducing or removing taxes or subsidies can incorporate climate change concerns into prices.** For example, a tax on the carbon content of oil, coal, and gas would discourage fossil-fuel use and so reduce carbon dioxide emissions. Carbon taxes have already been tried by a number of industrialized countries. Many economists believe that carbon taxes could achieve reductions in CO_2 emissions at minimum cost; however, because taxes give individuals and companies the flexibility to choose how to respond, they would be less effective at ensuring that a prescribed emissions level is reached. To be effective, the tax must be well designed and administered. A number of economic studies show that if such taxes are revenue neutral and replace taxes that inhibit investment and employment, they can result in net economic gains. Although such taxes tend to be somewhat regressive, requiring poorer households to pay a higher share of their income on energy bills than rich ones, other taxes and transfers can be adjusted to offset this negative impact.

◆ **Tradable emissions permits could also offer a cost-efficient and market-driven approach.** This is how permits can work: A government must determine how many tonnes of a particular gas may be emitted each year. It then divides this quantity up into a number of tradable emissions entitlements – measured, perhaps, in CO_2-equivalent tonnes – and allocates or sells them to individual firms. This gives each firm a quota of greenhouse gases that it can emit. Then the market takes over. Those polluters that can reduce their emissions relatively cheaply may find it profitable to do so and then sell their permits to other firms. Those that find it expensive to cut emissions may find it attractive to buy extra permits. Tradable emissions permits are already used in the US for certain non-greenhouse gas pollutants. The 1997 Kyoto Protocol contains provisions for the international trading of permits for greenhouse gas emissions amongst developed countries; the details of this scheme must still be elaborated.

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New energy technologies and policies

◆ **The production and use of energy is the leading source of humanity's greenhouse gas emissions.** The combustion of coal, oil, and natural gas accounts for roughly three quarters of all carbon dioxide emissions, or some six billion metric tonnes of carbon annually (as of 1992). Extracting and using fossil fuels emits almost one-fifth of all humanity's methane, some carbon dioxide, and large quantities of carbon monoxide and other air pollutants. The industrial sector accounts for more than a third of the global CO_2 emissions from fossil-fuel combustion (excluding the power generation sector), the residential and commercial sector 32%, and the transport sector a bit over 21% (and growing rapidly). These energy-related emissions could be significantly reduced through a combination of new technologies and policies.

◆ **Leaks and spills during the extraction and transport of fossil fuels can be minimized.** New "integrated recovery" techniques can cut methane emissions from coal mines by up to 80-90% compared to standard practices. Technologies available today can reduce methane emissions from natural-gas distribution systems by up to 80% (compared to the world average). In oil fields where natural gas is flared off or vented because its sale is uneconomic, small on-site power generators can be introduced to make electricity for local use, or the gas can be compressed or converted for use by transport or near-by industries. These and many other technologies could together reduce total fugitive emissions from energy extraction and fuel transport by 50-90%.

◆ **Fiscal and tax policies can encourage the early introduction of new technologies.** By the year 2100, the entire capital stock of the world's current commercial energy system will be replaced at least twice. Incentives for investing in more cost-effective and energy-efficient technologies could maximize the opportunity this replacement offers for reducing emissions. Taxing emissions or the carbon content of fuels can steer investments toward lower-emissions technologies. Economists estimate that a worldwide phase-out of fossil-fuel subsidies would cut global emissions by 4-18% while boosting real incomes.

◆ **The conversion efficiency of electric power plants can be raised.** The world-average conversion efficiency of 30% could be more than doubled in the longer term. The best available coal- and natural gas-fired power plants already convert fuel into useable energy with an efficiency of 45% and 52% respectively. One promising new technology is combined cycle power plants, where heat from the burning fuel drives steam turbines while the thermal expansion of the exhaust gases drives gas turbines. Another is cogeneration, or combined production of heat and power, which could increase the amount of useful energy produced to approximately 80-90% of the heat energy in the fuel; this is much higher than what could be achieved with separate electricity and heat production plants, although users needing cooling or heat must exist nearby. Raising the efficiency of a typical coal-fired plant from 40% to 41% would cut the plant's CO_2 emissions by 2.5%.

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◆ **Power-plant emissions can also be reduced by switching from coal to less carbon-intensive fuels.** Switching from coal to natural gas can reduce emissions by up to 40-50%. (A possible constraint is that estimated coal reserves far exceed those of natural gas.) The efficient use of biomass in steam and gas-turbine cogeneration systems can reduce emissions; these systems have already shown themselves to be commercially feasible for certain pulp and paper and agricultural applications in some developing regions. Renewable energy technologies such as wind, solar, and small hydro can also reduce emissions while distributing electricity more flexibly "off the grid".

◆ **Industry can further reduce its energy intensity while cutting production costs.** During the last two decades, fossil-fuel emissions from industry have declined or remained constant in developed countries due to technological trends and structural changes in the economy. These countries could reduce their industrial CO_2 emissions by 25% or more relative to 1990 levels simply by replacing existing facilities and processes with the most efficient technological options currently available. If this upgrading of equipment occurred at the time of normal capital stock turnover, it would be a cost-effective way to reduce industrial emissions. At the global level, industrial emissions are projected to grow dramatically as developing countries industrialize; slowing their rate of emissions growth will require that they have access to the most efficient technologies available.

◆ **The residential and commercial sectors can adopt energy-efficient technologies**. Technologies with pay-back periods of five years or less are available for many types of equipment now used in buildings. They could cut CO_2 emissions 20% by 2010, 25% by 2020, and up to 40% by 2050 compared to the baseline scenario (in which energy efficiency improves gradually without any deliberate climate-related policy intervention). Buildings can be made more energy-efficient through market-based programmes in which customers or manufacturers receive technical support or financial incentives. Other options are mandatory or voluntary energy-efficiency standards, public and private research into more efficient products, and information and training programs. A combination of regulatory, information, and incentive programmes may offer the best approach to boosting the energy efficiency of these sectors.

◆ **Non-fiscal policies can also promote low-emissions technologies.** The spread of new technologies and practices is often blocked by cultural, institutional, legal, informational, financial, and economic barriers. Government policies can help to remove some of the blockages. Information-sharing and product-labeling programmes, for example, can help consumers to recognize the broader consequences of their decisions. Governments can also support carefully targeted research, development, and demonstration projects for technologies that can reduce emissions and improve efficiency. While they will want to avoid trying to pick technology "winners", governments can play a valuable role by lowering the barriers faced by innovators and promoting a balanced national portfolio of energy options and research programmes. Another option is to introduce emissions targets together with tradable emissions permits that companies can buy and sell.

◆ **Deep reductions in greenhouse gas emissions from fossil fuels are possible over the next 50 to 100 years.** A "thought experiment" based on several scenarios for a Low CO_2-Emitting Energy Supply System (LESS) finds that current and expected technologies could reduce global fossil-fuel-related CO_2 emissions from about 6 billion tonnes of carbon annually in 1990 to about 4 billion tonnes in 2050 and 2 billion in 2100. Technology innovation and an emphasis on renewable energy sources, particularly biomass, will be essential for achieving these goals, and some countries may also consider nuclear energy. Since many different combinations of technologies could be used, this future energy-supply system could be constructed in any number of ways. In the short-term, however, with the global demand for energy certain to rise, actions to reduce emissions must continue to include improvements in energy efficiency.

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New transportation technologies and policies

◆ **The transport sector is a major and rapidly growing source of greenhouse gas emissions.** Fossil-fuel combustion in vehicles and transport equipment accounted for about one-fifth of global carbon dioxide emissions in 1990. Transportation's global fuel consumption rose by 50% between 1973 and 1990, largely because of higher incomes and steady or declining fuel costs. Without new measures to slow the growth in emissions, the use of fossil fuel for transportation is expected to increase by another 35-130% by the year 2025. Transportation also contributes to local and regional pollution problems through its emissions of carbon monoxide, lead, sulfur oxides (SO_x) and nitrogen oxides (NO_x).

◆ **Automobiles are the transport sector's largest consumer of petroleum and its largest source of carbon dioxide emissions.** The developed world has the highest per-capita ownership of private cars today; developing countries currently claim a mere 10% of the world's cars, but are expected to account for most of the future growth in automobile use.

◆ **New technologies can increase the efficiency of automobiles and reduce emissions per kilometer traveled.** New materials and designs can reduce a vehicle's mass and increase the efficiency at which it converts energy, thus lowering the amount of energy required to move it. With improved transmission designs, engines can operate closer to their optimal speed and load conditions. Technological improvements in combustion-engine technology and in petroleum formulations have already started to reduce per-vehicle emissions of both greenhouse gases and conventional pollutants. The energy intensity of these engines can probably still be improved by 15-30% using current technology. More dramatic improvements could be achieved by, for example, adopting hybrid cars that use a combination of fuel-fired engines and electric motors.

◆ **Switching to less carbon-intensive fuels can also reduce carbon dioxide emissions.** The feasibility of operating vehicles on fuels other than gasoline has been demonstrated in many countries. Alternative transport fuels include compressed natural gas, ethanol, methanol, and electricity derived from non-fossil sources. Compressed natural gas has been used successfully in fleet vehicles for a number of years in the US, Europe, and New Zealand. Brazil has a programme to promote the use of cars fueled by ethanol derived from sugar cane and other biomass. Such programmes can offer long-term global climate benefits in tandem with immediate improvements in local air quality.

◆ **Renewable energy technologies are becoming more and more competitive.** Renewable energy could one day offer cost-effective alternatives to petroleum-based fuels. Electricity derived from hydroelectric, solar photovoltaics, wind systems, and hydrogen fuel cells can power the movement of people and goods with almost zero greenhouse gas emissions. The combustion of liquid fuels derived

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from sustainably grown biomass does emit carbon, but an equal amount of carbon is recaptured by the vegetation grown to make new biomass. The use of renewable fuels in the transport sector can help to reduce new CO_2 emissions while delivering the degree of personal mobility that people desire.

◆ **Emissions can be further cut through changes in maintenance and operating practices.** Many vehicles are not adequately maintained due to high costs or to the limited local availability of spare parts. In some areas, maintenance may simply be a low priority for drivers and vehicle owners. Recent studies suggest that an average vehicle's fuel consumption can be reduced by as much as 2-10% just through regular engine tune-ups.

◆ **Policies to reduce road traffic congestion can save both emissions and costs.** The energy intensity of transport and the amount of congestion on the roads are strongly influenced by the average occupancy rate for passenger vehicles. Computerized routing systems for trucks can save money and fuel by optimizing payloads and minimizing time spent in traffic; some studies indicate that it is already technically possible to reduce energy use per tonne-kilometer by 25-30%. Similarly, measures to improve general traffic control and restrict the use of motor vehicles have reduced energy use in some areas by as much as 20-40%.

◆ **Urban planners can encourage low-emissions transport.** Convincing people to switch from automobiles to buses or trains can reduce primary energy use per passenger-seat-kilometer by 30-70%. A vital part of encouraging this transition is providing safe and efficient public transport systems. Cities can also promote walking, bicycling, and car pooling by limiting automobile access to certain roads, increasing the fees for public parking, and converting existing roads into bicycle lanes, bus-access roads, or "High Occupancy Vehicle" (HOV) lanes during peak hours. The introduction of computerized traffic-light control systems, more informative signs, and improved network designs, especially in urban areas with a high density of vehicles during peak travel hours, can also boost efficiency. In the short term, the greatest potential that urban planning has for affecting transport is in rapidly developing cities where cars are still in limited use.

◆ **Policies to reduce air traffic congestion can cut emissions while improving safety.** Present flight patterns seek to reduce fuel consumption and other in-flight costs. Nevertheless, crowding at airports leads to long holding times at many destinations and contributes to higher-than-necessary fuel emissions. Advances in booking systems, policies to increase seat occupancy rates, and efforts to discourage simultaneous, partly-filled flights on the same route could further reduce congestion, minimize landing delays, and decrease emissions. Additional aviation fuel taxes could also play a role in promoting energy efficiency.

◆ **Policies to accelerate the rate of capital stock turnover in automobile and aircraft fleets may be the quickest way to reduce the short-term rate of emissions growth.** This is especially true for developed countries, where large fleets with many older vehicles are already in place. Rewards can be offered for retiring older vehicles and airplanes that do not meet current national emissions standards, or small environmental "user fees" can be imposed, with the fees proportional to the vehicle's energy consumption. Fuel-efficiency standards for autos and aircraft are vital to reducing the energy intensity of transport over the longer term, but they affect only the newest vehicles.

◆ **The appropriate mix of policies will vary from city to city and country to country.** In addition, measures to reduce emissions in the transport sector can take years or even decades to show their full results. But if carried out with care, climate-friendly transport policies can play a major role in promoting economic development while minimizing the local costs of traffic congestion, road accidents, and air pollution.

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New approaches to forestry and agriculture

◆ **Forestry and agriculture are important sources of carbon dioxide, methane, and nitrous oxide.** The world's forests contain vast quantities of carbon. Some forests act as "sinks" by absorbing carbon from the air, while forests whose carbon flows are in balance act as "reservoirs". At the global level, deforestation and changes in land use make forests a net source of carbon dioxide. As for agriculture, it accounts for about 20% of the human-enhanced greenhouse effect. Intensive agricultural practices such as livestock rearing, wet rice cultivation, and fertilizer use emit 50% of human-related methane and 70% of our nitrous oxide. Fortunately, measures and technologies that are currently available could significantly reduce net emissions from both forests and agriculture - and in many cases cut production costs, increase yields, or offer other socio-economic benefits.

◆ **Forests will need better protection and management if their carbon dioxide emissions are to be reduced.** While legally protected preserves have a role, deforestation should also be tackled through policies that lessen the economic pressures on forest lands. A great deal of forest destruction and degradation is caused by the expansion of farming and grazing. Other forces are the market demand for wood as a commodity and the local demand for fuel-wood and other forest resources for subsistence living. These pressures may be eased by boosting agricultural productivity, slowing the rate of population growth, involving local people in sustainable forest management, adopting policies to ensure that commercial timber is harvested sustainably, and addressing the underlying socio-economic and political forces that spur migration into forest areas.

◆ **The carbon stored in trees, vegetation, soils, and durable wood products can be maximized through "storage management".** When secondary forests and degraded lands are protected, they usually regenerate naturally and start to absorb significant amounts of carbon. Their soils can hold additional carbon if they are deliberately enriched, for example with fertilizers, and new trees can be planted. The amount of carbon stored in wood products can be increased by designing products for the longest possible lifetimes, perhaps even longer than what is normal for living wood.

◆ **Sustainable forest management can generate forest biomass as a renewable resource.** Some of this biomass can be substituted for fossil fuels; this approach has a greater long-term potential for reducing net emissions than does growing trees to store carbon. Establishing forests on degraded or non-forested lands adds to the amount of carbon stored in trees and soils. In addition, the use of sustainably-grown fuel-wood in place of coal or oil can help to preserve the carbon reservoir contained in fossil fuels left unneeded underground.

◆ **Agricultural soils are a net source of carbon dioxide - but they could be made into a net sink.** As much as 400-800 million tonnes of carbon could be taken up by agricultural soils every year through improved management practices designed to increase agricultural productivity. Low-tech strategies include the use of composting and low- or no-tillage practices, since carbon is more easily liberated from soil that is turned over or left bare. In the tropics, soil carbon can be increased by returning more crop residues to the soil, introducing perennial (year-round) cropping practices, and reducing periods when fallow fields lie bare. In semi-arid areas, the need for summer fallow could be reduced through better water management or by the introduction of perennial forage crops (which would also eliminate the need for tillage). In temperate regions, soil carbon could be increased by the use of more animal manure. One recent study suggests that reduced tillage practices alone could convert US agricultural soils from an estimated net source of 200 million tonnes of carbon per year to a net sink of 200-300 million tonnes by the year 2020, while improving yields for some crops.

◆ **Methane emissions from livestock could be cut with new feed mixtures.** Cattle and buffalo account for an estimated 80% of annual global methane emissions from domestic livestock. Additives can increase the efficiency of animal feed and boost animals' growth rates, leading to a net decrease of 5-15% in methane emissions per unit of beef produced. In rural development projects in India and Kenya, adding vitamin and mineral supplements to the feed mixture of local dairy cows has significantly increased milk production and decreased methane emissions. Laboratory experiments with bovine somatotropin, a growth hormone for cows, have increased milk production in dairy cows while reducing methane emissions by up to 9%.

◆ **Methane from wet rice cultivation can be reduced significantly through changes in irrigation and fertilizer use.** Some 50% of the total cropland used to grow rice is irrigated. Today's rice farmers can only control flooding and drainage in about one-third of the world's rice paddies, and methane emissions are higher in continually flooded systems. Recent experiments suggest that draining a field at specific times during the crop cycle can reduce methane emissions by up to 50% without decreasing rice yields. Additional technical options for reducing methane emissions are to add sodium sulfate or coated calcium carbide to the urea-based fertilizers now in common use, or to replace urea altogether with ammonium sulfate as a source of nitrogen for rice crops.

◆ **Nitrous oxide emissions from agriculture can be minimized with new fertilizers and practices.** Fertilizing soils with mineral nitrogen and with animal manure releases N_2O into the atmosphere. By increasing the efficiency with which crops use nitrogen, it is possible to reduce the amount of nitrogen needed to produce a given quantity of food. Other strategies aim to reduce the amount of nitrous oxide produced as a result of fertilizer use and the amount of N_2O that then leaks from the agricultural system into the atmosphere. One approach, for example, is to match the timing and amount of nitrogen supply to a crop's specific demands. Another is to use advanced fertilization techniques such as controlled-release fertilizers and systems that deliver fertilizer to the plant's roots through its leaves rather than through the soil (where most nitrous oxide production occurs). The fertilizer's interactions with local soil and climate conditions can also be influenced by optimizing tillage, irrigation, and drainage systems.

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Financing action under the Convention

◆ **Developing countries need financial resources so that they can address the causes and consequences of climate change.** The Climate Change Convention therefore states that developed countries should provide "new and additional" funds to help developing countries meet their treaty commitments. Support can come from bilateral donors, multilateral sources, or the private sector.

◆ **The Convention's financial "mechanism" is a major source of funding.** Its role is to transfer funds and technology to developing countries and to countries with economies in transition on a grant or concessional basis. The mechanism must be guided by, and accountable to, the Conference of the Parties (COP) to the Convention, which decides on policies, programme priorities, and eligibility criteria. The Convention states that the operation of the financial mechanism can be entrusted to one or more international entities with "an equitable and balanced representation of all Parties within a transparent system of governance". The COP has given this responsibility to the Global Environment Facility (GEF).

◆ **The Global Environment Facility was established in 1990, before the start of the Convention negotiations.** The idea of an international mechanism to support projects benefiting the global environment was first discussed in 1987 by the Brundtland Commission. The GEF was launched several years later with the World Bank, the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP) as the implementing agencies. By the time the Earth Summit was held in 1992, the GEF was considered a possible source of funds for the implementation of the biodiversity and climate change conventions.

◆ **The GEF pays the "agreed full incremental costs" of projects to protect the global environment.** GEF funds complement regular development assistance, offering developing countries the opportunity to incorporate environmentally-friendly features that address global environmental concerns. For example, if a country invests in a new power plant to promote economic development, the GEF may provide the additional, or incremental, funds needed to buy equipment for reducing the emissions of greenhouse gases. In this way, GEF funds normally cover only a portion of a project's entire costs.

◆ **The available funds are based on voluntary contributions from governments.** During the "pilot phase" of 1991-94, the GEF trust fund contained some $800 million from participating governments. When the GEF was later restructured to make it more universal, democratic, and transparent, it was replenished from 1 July 1994 through 30 June 1998 with over $2 billion. The second replenishment for the four-year period starting in 1998 will be based on pledges from 36 governments totaling $2.75 billion.

◆ **Projects must be country-driven and based on national priorities that support sustainable development.** The GEF covers four focal areas: climate change, biological diversity, international waters, and protection of the ozone layer. In addition, the agreed incremental costs of activities to combat land degradation (primarily desertification and deforestation) as they relate to the four focal areas may also be eligible for funding. So too are the agreed incremental costs of other activities under Agenda 21, insofar as they achieve global environmental benefits in the focal areas. At the end of 1996, climate change activities accounted for about 38% of the gross funds allocated in the GEF portfolio.

◆ **In addition to technical assistance and investment projects, the GEF supports various "enabling activities."** These activities help countries to develop the necessary institutional capacity for developing and carrying out strategies and projects. In particular, the GEF pays the full costs of preparing the national communications that are required by the Convention. Projects relating to grassroots action sponsored by non-governmental organizations are supported through a Small Grants Programme managed by UNDP, while medium-sized projects (under $1 million) can be financed through UNDP, UNEP, or the World Bank. Besides directly providing grants, the GEF facilitates other bilateral, co-financing, and parallel financing arrangements. It also promotes the leveraging of private-sector participation and resources.

◆ **Funding proposals are submitted to the GEF through one of the three implementing agencies.** UNDP, UNEP, and the World Bank each has its own special role to play in promoting projects and supporting the GEF process. The GEF Secretariat oversees the work programme and helps to ensure that projects comply with GEF programming strategies and policies. Once approved, projects are carried out by a wide range of executing agencies, such as government ministries, non-governmental organizations (NGOs), UN bodies, regional multilateral institutions, and private firms. The final authority for all funding decisions and operational, programmatic, and strategic issues is vested in the GEF Council. The Council consists of 32 of the GEF's 157 members and meets semi-annually, while the Assembly of all participating countries meets every three years.

◆ **In 1999, the COP asked the GEF to continue operating the financial mechanism.** It decided to review the situation again within four years. As required by the Convention, the COP continues to provide guidance on the GEF's policies, programme priorities, and eligibility criteria relating to climate change projects. It has emphasized that projects funded by the GEF should be cost-effective and supportive of national development priorities, and that they should focus, at least initially, on enabling activities that help developing countries prepare and submit information about their implementation of the Convention.

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Global cooperation on technology

◆ **Climate change is a global problem that requires a global solution.** Developed countries account for the largest part of historical and current greenhouse gas emissions; their share for 1994 was about 75% of the global total. However, while per-capita emissions in developed countries are likely to stabilize (at well above the world average), developing-country emissions continue to rise steadily and are expected to represent some 50% of the global total before the year 2025.

◆ **Developing countries will need access to climate-friendly technologies if they are to limit emissions from their growing economies.** Such technologies are essential to establishing a low-emissions industrial infrastructure. Under the Climate Change Convention, the richest countries (essentially the OECD members) agree to "take all practical steps to promote, facilitate, and finance, as appropriate, the transfer of, or access to, environmentally-sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the Convention."

◆ **Technology can be transferred through several different channels.** The traditional channel has been bilateral and multilateral development assistance in the form of export credits, insurance, and other trade support. Incorporating climate change considerations into the programmes of national development offices and multilateral development banks would greatly increase the transfer of low-emissions technologies. The Convention also provides for two new channels. The first is the government-funded Global Environment Facility (GEF). The second is "Activities Implemented Jointly", or AIJ, which seeks to attract private sector funds for the transfer of technology and know-how to developing countries and countries with economies in transition. The Convention emphasizes that these two new channels must add to, rather than replace, traditional development assistance.

◆ **The GEF has a critical role to play in the co-development and transfer of advanced technologies.** The GEF supports both the development and demonstration of technologies that can improve economic efficiency and reduce greenhouse gas emissions while promoting sustainable development in developing and transition countries. GEF projects can be used to demonstrate the technological feasibility and cost-effectiveness of renewable energy technologies and energy efficiency options. In these cases, the GEF pays the added cost of introducing a climate-friendly technology in place of a more polluting one.

◆ **Activities Implemented Jointly has been conceived as one way of channeling private-sector money into climate change activities.** If successful, AIJ could promote the co-development of advanced technologies and their transfer from developed countries to other parts of the world. These technologies would need to be appropriate to local circumstances, environmentally sound, and economically competitive. AIJ is carried out through partnerships between an investing company in a developed country and a counterpart in a host country (which could be developed, developing, or in transition to a market economy). The investing partner is expected to provide most of the required technology and financial capital. The host-country partner may provide the site, the principal staff, and the organization needed to launch and sustain the project.

◆ **AIJ is currently being tested through a pilot phase that will end by 1999.** Proponents argue that AIJ can reduce global emissions cost-effectively, as reducing a given quantity of emissions may be cheaper in many developing and transition countries than in some developed countries. Skeptics are concerned that AIJ will not only transfer technology but – contrary to the spirit of the Convention – the responsibility for combating climate change from developed to developing countries. Under the pilot phase, the investing country does not receive credits for the emissions it helps to reduce in another country, although supporters of the concept emphasize the importance of a credit system if AIJ is to achieve its full potential. Other issues include how to structure the reporting and regulatory regime and how to prevent the transfer of uncompetitive and inappropriate technologies.

◆ **Technology transfer must be accompanied by capacity building.** The delivery of new hardware alone rarely leads to "real, measurable and long-term environmental benefits" in the host country. In many cases it is absolutely essential to strengthen existing local institutions. This includes building managerial and technical skills and transferring the know-how for operating and replicating new technological systems on a sustainable basis. Without such preparation, advanced technologies may fail to penetrate the market. Capacity building also has a role to play in ensuring that new technologies are, in the words of the Convention, "compatible with and supportive of national environment and development priorities and strategies, [and] contribute to cost-effectiveness in achieving global benefits."

◆ **The 1997 Kyoto Protocol provides for a "clean development mechanism".** This mechanism is intended to help developing countries achieve sustainable development and contribute to the Convention's goals. It will be guided by the Parties to the Protocol, supervised by an executive board, and based on voluntary participation. Project activities will result in "certified emissions reductions" that developed countries can use to meet their own binding emissions targets. These projects can involve private or public entities and must lead to real and measurable long-term emissions-limitation benefits. The details of just how this mechanism will work in practice must still be developed.

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DATA on greenhouse gas emissions and sources

Table 1: A sample of greenhouse gases affected by human activities

	CO_2 (carbon dioxide)	CH_4 (methane)	N_2O (nitrous oxide)	CFC-11	HCFC-22 (a CFC substitute)	CF_4 (a perfluoro-carbon)	SF_6 (sulphur hexafluoride)
Pre-industrial level	~280 ppmv+	~700 ppbv	~275 ppbv	zero	zero	zero	zero
1994 Concentration	358 ppmv	1720 ppbv	312§ ppbv	268§ pptv	110 pptv	72§ pptv	3-4 pptv
Rate increase*	1.5 ppmv/yr	10 ppbv/yr	0.8 ppbv/yr	0 pptv/yr	5 pptv/yr	1.2 pptv/yr	0.2/pptv/yr
	0.4%/yr	0.6%/yr	0.25%/yr	0%/yr	5%/yr	2%/yr	~5%/yr
Lifetime (years)	50-200++	12+++	120	50	12	50,000	3,200

§ Estimated from 1992-93 data.
\+ 1 ppmv = 1 part per million by volume; 1 ppbv = 1 part per billion by volume; 1 pptv = 1 part per trillion (million million) by volume.
++ No single lifetime for CO2 can be defined because of the different rates of uptake by different sink processes.
+++ This has been defined as an adjustment time which takes into account the indirect effect of methane on its own lifetime.
* The growth rates of CO_2, CH_4 and N_2O are averaged over the decade beginning 1984; halocarbon growth rates are based on recent years (1990s). (Ed. note: 1kg of carbon = 3.664 kg of CO_2.)

Source: Climate Change 1995, IPCC Working Group I, p. 15.

Table 2: Global energy consumption in 1990 by energy source and by sector, in EJ/yr

	Coal	Oil	Gas	Nuclear	Hydro[a]	Electricity	Heat	Biomass	Total
Primary	91	128	71	19	21	—	—	55	385
Final	36	106	41	—	—	35	8	53	279
Industry	25	15	22	—	—	17	4	3	86
Transport	1	59	0	—	—	1	0	0	61
Others	10	18	18	—	—	17	4	50	117
Feedstocks[b]	0	14	1	—	—	—	—	—	15

Notes: Primary energy is recovered or gathered directly from natural sources (e.g., mined coal, collected biomass, or harnessed hydroelectricity), then is converted into fuels and electricity (e.g., electricity, gasoline, and charcoal), resulting in final energy after distribution and delivery to the point of consumption. (An EJ, or exajoule, is one billion joules, equal to the energy content of about 24 million tonnes of oil - ed.)
[a] Nuclear and hydropower electricity have been converted into primary thermal equivalent, with an average factor of 38.5% (WEC, 1983).
[b] Feedstocks represent non-energy use of hydrocarbons.

Source: Climate Change 1995, IPCC Working Group II, p. 83; based on IEA, 1993; Hall, 1991, 1993; UN, 1993; WEC, 1983, 1993a, 1993b: Nakicenovic et al., 1993.

Table 3: Land area and use, 1982-94

				Land use (000 hectares)							
				Cropland		Permanent pasture		Forest & woodland		Other land	
	Land area (000 hectares)	Population density (per 1,000 hectares) 1996	Domes-ticated land as a % of land area[a] 1994	1992-4	% change since 1982-4	1992-4	% change since 1982-4	1992-4	% change since 1982-4	1992-4	% change since 1982-4
World[b]	13,048,300	442	37	1,465,814	2.0	3,410,203	3.2	4,177,088	(2.2)	3,992,533	(1.0)
Africa	2,963,468	249	36	189,803	6.5	889,350	0.0	713,405	(0.3)	1,171,024	(0.8)
Europe	2,260,320	322	22	317,837	X	178,549	X	947,761	X	816,036	X
North America	1,838,009	163	27	233,276	(1.1)	267,072	1.2	749,290	2.9	588,371	(2.6)
Central America	264,835	475	53	40,053	5.4	98,503	6.2	74,524	1.2	85,910	(9.2)
South America	1,752,925	184	35	113,116	9.0	495,341	3.0	934,860	0.6	209,471	(12.3)
Asia	3,085,414	1,130	51	520,175	X	1,051,311	X	556,996	X	956,913	X
Oceania	849,135	34	57	51,553	1.4	430,077	(2.8)	200,252	(0.2)	164,807	6.3

Notes: [a] Domesticated land is the sum of cropland and permanent pasture. [b] Does not include Antarctica. X = not available; negative numbers are shown in parentheses.

Source: Adapted from World Resources 1998-99, published by WRI, UNEP, UNDP, and the World Bank, pp. 298-99; based on Food and Agriculture Organization of the United Nations, the United Nations Population Division and other sources.

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Table 4: Total anthropogenic CO_2 emissions, excluding land-use change and forestry, 1990-1995, and projections for 2000

	Percentage relative to 1990, 1990=100						Projections	
	1990[a] (Gg)	1991 %	1992 %	1993 %	1994 %	1995 %	2000 (Gg)	percentage change from baseline[b] %
Australia	273 123	101	102	103	105	109	311 200	19
Austria	61 880	107	97	96	96	100	57 300	-7
Belgium	116 090	103	102	99	104		125 200	8
Bulgaria	96 878	68	62	64	61	64	74 730	-11
Canada	464 000	98	101	101	104	108	500 600	8
Czech Republic	165 490	93	85	81	77	78	139 000	-17
Denmark	52 277	120	110	114	121	114	54 309	-9
Estonia	37 797	98	73	58	60	55	19 700	-47
Finland[c]	53 800		97	99	110	104	(58 000 - 60 000)	(8 - 12)
France	378 379	106	106	99	99	102	372 934	-2
Germany	1 014 155	96	91	91	89	88	894 000	-12
Greece	84 575	100	102	103	105	107	89 120	16
Hungary	83 676	81	72	73	71	71	64 300	-23
Iceland	2 147	96	102	107	105	106	2 697	26
Ireland	30 719	103	105	104	108	110	34 998	14
Italy[c]	432150				95	101	421 272	5
Japan	1 124 532	102	103	101	108	108		
Latvia	24 771	78	66	58	48	49	12 274	-51
Lithuania[c]	39 535						27 147	-31
Luxembourg[c]	12 750				94	75	5 684	-45
Monaco[c]	71							
Netherlands	167 550	104	103	105	105	109	173 500	0
New Zealand	25 476	102	110	107	107	107	31 080	22
Norway	35 544	95	97	101	106	107	44 000	22
Poland[c]	476 625		78		78		425 000	-12
Portugal[c]	47 123	104	112	107	108		50 130	35
Romania[c]	198 479	71	62	61				
Russian Fed.[c]	2 372 300	93	85	78	70		1 750 000	-26
Slovak Rep.	60 032	88	81	77	72	81	(44 780 - 46 178)	(-25) - (-23)
Slovenia[c]	13 935							
Spain[c]	226 423	100	104	100	102		258 247	14
Sweden	55 445	100	101	101	106	105	60 100	3
Switzerland	45 070	104	101	98	96	98	43 900	-7
Ukraine[c]	700 107						530 042	-25
United Kingdom	583 747	101	98	95	95	93	550 000	-5
United States	4 960 432	99	100	103	104	105	5 627 310	13

Source: Climate Change Secretariat: "Second compilation and synthesis of second national communications", Doc. FCCC/CP/1998/11/Add.2. Data for Romania is from Doc. FCCC/SBI/1997/INF.4

Notes: Gg = 1,000 tonnes

[a] In accordance with decision 9/CP.2 some Parties with economies in transition use base years other than 1990: Bulgaria (1988), Hungary (average of 1985-87), Poland (1988) and Romania (1989).

[b] The baseline figure used for calculation of percentage change may differ than that of the 1990 figure given in this table due to use of a different baseline other than 1990, use of only a subset of the 1990 figure, subsequent updating of inventory data, calibration of projection models or rounding.

[c]Party did not provide estimates for all years subsequent to 1990.

Table 5: Greenhouse gas emissions, 1991 (000 metric tons)

	CO_2 emissions from industrial processes	CO_2 emissions from land use change	Methane from anthropogenic sources: Solid waste	Coal mining	Oil & gas production	Wet rice agriculture	Livestock	Total
World	22,339,408	4,100,000	43,000	36,000	44,000	69,000	81,000	270,000
Africa	715,773	730,000	1,700	1,700	6,000	2,400	9,000	21,000
Europe	6,866,494	11,000	17,000	6,600	15,000	420	14,000	53,000
North & Central America	5,715,466	190,000	11,000	6,100	8,200	590	9,200	35,000
South America	605,029	1,800,000	2,200	280	2,200	870	15,000	21,000
Asia	7,118,317	1,300,000	9,900	20,000	12,000	65,000	30,000	140,000
Oceania	297,246	38,000	690	1,400	310	75	3,300	5,800

Source: World Resources Institute, as cited in World Resources 1996-97, pp. 326-329.

Table 6: Per-capita CO_2 emissions (metric tons): 10 indicative rates

Brazil	1.6
China	2.7
Czech Republic	10.9
Japan	9.0
Russian Fed.	12.2
Swaziland	0.5
India	1.0
Malaysia	5.3
UK	9.3
US	20.5

Source: 1995 figures; adapted from CDIAC as cited in World Resources 1998-99.

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