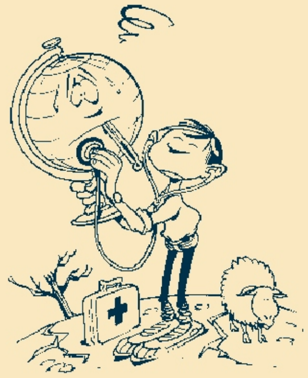

Climate Change

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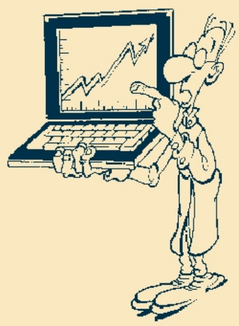

Published by UNEP and UNFCCC

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Updated in July 2002 based on the IPCC's "Climate Change: 2001" assessment report and current activities under the UN Framework Convention on Climate Change. Published by the United Nations Environment Programme and the Climate Change Secretariat (UNFCCC) and sponsored by UNEP, the UN Development Programme, the UN Department of Economic and Social Affairs, the UN Institute for Training and Research, the World Meteorological Organization, the World Health Organization, and the UNFCCC. Edited by Michael Williams. For additional copies, please contact UNEP's Information Unit for Conventions, International Environment House (Geneva), 15 chemin des Anémones, 1219 Châtelaine, Switzerland. Tel. (+41-22) 917-8244/8196/8242; Fax (+41-22) 797 3464; e-mail iuc@unep.ch. Also available at www.unep.ch/conventions/ and www.unfccc.int.

Foreword

When the United Nations Environment Programme and the World Meteorological Organization launched the Intergovernmental Panel on Climate Change (IPCC) in 1988, few people anticipated just how effective and influential its work would become.

Everyone agrees that environmental policy must be based on sound science. Prudent policy choices must be rooted in rigorous, careful and balanced analyses of the best scientific and technical information.

The IPCC has shown the way, developing a process which engages hundreds of the world's leading experts in reviewing the most up-to-date, peer-reviewed literature on the scientific and technical aspects of climate change. The IPCC integrates its assessments into a policy-relevant format universally accepted as a basis for decision-making by the 185 member governments of the United Nations Framework Convention on Climate Change.

The IPCC's three-volume Third Assessment Report was finalized in early 2001. Its message is clear: intensive climate research and monitoring gives scientists much greater confidence in their understanding of the causes and consequences of global warming. The Assessment presents a compelling snapshot of what the earth will probably look like in the late 21st century, when a global warming of 1.4 – 5.8°C (2.5-10.4°F) will influence weather patterns, water resources, the cycling of the seasons, ecosystems, extreme climate events, and much more. Even greater changes are expected in the more distant future.

The international community is working together to minimize these risks through the 1992 Convention and its 1997 Kyoto Protocol. Undoubtedly the most complex and ambitious agreements on environment and sustainable development ever adopted, the climate change treaties set out the principles, institutions, and rules for addressing global warming. They establish a regime that is dynamic and action-oriented. At the same time, it is flexible enough to evolve over the coming decades in response to changes in the political landscape and in scientific understanding.

With this global process now in place, governments need to move forward quickly to design and carry out their national climate change policies. The IPCC Assessment confirms that well-designed, market-oriented policies can reduce emissions and the costs of adapting to the unavoidable impacts of climate change while simultaneously generating significant economic benefits. These benefits include more cost-effective energy systems, more rapid technological innovation, reduced expenditures on inappropriate subsidies, and more efficient markets. Cutting emissions can also reduce damage from local environmental problems, including the health effects of air pollution.

The IPCC and the Climate Change Convention both demonstrate that the peoples of the world can tackle global problems together by collaborating through the United Nations system. The fact sheets in this information kit seek to summarize in simple language the most up-to-date findings of the IPCC and the most recent developments under the Convention and Protocol. We hope you find them useful in your own work.

Klaus Töpfer
Executive Director
United Nations Environment Programme (UNEP)

Joke Waller Hunter
Executive Secretary
Climate Change Secretariat (UNFCCC)

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 (SF_6) are released by industrial processes. Ozone in the lower atmosphere is generated indirectly by automobile exhaust fumes and other sources.

◆ **Rising levels of greenhouse gases are already changing the climate.** By absorbing infrared radiation, these gases control the way natural energy flows through the climate system. In response to humanity's emissions, the climate has started 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. Observations show that global temperatures have risen by about 0.6 °C over the 20th century. There is new and stronger evidence that most of the observed warming over the last 50 years is attributable to human activities.

◆ **Climate models predict that the global temperature will rise by about 1.4 – 5.8°C by the year 2100.** This change would be much larger than any climate change experienced over at least the last 10,000 years. The projection is based on a wide range of assumptions about the main forces driving future emissions (such as population growth and technological change) but does not reflect any efforts to control emissions due to concerns about climate change. 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 hundreds of years after atmospheric concentrations have stabilized.

◆ **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 9 - 88 cm by the year 2100, causing flooding of low-lying areas and other damage. Other effects could include an increase in global precipitation and changes in the severity or frequency of extreme events. Climatic zones could shift poleward and vertically, disrupting forests, deserts, rangelands, and other unmanaged ecosystems. As a result, many will decline or fragment, and individual species could 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

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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.

◆ **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. Fortunately, many strategies are available for adapting to the expected effects of climate change.

◆ **Stabilizing atmospheric concentrations of greenhouse gases will demand a major effort.** Without emissions-control policies motivated by concerns about climate change, atmospheric concentrations of carbon dioxide are expected to rise from today's 367 parts per million to 490 – 1,260 ppm by the year 2100. This would represent a 75 – 350% increase since the year 1750. Stabilizing concentrations at, for example, 450 ppm would require world-wide emissions to fall below 1990 levels within the next few decades. Given an expanding global 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 185 members, the Convention seeks to stabilize atmospheric concentrations of greenhouse gases at safe levels. It commits all countries to limit their emissions, gather relevant information, develop strategies for adapting to climate change, and cooperate on research and technology. It also requires developed countries to take measures aimed at returning their emissions to 1990 levels.

◆ **The Kyoto Protocol would require governments to take even stronger action.** In 1997, the Parties to the Convention agreed by consensus that developed countries should accept 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". However, the Protocol has not yet received enough ratifications to enter into force.

◆ **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 agriculture. 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.

◆ **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.

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 remaining 70% 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, 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 halocarbons and other industrial gases.** Apart from the industrial gases, 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 mainly to agriculture and changes in land use), ozone (generated by automobile exhaust fumes and other sources) and long-lived industrial gases such as CFCs, HFCs, and PFCs 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).

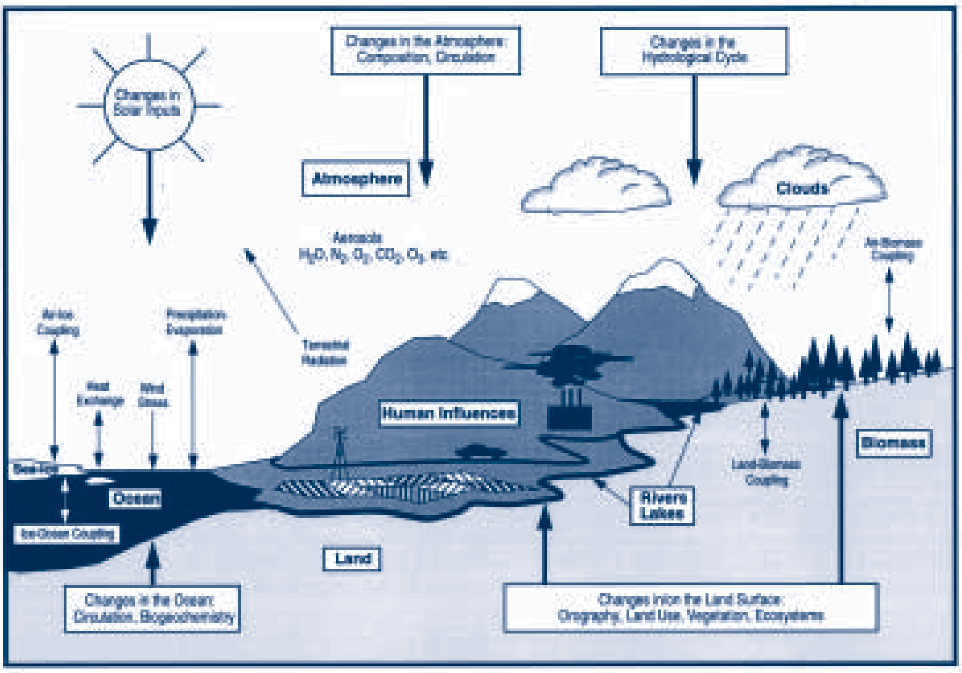
◆ **Meanwhile, man-made aerosols have an overall cooling effect.** Sulphur emissions from coal- and oil-fired power stations and the burning of organic material produce microscopic particles that can reflect sunlight back out into space and also affect clouds. The resultant cooling partly counteracts greenhouse warming. These aerosols, however, remain in the atmosphere for a relatively short time compared to the long-lived greenhouse gases, so their cooling effect is localized. They also cause acid rain and poor air quality, problems that need to be addressed. This means we should not rely indefinitely on the cooling effect of aerosols.

◆ **Climate models estimate that the global average temperature will rise by about 1.4 – 5.8°C (2.5 – 10.4°F) by the year 2100.** This projection uses 1990 as a baseline and assumes that no policies are adopted for minimizing climate change. It also takes into account climate feedbacks and the effects of aerosols as they are presently understood.

◆ **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 hundreds of 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 new and stronger evidence that climate change has already begun.** The climate varies naturally, making it difficult to identify the effects of rising greenhouse gases. However, an increasing body of observation now presents a collective picture of a warming world. For example, the pattern of temperature trends over the past few decades resembles the pattern of greenhouse warming predicted by models; these trends are unlikely to be due entirely to known sources of natural variability. Many uncertainties remain, however, such as how changes in cloud cover will influence future climate.

A schematic illustration of the climate system



Source: IPCC 1995.

Greenhouse gases and aerosols

◆ **Greenhouse gases (GHGs) control energy flows in the atmosphere by absorbing infra-red radiation emitted by the earth.** They act like a blanket to keep the earth's surface some 20°C warmer than it would be if the atmosphere contained only oxygen and nitrogen. The trace gases that cause this natural greenhouse effect 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. Apart from industrial chemicals like CFCs and HFCs, greenhouse gases have been present naturally in the atmosphere for millions of years. Humans however, are affecting 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. Because modeling climate processes involving clouds and rainfall is particularly difficult, the exact size of this crucial feedback remains uncertain.

◆ **Carbon dioxide is currently responsible for over 60% of the "enhanced" greenhouse effect.** 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 23 billion metric tons of carbon dioxide, 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 over 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.

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◆ **Most aerosols cool the climate locally by scattering sunlight back into space and by affecting clouds.** Aerosol particles can 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 levels have already increased by a factor of two and a half during the industrial era.** The main “new” sources of this powerful greenhouse gas 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. Methane is removed from the atmosphere by chemical reactions that are very difficult to model and predict.

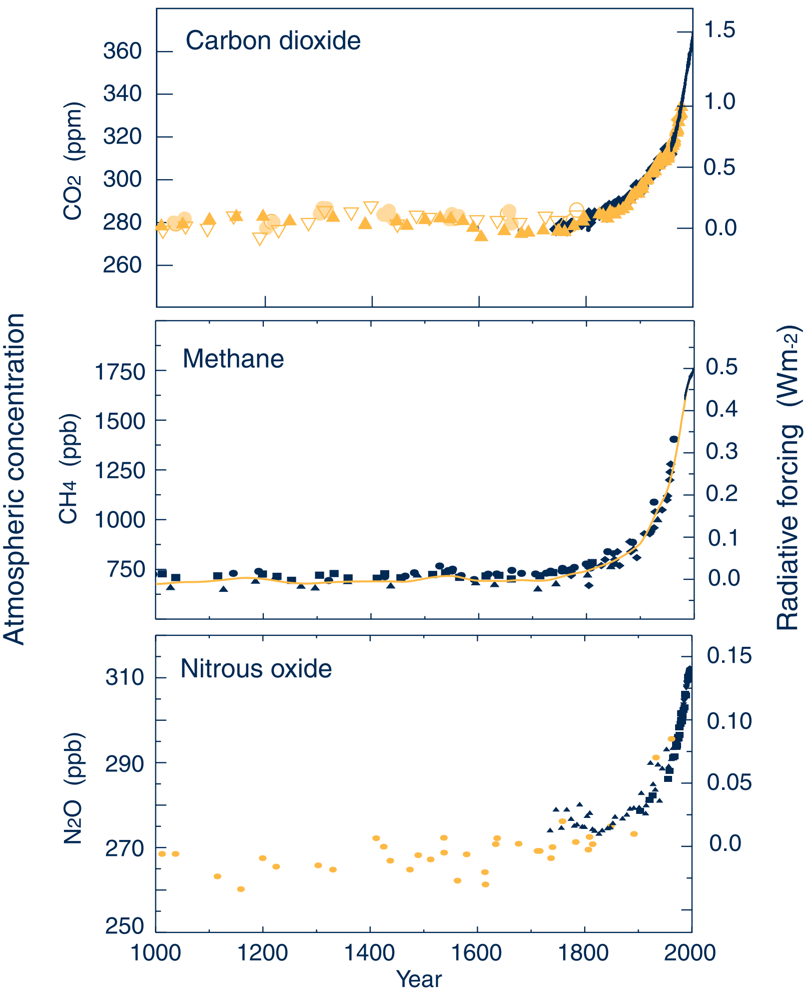
◆ **Methane from past emissions currently contributes 20% of the enhanced greenhouse effect.** The rapid rise in methane started more recently than the rise in carbon dioxide, but methane’s contribution has been catching up fast. However, methane has an effective atmospheric lifetime of only 12 years, whereas carbon dioxide survives much longer.

◆ **Nitrous oxide, a number of industrial gases, and ozone contribute the remaining 20% of the enhanced greenhouse effect.** Nitrous oxide levels have risen by 16%, mainly due to more intensive agriculture. While chlorofluorocarbons (CFCs) are stabilizing due to emission controls introduced under the Montreal Protocol to protect the stratospheric ozone layer, levels of long-lived gases such as HFCs, PFCs and sulphur hexafluoride are increasing. Ozone 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 released by burning 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.

Indicators of the human influence on the atmosphere during the Industrial Era

Global atmospheric concentrations of three well mixed greenhouse gases



Indicators of the human influence on the atmosphere during the Industrial Era Source: IPCC, “Climate Change 2001: The Scientific Basis. Summary for Policymakers”, page 6

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 (which may be quite wrong), a scenario can project growing, stable, or declining emissions.

◆ **Four storylines have recently been developed as a basis for producing scenarios.** The resulting four scenario "families" contain a total of 40 individual scenarios. One storyline describes a future world marked by very rapid economic growth, a population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. A second storyline is similar but assumes a rapid transition towards a cleaner economy based on services and information. A third describes a world where population continues to increase, economic development trends are regional rather than global, and per-capita economic growth and technological change are slower and more fragmented. A fourth emphasizes local and regional solutions to sustainability, with a slowly but steadily growing population and medium economic development. None of these scenarios explicitly assumes that the Climate Change Convention is implemented or that policies are adopted to achieve the Kyoto Protocol's emissions targets. Nevertheless, they do include scenarios where there is less emphasis on fossil fuels than at present.

◆ **The future concentrations of greenhouse gases and aerosols resulting from these storylines vary widely.** For example, carbon cycle models project concentrations of carbon dioxide for the year 2100 of 490 to 1,260 parts per million. This represents anywhere from a 75 to 350% increase over pre-industrial levels. Projected changes in methane range from –10% to +120%, and increases in nitrous oxide range from 13 to 47%.

◆ **"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 would respond to the introduction of climate change policies such as taxes on carbon-rich fossil fuels.

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◆ **Existing international commitments could slightly reduce the rate of growth in emissions.** Under the Climate Change Convention and its Kyoto Protocol, developed countries are to reduce their greenhouse gas emissions to 1990 levels and to 5% below these levels, respectively. Such commitments are important first steps, but they will make only a small contribution towards the ultimate goal of stabilizing greenhouse gas concentrations in the atmosphere..

◆ **Stabilizing greenhouse gas concentrations will require a major effort.** Stabilizing carbon dioxide concentrations at 450 ppm (some 23% above current levels) would require global emissions to drop below 1990 levels within a few decades. Stabilizing CO_2 at 650 ppm or 1,000 ppm would require the same emissions decline within about one century or two centuries, respectively, with continued steady declines thereafter. Eventually CO_2 emissions would need to decline to a very small fraction of 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.** Stabilizing or reducing emissions world-wide would have consequences for 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?

How will the climate change?

◆ **Current climate models predict a global warming of about 1.4 – 5.8°C between 1990 and 2100.** These projections are based on a wide range of assumptions about the main forces driving future emissions (such as population growth and technological change) but do not assume any climate change policies for reducing emissions. Even a 1.4°C rise would be larger than any century-time-scale trend for the past 10,000 years. These projections take into account the effects of aerosols and the delaying effect of the oceans. Oceanic inertia means that the earth's surface and lower atmosphere would continue to warm for hundreds of years even if greenhouse gas concentrations stopped rising in 2100.

◆ **The average sea level is predicted to rise by 9 to 88 cm by 2100.** This would be caused mainly by the thermal expansion of the upper layers of the ocean as they warm, with some contribution from melting glaciers. The uncertainty range is large, and changing ocean currents, local land movement and other factors will cause local and regional sea levels to rise much more or much less than the global average. Slightly faster melting of the Greenland and Antarctica ice sheets is likely to be counteracted by increased snowfall in both regions. As the warming penetrates deeper into the oceans and ice continues to melt, the sea level will continue rising long after surface temperatures have leveled 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, winter temperatures in northern Canada, Greenland and northern Asia are predicted to rise by 40% more than the global average.

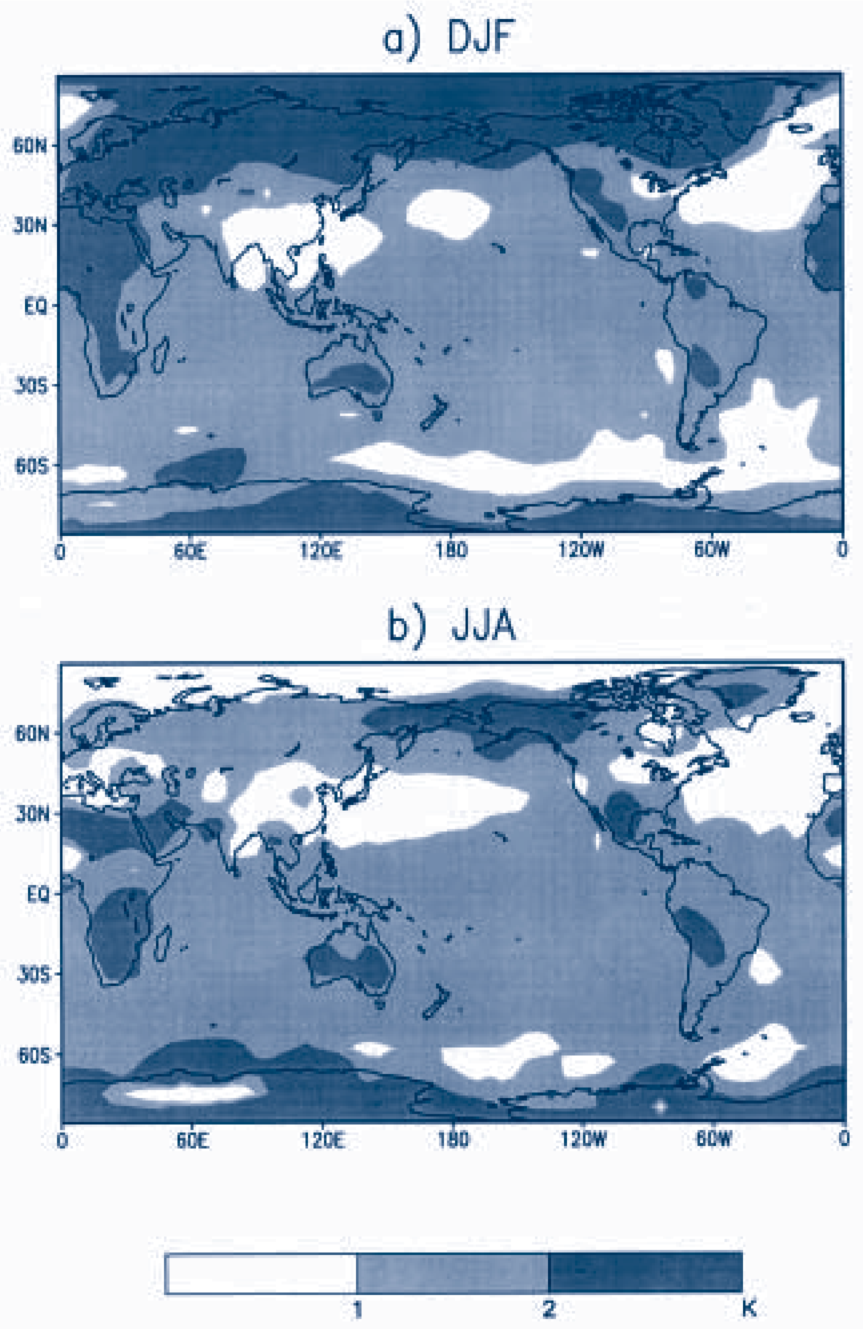
◆ **Inland regions are projected to warm faster than oceans and coastal zones.** The reason is simply the ocean delay, which prevents the sea surface from warming as fast as the land. The size of this delay depends on how deep any warming penetrates into the oceans. Over most of the oceans, the uppermost 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.

◆ **Global precipitation is predicted to increase, but at the local level trends are much less certain.** By the second half of the 21st century, it is likely that wintertime precipitation in the northern mid- to high latitudes and in Antarctica will rise. For the tropics, models suggest that some land areas will see more precipitation, and others less. Australia, Central American and southern Africa show consistent decreases in winter rainfall.

◆ **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 are likely to change.** With increasing global temperatures the world is likely to experience more hot days and heat waves and fewer frost days and cold spells. Climate models also consistently show extreme precipitation events becoming more frequent over many areas and the risk of drought becoming greater over continental areas in summer. There is also some evidence to show that hurricanes could be more intense (with stronger winds and more rainfall) in some areas. There is little agreement amongst models concerning changes in mid-latitude storms. There are also other phenomena, such as thunderstorms and tornadoes, where knowledge is currently inadequate for making projections.

◆ **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 during the 21st century. There is evidence that changes in ocean circulation having 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. Climate models that do show a weakening in the Gulf Stream still project warming over Europe.



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.

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. Scientists are now convinced that a growing body of evidence gives a collective picture of a warming world and other changes in the climate system.

◆ **Measurement records indicate an increase of 0.6±0.2°C in global average temperature since the late 19th century.** These observation are in line with model projections of the size of warming to date, particularly when the cooling effect of aerosols is included. Most of the warming occurred from 1910 to 1940 and from 1976 to the present. In the Northern Hemisphere (where there are sufficient data to make such analyses), it is likely that the rate and duration of 20th century warming has been greater than any other time during the last 1,000 years. In addition, the 1990s are likely to have been the warmest decade of the millennium, and 1998 the warmest year.

◆ **Mean sea level has risen by 10 to 20 cm.** As the upper layers of the oceans warm, water expands and sea level rises. Models suggest that a 0.6°C warming should indeed result in the sea-level rise to date. 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.

◆ **Snow cover has declined by some 10% since the late 1960s in the mid- and high latitudes of the Northern Hemisphere.** It is also very likely that the annual duration of lake and river ice cover has shortened by about two weeks over the course of the 20th century. Almost all recorded mountain glaciers in non-polar regions have retreated during this time as well. In recent decades, the extent of Arctic sea-ice in the spring and summer has decreased by about 10 – 15%, and the ice has likely thinned by 40% during late summer and early autumn.

◆ **There is more precipitation in many regions of the world.** An increase of 0.5 – 1% per decade has been measured over most mid- and high latitude areas of the Northern Hemisphere continents, accompanied by a 2% expansion in cloud cover. Precipitation over the tropical land areas (10°N – 10°S) seems to have increased by 0.2 – 0.3% per decade. On the other hand, declines have been observed over Northern Hemisphere sub-tropical land areas (10 –30°N) during the 20th century, of about 0.3% per decade. In parts of Africa and Asia the frequency and intensity of droughts seem to have worsened.

◆ **The way climate has changed over the 20th century is consistent with what we would expect as a result of increases in greenhouse gases and aerosols.**

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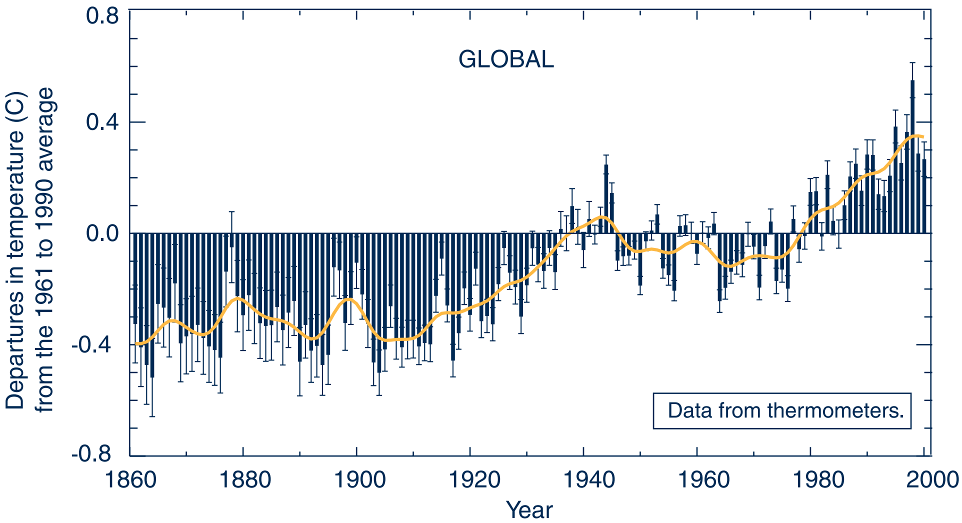
Observed spatial patterns of warming are consistent with model predictions. For example, surface, balloon and satellite measurements show that while the earth's surface has been warming, the stratosphere has cooled. In addition, the earth is warming more slowly over the oceans than over the land, particular in those ocean regions where surface water mixes down, distributing any warming to the ocean depths. Yet another example is reduced warming in areas affected by aerosols.

◆ **Overall, there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.**

Variations of the Earth's surface temperature for the past 140 years



Combined annual land-surface air and sea surface temperature anamolies (ºC) 1861 to 2000, relative to 1961 to 1990. Two standard error uncertainties are shown as bars on the annual number."
Source: IPCC, "Climate Change 2001: The Scientific Basis. Technical Summary", page 26

The role of 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 temperature were the only thing to change, it would be relatively straightforward to predict a warming of around 1°C for a doubling of carbon dioxide concentrations. But this "direct response" would be almost meaningless because it would be physically impossible for the climate system to warm up by over 1°C without changes in clouds, water vapour, snow and ice, and so forth.

◆ **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. Although major improvements have been made in modeling some ocean processes, the exchange of heat between the atmosphere and ocean depths remains an important source of uncertainty.

◆ **Confidence in the ability of models to project future climate is growing.** The representation of many processes, such as water vapour and the horizontal transport of heat in the oceans, has improved. Climate models provide credible simulations of climate, at least down to sub-continental scales. They have been able to reproduce, for example, the 20th century's warming trends, as well as some aspects of ancient climates and the El Niño/Southern Oscillation. As a result of these improvements, several climate models have now been run successfully without the need for non-physical adjustments (flux adjustments or flux corrections) to keep their climates stable. However, models cannot yet simulate all aspects of climate. For example, they still cannot account fully for the observed trend in the temperature difference between the surface and the lower atmosphere. There are also significant uncertainties regarding clouds and their interaction with radiation and aerosols.

◆ **Climate models are scientific tools, not crystal balls.** Large climate modeling 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. 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.

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.

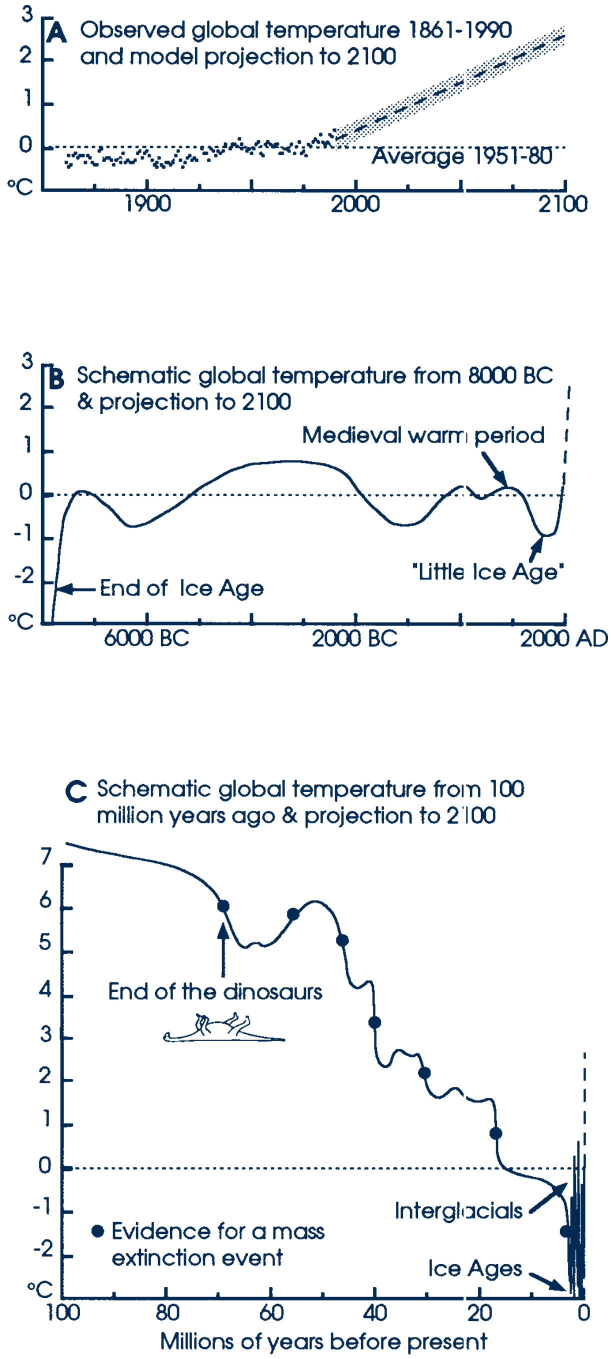
◆ **Changes in greenhouse gas concentrations may have helped to amplify ice-age cycles.** The small fluctuations in energy arriving from the sun due to the earth's orbital wobbles are not large enough to account for the size of global temperature changes during the ice age cycles. Ice-core samples show 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 5ºC colder at the peak of the last ice age, while others suggest only 1-2ºC. 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 2ºC warmer than they are today. However, models are predicting that temperatures could rise by much more than this over large stretches 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.

Adapting to climate change impacts

◆ **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.** Many ecosystems are sensitive to humanity's management practices and increasing demands for resources. For example, human activities may limit the potential of forest ecosystems for adapting naturally to climate change. Fragmentation of ecosystems will also complicate human efforts to assist adaptation, for example by creating migration corridors.

◆ **Social and economic systems tend to be more vulnerable in developing countries with weaker economies and institutions.** In addition, 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 in many parts of the world 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 the costs of negative impacts and maximize the benefits from positive impacts. 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 or reforesting degraded hillsides. It may be possible to ***reduce losses*** to a tolerable level, including by 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 or relocating agricultural activities from steep hill slopes. 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. More generally, many policies that promote adaptation – for example by improving natural resource management or bettering social conditions – are also vital for promoting sustainable development. Despite such synergies, however, it is clear that adaptation will also involve real costs and will not prevent all of the expected damage.

◆ **Crafting adaptation strategies is complicated by uncertainty.** It is still not possible to quantify with any precision the likely future impacts on any particular system at any particular location. This is because climate change projections 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. Knowledge has increased dramatically in recent years, but research and monitoring will remain essential for gaining a better understanding of potential impacts and the adaptation strategies needed to deal with them.

Agriculture and food security

◆ **Global agriculture will face many challenges over the coming decades.** Degrading soils and water resources will place enormous strains on achieving food security for growing populations. These conditions may be worsened by climate change. While a global warming of less than 2.5°C could have no significant effect on overall food production, a warming of more than 2.5°C could reduce global food supplies and contribute to higher food prices.

◆ **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 by as much as a third in the tropics and subtropics, where crops are already near their maximum heat tolerance. Mid-continental areas such as the US grain belt, vast sections of mid-latitude Asia, sub-Saharan Africa and parts of Australia are all expected to experience drier and hotter conditions. Meanwhile, longer growing seasons and increased rains may boost yields in many temperate regions; records show that the season has already lengthened in the UK, Scandinavia, Europe and North America.

◆ **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 losses.

◆ **Soil moisture will be affected by changing precipitation patterns.** Based on a global warming of 1.4 – 5.8°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 and increased erosion. 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.

◆ **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. 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. Experiments based on a 50% increase of current CO_2 concentrations have confirmed that "CO_2 fertilization" can increase mean yields of C3 crops by 15% under optimal conditions. C4 plants

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would also use water more efficiently, but the effects on yields would be smaller in the absence of water shortages. C4 plants include such tropical crops as maize, sugar cane, sorghum and millet, which are important for the food security of many developing countries, as well as pasture and forage grasses. These positive effects could be 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 and where livestock depend more fully on the productivity and quality of the rangelands, which may become degraded.

◆ **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 with moderate climate change (below a 2°C warming). 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.

Sea levels, oceans, and coastal areas

◆ **The global average sea level has risen by 10 to 20 cm over the past 100 years.** The rate of increase has been 1 – 2 mm per year – some 10 times faster than the rate observed for the previous 3,000 years. It is likely that much of this rise is related to an increase of 0.6±0.2°C in the lower atmosphere's global average temperature since 1860. Related effects now being detected include warming sea-surface temperatures, melting sea ice, greater evaporation, and changes in the marine food web.

◆ **Models project that sea levels will rise another 9 to 88 cm by the year 2100.** This will occur due to the thermal expansion of warming ocean water and an influx of freshwater from melting glaciers and ice. 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. Already over the past 100 years, 70% of sandy shorelines have been retreating.

◆ **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. Rising sea levels are already contaminating underground fresh water supplies in Israel and Thailand, in small atolls scattered across the Pacific and Indian oceans and the Caribbean Sea, and in some of the world's most productive deltas such as China's Yangtze Delta and Vietnam's Mekong Delta.

◆ **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 will reduce sea-ice cover; decreases of up to 14% have been measured in the Arctic during the past two decades, and a decline of 25% has been recorded in the Antarctic from the mid-1950s to early 1970s. Climate change will also alter ocean circulation patterns, the vertical mixing of waters, and wave patterns. These changes can be expected to affect 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). Any changes in plankton activity could affect the oceans' ability to absorb and store carbon. This could "feedback" into the climate system and either 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. In addition, 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. Possible response strategies include protection (dikes, dune restoration, wetland creation), accommodation (new building codes, protection of threatened ecosystems), and planned retreat (regulations against new coastal development). Some countries, including Australia, China, Japan, the Netherlands, the UK, and the US, have already designated withdrawal corridors where buildings will be removed to allow precious wetlands to move inland. Other specific responses are dredging ports, strengthening fisheries management, and improving design standards for offshore structures.

Biological diversity and ecosystems

◆ **Biological diversity – the source of enormous environmental, economic, and cultural value – will be threatened by rapid climate change.** The composition and geographic distribution of ecosystems will change as individual species respond to new conditions created by climate change. At the same time, habitats may degrade and fragment in response to other human pressures. Species that cannot adapt quickly enough may become extinct – an irreversible loss.

◆ **Species and ecosystems have already started responding to global warming.** Scientists have observed climate-induced changes in at least 420 physical processes and biological species or communities. Changes include migratory birds arriving earlier in the spring and leaving later in the autumn, a lengthening by 10.8 days of the European growing season for controlled mix-species gardens from 1959 to 1993, earlier springtime reproduction for many birds and amphibians, and the northward movement of cold-sensitive butterflies, beetles, and dragonflies.

◆ **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. The composition of species in existing forests will change, while new combinations of species, and hence new ecosystems, may be established. Other stresses caused by warming will 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; Alaska's boreal forests are already expanding northward at the rate of 100 kilometres per degree Centigrade.

◆ **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 if mortality releases carbon faster than regeneration and 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 limited to mountain tops may have nowhere to go and become extinct; observations show that some plant species are moving up in the European Alps by one to four metres per decade and that some mountaintop species have already disappeared. 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 continue to shrink.** Representing nearly 80% of all freshwater, the cryosphere encompasses all of the earth's snow, ice, and permafrost. Permafrost is thawing worldwide – even around Siberia's Lake Baikal, the coldest place in the Northern Hemisphere – destabilizing infrastructure and releasing additional carbon and methane into the atmosphere. Mountains glaciers are declining: almost two thirds of Himalayan glaciers have retreated in the past decade, and Andean glaciers have retreated dramatically or disappeared. This will affect nearby ecosystems and communities as well as seasonal river flows and water supplies, which in turn has implications for hydropower and agriculture. The landscapes of many high mountain ranges and polar regions will change dramatically. Reduced sea-ice could lengthen the navigation season for certain rivers and coastal areas. Arctic sea ice has thinned by 40% in the past three decades, and its extent has shrunk by about 10-15%. 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.** 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.

Water resources

◆ **Changing precipitation patterns are already affecting water supplies.** Increasingly heavy rain and snow are falling on the mid- and high latitudes of the Northern Hemisphere, while rains have decreased in the tropics and subtropics in both hemispheres. In large parts of eastern Europe, western Russia, central Canada and California, peak stream flows have shifted from spring to winter as more precipitation falls as rain rather than snow, therefore reaching the rivers more rapidly. Meanwhile, in Africa's large basins of the Niger, Lake Chad and Senegal, total available water has decreased by 40 – 60%.

◆ **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.** Making regional predictions is complicated by the extreme complexity of the hydrological cycle: a change in precipitation may affect surface wetness, reflectivity, and vegetation, which then affect evapo-transpiration and cloud formation, which in turn affect precipitation. In addition, the hydrological system is responding not only to changes in climate and precipitation but also to human activities such as deforestation, urbanization, and the over-use of water supplies.

◆ **Changing precipitation patterns will affect how much water can be captured.** Many climate models suggest that downpours will in general become more intense. This would increase runoff and floods 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. At the local level, the vegetation and physical properties of the catchment area will further influence how much water is retained.

◆ **The drier the climate, the more sensitive is the local hydrology.** In dry climates, 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. Many climate models project declining mean precipitation in the already-dry regions of central Asia, the Mediterranean, southern Africa and Australia.

◆ **High-latitude regions may see more runoff due to greater precipitation.** Run-off 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. 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.

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- **The effects on the tropics are harder to predict.** Different climate models produce different results for the future intensity and distribution of tropical rainfall. South Asia, however, is expected to see increased precipitation from June through August whereas Central America is expected to see less rain during these months.

- **New patterns of runoff and evaporation will 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 oxygen, and therefore the quality and clarity of the water.

- **Reservoirs and wells would be also affected.** Surface water storage could decline as extreme rainfalls and landslides encourage siltation and thus reduced reservoir capacity. An increase in extreme rainfalls and flooding could also lead to more water being lost as run-off. In the longer term this could also affect aquifers. Water quality may also respond to changes in the amount and timing of precipitation.

- **Rising seas could invade coastal freshwater supplies.** Coastal freshwater aquifers may be polluted by saline intrusion as salty groundwater rises. The movement of the saltwater-front up estuaries would affect upriver freshwater-pumping plants, brackish-water fisheries, and agriculture.

- **Reduced water supplies would place additional stress on people, agriculture, and the environment.** Already, some 1.7 billion people – a third of the world population – live in water-stressed countries, a figure expected to rise to 5 billion by 2025. 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.

- **Tensions could rise due to 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 strategies for supply and demand management could 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, improvements in water-management operations and institutions, and the encouragement of local or traditional solutions. Other adaptation measures can include protecting waterside vegetation, restoring river channels to their natural form, and reducing water pollution.

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.

◆ **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 and the urban poor. While the biggest rise in heat stress is expected in mid- and high latitude cities, milder winters in temperate climates would probably reduce cold-related deaths in some countries. A greater frequency of warm or hot weather, thermal inversions (a meteorological phenomenon that can delay the dispersal of pollutants), and wildfires may also worsen air quality in many cities.

◆ **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 higher 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.

◆ **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 just 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 defenses are upgraded.

◆ **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.

◆ **Higher temperatures may alter the geographical distribution of species that transmit disease.** In a warmer world, mosquitoes, ticks, and rodents could expand their range to higher latitudes and higher altitudes. Climate change impacts models suggest that the largest changes in the potential for malaria 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. In addition, climate-induced changes in the

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formation and persistence of pollens, spores, and certain pollutants could promote more asthma, allergic disorders, and cardio-respiratory diseases.

◆ **Warmer seas could also influence the spread of disease.** Studies using remote sensing have shown a correlation between cholera cases and sea surface temperature in the Bay of Bengal. There is also evidence of an association between El Niño (which warms the waters of the south-western Pacific) and epidemics of malaria and dengue. Enhanced production of aquatic pathogens and biotoxins may jeopardize the safety of seafood. Warmer waters would also increase the occurrence of toxic algal blooms.

◆ **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.

Human settlements, energy and industry

◆ **Climate change will affect human settlements.** Settlements that depend heavily on commercial fishing, subsistence agriculture and other natural resources are particularly vulnerable. Also at risk are low-lying areas and deltas, large coastal cities, squatter camps located in flood plains and on steep hillsides, settlements in forested areas where seasonal wildfires may increase, and settlements stressed by population growth, poverty and environmental degradation. In all cases, the poorest people will be the most affected. Though climate change will often have less impact on this sector than will economic development, technological change, and other social and environmental forces, it is likely to exacerbate the total stress on settlements.

◆ **Infrastructure will become more vulnerable to flooding and landslides.** More intense and frequent precipitation events are expected to intensify urban flooding. The flood risks may also increase for settlements along rivers and within flood plains. The risk of more landslides is greatest for hillside areas.

◆ **Tropical cyclones are expected to become more destructive in some areas.** Also known as hurricanes and typhoons, these massive storm systems combine the effects of heavy rainfall, high winds, and storm surge and sea-level rise. The risk is that warmer oceans will increase the frequency and intensity of such storms.

◆ **Warming, dryness and flooding could undermine water supplies.** Settlements in regions that are already water-deficient – including much of North Africa, the Middle East, Southwest Asia, portions of western North America and some Pacific islands – can be expected to face still-higher demands for water as the climate warms. There are no obvious low-cost ways in which to obtain increased freshwater supplies in many of these regions. In some regions, repeated flooding could create problems with water quality.

◆ **The danger of fire could increase.** However, there are many uncertainties about how hotter and drier weather will combine with other factors to affect the risk of fire.

◆ **Agriculture and fisheries are sensitive to climate change.** In some cases agricultural yields may be reduced by up to several tens of percent as a result of hotter weather, greater evaporation, and lower precipitation, particularly in mid-continental growing regions. However, other regions may benefit and could experience higher yields. Fisheries will be affected because changes in ocean conditions caused by warming can substantially impact the locations and types of target species.

◆ **Heat waves would become a greater threat to human health and productivity.** Heat waves have their most severe effects on the old, the chronically ill and the very young. The likely effects on the overall death rate are less clear. Stronger urban heat-island effects would further exacerbate the oppressive effects of heat

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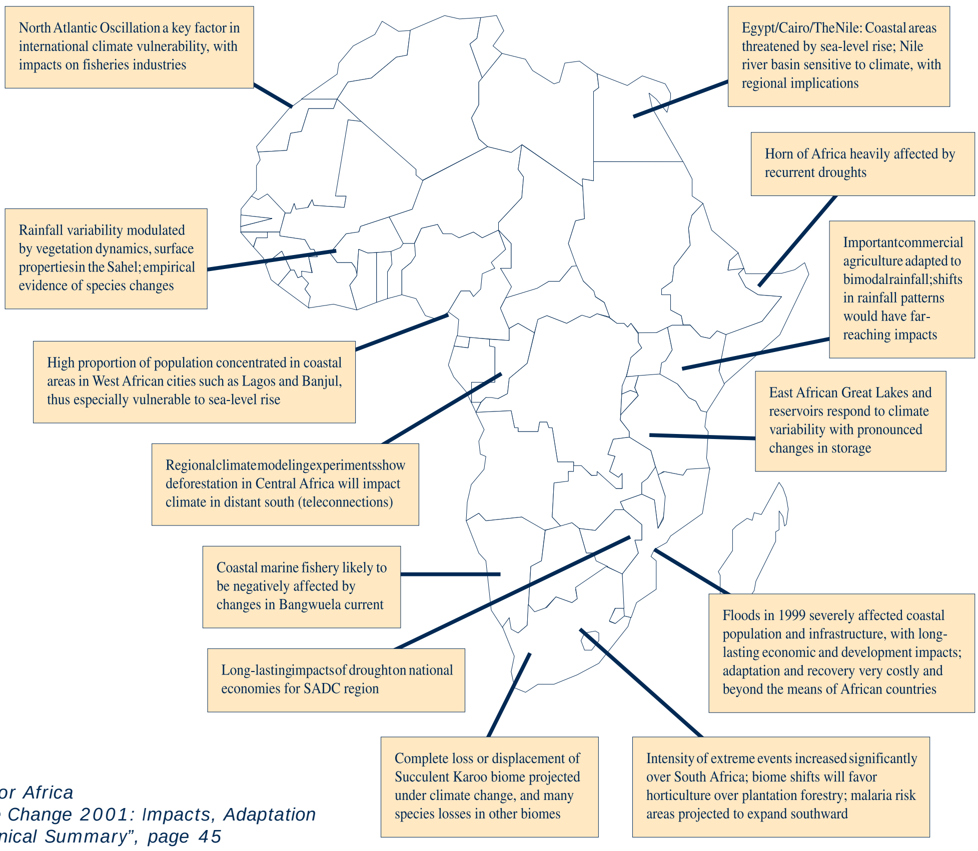
waves by increasing the temperatures experienced in the summer by up to several degrees Centigrade. Meanwhile, as the weather becomes very warm, the economic productivity of unprotected and outdoor populations declines.

◆ **Sea-level rise will affect coastal infrastructure and resource-based industries.** Many coastlines are highly developed and contain human settlements, industry, ports, and other infrastructure. Many of the most vulnerable regions include some small island nations, low-lying deltas, developing countries and densely populated coasts that currently lack extensive sea and coastal defense systems. Several industries such as tourism and recreation – the principle earners for many island economies – are particularly dependent on coastal resources.

◆ **Energy demand is sensitive to climate change.** Heating requirements at mid- and high latitudes and altitudes would decline but cooling requirements would increase. The net overall impact of these changes on energy use would depend on local circumstances. For example, if temperature increases take place primarily at night and during the winter months, the demand for heating would be less, as would the demand for cooling and for irrigation. Meanwhile, energy supply systems will be vulnerable to changes resulting from global warming. For example, increased water deficits, less winter snowfall to fill summer streams, and more demand for freshwater supplies would affect hydropower production.

◆ **Infrastructure in permafrost regions is vulnerable to warming.** Permafrost melting is a threat to infrastructure in these regions because it would increase landslides and reduce the stability of foundations for structures. Other impacts would include greater damage from freeze-thaw cycles. In addition, melting permafrost is thought to be a source of methane and carbon dioxide emissions.

◆ **Local capacity is critical to successful adaptation.** The capacity of local communities to adapt tends to be strongly correlated with wealth, human capital and institutional strength. The most effective sustainable solutions are those that are strongly supported – and often developed – locally. The role of higher-level bodies is then to provide technical assistance and institutional support. A clear message for policy-makers is to always anticipate the likely future impacts of climate change when they take decisions regarding human settlements and make investments in infrastructure.



Selected key impacts for Africa
Source: IPCC, "Climate Change 2001: Impacts, Adaptation and Vulnerability. Technical Summary", page 45

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.** On time-scales of days, months, and years, weather and climate variability can produce heat waves, frosts, floods, droughts, avalanches, and severe storms. Such extremes represent a significant departure from the average state of the climate system, irrespective of their actual impact on life or the earth's ecology. Record-breaking extremes occur from time to time in every region of the world.

◆ **Growing human vulnerability is transforming more and more extreme events into climatic disasters.** A climate extreme is called a climatic disaster when it has a major adverse impact on human welfare. In some parts of the world, climatic disasters occur so frequently that they may be considered part of the norm. Vulnerability to disasters is increasing as growing numbers of people are forced to live in exposed and marginal areas. Elsewhere, greater vulnerability is being caused by the development of more high-value property in high-risk zones.

◆ **Climate change is expected to increase the frequency and severity of heat waves.** More hot weather will cause more deaths and illnesses among the elderly and urban poor. Together with increased summer drying, it will lead to greater heat stress for livestock and wildlife, more damage to crops, more forest fires, and more pressure on water supplies. Other likely impacts are a shift in tourist destinations and a boost in demand for energy. Meanwhile, fewer cold snaps should reduce cold-related risks to humans and agriculture and reduce the energy demand for heating while extending the range and activity of some pests and diseases.

◆ **More intense rainfall events may lead to greater flooding in some regions.** Global warming is expected to accelerate the hydrological cycle and thus raise the percentage of precipitation that falls in violent bursts. In addition to floods, this could contribute to more landslides, avalanches, and soil erosion. Greater flood runoff could decrease the amount of surface water captured for irrigation and other purposes, although it could help to recharge some floodplain aquifers.

◆ **The intensity of tropical cyclones is likely to worsen over some areas.** The risks include direct threats to human life, epidemics and other health risks, damage to infrastructure and buildings, coastal erosion, and destruction of ecosystems such as coral reefs and mangroves.

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◆ **Major climate patterns could shift.** Although centered in the Southern Pacific, the El Nino/Southern Oscillation (ENSO) phenomenon affects the weather and climate in much of the tropics. Climate change could intensify the droughts and floods that are associated with El Niño events in these regions. Similarly, new patterns could emerge for the Asian summer monsoon, which affects large areas of temperate and tropical Asia. Likely impacts would include a greater annual variability in the monsoon's precipitation levels, leading to more intense floods and droughts.

◆ **It is difficult to predict local and regional trends for extreme events.** 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. Another example: because climate models are poor at representing small-scale events, they tend to disagree on whether or not the intensity of mid-latitude storms will change.

◆ **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.

◆ **Climate change also has the potential to cause large-scale singular events.** Unlike most extreme events, singular events would have broad regional or global implications and be essentially irreversible. Examples of such calamities would include a significant slowing of the ocean's transport of warm water to the North Atlantic (which is responsible for Europe's relatively benign climate), a major shrinking of the Greenland or West Antarctic ice sheets (which would raise sea levels by three metres each over the next 1,000 years), and an accelerated warming due to carbon cycle feedbacks in the terrestrial biosphere, the release of carbon from melting permafrost, or the emission of methane from coastal sediments. Such risks have not yet been reliably quantified, but fortunately they are expected to be quite low.

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 government must then 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 finalized 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 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. Because there was not enough time to finalize all the operational details of how the Protocol would work in practice, COP-4, held in Buenos Aires from 2-13 November 1998, agreed a two-year Plan of Action for completing the Kyoto rulebook. The agenda of COP-5, which took place in Bonn from 15 October – 5 November 1999, was based on this Plan.

◆ **A political agreement on the operational rulebook for the Protocol was reached at COP-6.** Meeting from 6 to 25 November 2000, COP-6 made good progress but could not resolve all the issues in the time available. The meeting was suspended and then resumed from 16 to 27 July 2001 in Bonn. The resumed session reached agreement on the political principles of the operational rulebook for the Kyoto Protocol. This agreement addressed the emissions trading system, the Clean Development Mechanism, the rules for counting emissions reductions from carbon "sinks", and the compliance regime. It also outlined a package of financial and technological support to help developing countries contribute to global action on climate change. The work of translating the Bonn Agreements into detailed legal texts was finalized at COP-7, which was held in Marrakech, Morocco, from 29 October to 9 November 2001. The Protocol is now ready for implementation.

◆ **The IPCC finalized its Third Assessment Report in early 2001.** The Report concluded that the evidence for humanity's influence on the global climate is now stronger than ever before, and it presented the most detailed picture to date of how global warming will affect various regions. It also confirmed that many cost-effective solutions to rising greenhouse gas emissions are available today; in many cases, however, governments will need to address various institutional, behavioral and other barriers before these solutions can realize their potential.

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 – committed themselves to adopting policies and measures aimed at returning their greenhouse gas emissions to 1990 levels by the year 2000 (emissions targets for the post-2000 period are addressed by the Kyoto Protocol). 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 (185 as of July 2001). 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 binding emissions targets for developed countries.

◆ **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. In 2001 the COP agreed on the need to establish two new funds under the Convention – a Special Climate Change Fund and a fund for least developed countries – to help developing countries adapt to climate change impacts, obtain clean technologies, and limit the growth in their emissions. These funds are to be managed within the GEF framework. (The COP also agreed to establish an Adaptation Fund under the 1997 Kyoto Protocol.)

◆ **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. It is based in Bonn, Germany (see www.unfccc.int).

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 – 185 as of July 2002. 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 mid-2002 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, 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

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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 would be fully operational when it entered into force, governments agreed to a COP-6 deadline for deciding just how its "mechanisms" will function. The Plan also addressed compliance issues, policies and measures, and Convention-related issues such as the transfer of climate-friendly technologies to developing countries. COP-4 was held in Buenos Aires from 2 - 13 November 1998.

◆ **COP-5 set an aggressive timetable for completing work on the Protocol.** This included establishing the process that negotiators would follow over the next 12 critical months. Other decisions settled important substantive issues. For example, agreement was reached on how to improve the rigor of national reports from industrialized countries and how to strengthen the guidelines for measuring their greenhouse gas emissions. Action was also taken to address bottlenecks in the delivery and consideration of national communications by developing countries.

◆ **COP-6 adopted a broad political agreement on the Protocol's operational rulebook.** Meeting from 6 – 25 November, COP-6 made progress in outlining a package of financial support and technology transfer to assist developing countries in contributing to global action on climate change. But key political issues – including an international emissions trading system, a "clean development mechanism", the rules for counting emissions reductions from carbon sinks, and a compliance regime – could not be resolved in the time available. The session was therefore suspended and resumed some months later in Bonn, from 16 – 27 July. This time the Parties were able to reach agreement on the broad political principles underlying the rulebook.

◆ **COP-7 finalized the Protocol's institutions and detailed procedures.** The finalized Kyoto rulebook specifies how to measure emissions and reductions, the extent to which carbon dioxide absorbed by carbon sinks can be counted towards the Kyoto targets, how the joint implementation and emissions trading systems will work, and how to ensure compliance with the commitments.

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.

◆ **Developed countries and countries with economies in transition provide 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 minimize and reduce their emissions. They also provide detailed annual inventories of their net greenhouse gas emissions.

◆ **National communications from Annex I countries are subjected to a three-step review process.** A team of experts from developed and developing countries and from international organizations is assembled by the Convention's secretariat for each review. Their first step is to compile and synthesize the information contained in all the submissions.

◆ **The second step is the in-depth review of individual communications.** The experts conduct a comprehensive technical assessment of each submission, based in part on on-site visits. 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 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.

◆ **National inventories of greenhouse gas emissions and removals are submitted annually.** These data detail 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. The inventories are subjected to an annual technical review by experts.

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◆ **The latest available data (1999) reveal that greenhouse gas emissions in the richest (essentially OECD) countries have risen by 6.5% since 1990.** This figure excludes sequestration by sinks. Meanwhile, emissions in the economies in transition (Central/Eastern Europe and the former Soviet Union) had declined by 40% due to economic restructuring. As a result, overall emissions from developed countries had declined by 7.6% since 1990. (For details on CO_2 see Table 3 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.

The Kyoto Protocol

◆ **The Kyoto Protocol to the United Nations Framework Convention on Climate Change will strengthen 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 (industrialized) countries. 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 are to reduce 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 group target by distributing different rates among 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 some 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 use of these three mechanisms is to be supplemental to domestic action.

◆ **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 manage carbon "sinks" such as forest, croplands and grazing lands. The methodologies for measuring changes in net emissions (calculated as emissions minus removals of CO_2) due to the use of sinks are particularly complex.

◆ **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; a Kyoto Protocol Adaptation Fund was established in 2001.

◆ **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. Political disagreements in late 2000 and 2001 over how to implement the Protocol have slowed down the rate of ratification. 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.

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 80 percent of mankind's carbon dioxide (CO_2) emissions, 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 and other land-use changes, but it is estimated that from 800 million to 2.4 billion tonnes of carbon are released globally every year.

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◆ **Producing lime (calcium oxide) to make cement accounts for 3% 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 30% of the methane emissions from human activities.

◆ **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 mineral and organic fertilizers and manures 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.

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 the bulk of historical greenhouse gas emissions, their strong economies and institutions leave them better positioned than developing countries to cope with changes in climate. Quantifying the economic costs of climate change involves many uncertainties and caveats; nevertheless, some analysts estimate that damages resulting from a moderate climate change (+2.5°C warming) could cut the US's current GDP by 0.5%, the EU's by 2.8%, Africa's by 3.9%, and India's by 4.9%. Again, it must be emphasized that these estimates include only readily monetized damages and thus understate the likely costs.

◆ **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 because of differing assumptions and large uncertainties. For countries with economies in transition, the enormous opportunities for improving energy efficiency could ensure negligible costs or even net GDP gains of several percentage points. The highly industrialized countries of the OECD could rely on the Kyoto Protocol's emissions trading system to limit costs to a 0.1 – 1.1% reduction in projected GDP for the year 2010; or, expressed another way, the *rate* of annual economic growth over the next 10 years could be 0.1% lower than it would be otherwise. If reduced air pollution costs, the removal of market imperfections, and other factors are included, the costs are reduced even further.

◆ **Many cost-effective policies and technologies for cutting emissions are already available …** Some of the more recent technological breakthroughs include the market introduction of efficient hybrid engine cars and wind turbines, the demonstration of underground carbon dioxide storage, and advances in fuel cell technology. Hundreds of existing technologies and practices for end-use energy efficiency in buildings, transport and manufacturing industry could also be more fully exploited to reduce emissions – often with a net financial benefit.

◆ **… but governments will need to promote these solutions actively.** In many cases governments will have to address a range of institutional, behavioral and other barriers before climate-friendly policies and technologies can gain widespread acceptance. These can include market prices that do not incorporate externalities such as pollution, misplaced incentives, vested interests, lack of effective regulatory agencies, imperfect information, and so on.

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◆ **Energy policies hold the key to the cost and effectiveness of efforts to cut emissions.** The choice of energy mix and associated investments will determine whether atmospheric concentrations of greenhouse gases can be stabilized, and at what level and cost. Currently most such investment is directed towards discovering and developing more fossil resources, including both conventional and unconventional. But the progress over the last few years on developing technologies that reduce greenhouse gas emissions has been faster than anticipated.

◆ **"No regrets" measures for tackling emissions can have multiple benefits.** Many researchers believe it will be possible to reduce emissions 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 that do indeed have net costs.

◆ **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.

◆ **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 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.

◆ **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

Crafting cost-effective policies

◆ **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. They can involve removing market imperfections (such as counter-productive fossil fuel subsidies), creating supplementary benefits (greater industrial competitiveness through energy efficiency), and generating "double dividends" (when revenues from taxes or other climate change instruments are used to finance reductions in existing distortionary taxes). While no-regrets policies are certainly justified, the precautionary principle and the level of net damage expected from climate change also 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. Some 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

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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 in some cases 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 a national system can work: A government determines 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. The 1997 Kyoto Protocol establishes an emissions trading system for governments at the international level.

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 80% of all carbon dioxide emissions. Extracting and using fossil fuels also emits methane, some carbon dioxide, and large quantities of carbon monoxide and other air pollutants. The industrial sector accounts for 43% of the global CO_2 emissions from fossil-fuel combustion, the building sector 31%, transport 22% (and growing rapidly) and agriculture 4%. 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 technologies can dramatically cut methane emissions from coalmines and from natural-gas distribution systems. 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.

◆ **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. At the same time, phasing out existing fossil-fuel subsidies would cut global emissions while supporting national economic development.

◆ **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. This could be achieved in part through the transition to combined cycle gas turbines (CCGTs), which are likely to become the largest worldwide provider of new energy capacity between now and 2020. The newest models already boast conversion efficiencies approaching 60%. This is possible because the heat from the burning fuel drives steam turbines while the thermal expansion of the exhaust gases drives gas turbines.

◆ **Power-plant emissions can also be reduced by switching to renewable sources.** Renewable energy technologies such as wind, solar, and small hydro can cut emissions while distributing electricity more flexibly "off the grid". The use of wind turbines is now growing by over 25% per year. Solar and biomass also continue to grow as costs decline. Total contributions from non-hydro renewable sources are currently below 2% globally, but by 2010 more efficient photovoltaics, off-shore wind farms, ethanol-based biofuels and other low- or zero-emissions fuel sources are expected to penetrate the market.

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◆ **Industry can further reduce its energy intensity while cutting production costs.** This is the only sector where emissions in the richest countries are already declining due to increased efficiency in the use of energy and of materials. But these countries could reduce their industrial CO_2 emissions even further 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 more energy-efficient technologies**. Emissions from buildings continue to rise because higher demand for building services has outpaced technology improvements. These improvements include new building controls, passive solar design, integrated building design, new chemicals for refrigeration and insulation, and more efficient refrigerators and cooling and heating systems. Further steps could include market-based programmes in which customers or manufacturers receive technical support or financial incentives, mandatory or voluntary energy-efficiency standards, public and private research into more efficient products, and information and training programs.

◆ **Governments can remove barriers that slow the spread of low-emissions technologies.** The diffusion 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.

◆ **Deep reductions in fossil fuel emissions needed to stabilize greenhouse gas concentrations are possible over the next 50 to 100 years.** Technology innovation, energy efficiency, and an emphasis on renewable energy sources will be essential for achieving this goal. Since many different combinations of technologies and policies 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 a heavy emphasis on energy efficiency.

New transportation technologies and policies

◆ **The transport sector is a major and rapidly growing source of greenhouse gas emissions.** Carbon dioxide emissions from vehicles and transport equipment are rising by a significant 2.5% per year. 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). This sector's heavy reliance on liquid fossil fuels makes controlling greenhouse gas emissions particularly difficult.

◆ **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 (484 cars per 1,000 people in North America in 1996, compared to 32 in South America), although developing countries 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. Hybrid gasoline-electric vehicles now available on the market are twice as energy efficient as regular vehicles of comparable size.

◆ **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. Biodiesel, supported by tax exemptions, is gaining market share in Europe. Fuel cell-powered vehicles are developing rapidly and are to enter the market in 2003. Biofuels produced from wood, energy crops, and waste also promise to play any increasingly important role in the transport sector. These fuels and technologies 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 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.

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◆ **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. Studies have suggested 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. Similarly, measures to improve general traffic control and restrict the use of motor vehicles can reduce energy use significantly.

◆ **Urban planners can encourage low-emissions transport.** Convincing people to switch from automobiles to buses or trains can dramatically reduce primary energy use per passenger-seat-kilometer. 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.

New approaches to forestry and agriculture

◆ **Forestry and agriculture are important sources of carbon dioxide, methane, and nitrous oxide.** 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”. Deforestation and changes in land use make the world’s forests a net source of carbon dioxide. As for agriculture, it accounts for over 20% of the human-enhanced greenhouse effect. Intensive agricultural practices such as livestock rearing, wet rice cultivation, and fertilizer use emit 58% of human-related methane and much 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 and wood-harvesting practices, 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 or sustainably managed, 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.** Improved management practices designed to increase

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agricultural productivity could enable agricultural soils to absorb and hold more carbon. Low-tech strategies include the use of crop residues 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 more efficient use of animal manure.

◆ **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 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.

◆ **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 dramatically 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 fertilization 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. A fertilizer's interactions with local soil and climate conditions can also be influenced by optimizing tillage, irrigation, and drainage systems.

◆ **Storing carbon in agricultural soils can also serve other environmental and socio-economic goals.** Often, it improves soil productivity. In addition, practices such as reduced tillage, increased vegetative cover, and greater use of perennial crops prevent erosion, thus improving water and air quality. As a result of these benefits, carbon storage practices are often justified above and beyond their contribution to minimizing climate change. Care must be taken, however, to ensure that carbon storage does not lead to higher nitrous oxide levels as a result of increased soil moisture or fertilizer use.

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 both bilateral and multilateral sources.

◆ **The Convention's "financial mechanism" is a major source of funding.** Its role is to transfer funds and technology to developing countries on a grant or concessional basis. The mechanism is 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 1991, 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 implementing agencies. By the time the Earth Summit was held in 1992, the GEF was considered a possible source of funds for 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 GEF also funds enabling activities, including the "agreed full costs" of preparing national communications.

◆ **The available funds are based on voluntary contributions from governments.** During the "pilot phase" of 1991-94, the GEF trust fund contained $800 million from participating governments. When the GEF was later restructured to make it more universal, democratic, and transparent, it was replenished from July 1994 through June 1998 with $2 billion. The second replenishment for the four-year period ending June 2002 was based on pledges totaling $2.75 billion. Pledges for the four-year period starting July 2002 total $2.92 billion from 32 donor countries.

◆ **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 (for East European and Central Asian countries only) protection of the ozone layer. In addition, activities to combat land degradation (primarily desertification and deforestation) have been approved for funding since they are relevant to some focal areas. (The GEF Council agreed in 2001 to consider setting up new focal areas for the Convention to Combat Desertification as well as the Stockholm Convention on Persistent Organic Pollutants.) Also eligible are the agreed incremental costs of other activities under Agenda 21, insofar as they achieve global environmental benefits in the focal areas. Since 1991, the GEF has allocated some US$1.5 billion in grants to climate change projects and activities; this funding has leveraged an additional $5 billion in co-financing contributions. Climate change now represents about a third of the GEF's 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 Climate Change 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 COP decisions and with GEF programming strategies and policies. Once approved, projects are carried out by a wide range of 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 166 members and meets semi-annually, while the Assembly of all participating countries meets every three years.

◆ **In 1998, the Parties to the Convention asked the GEF to continue operating the financial mechanism.** They decided to review the financial mechanism's effectiveness again within four years; this second review is expected to conclude by November 2002. As required by the Convention, the Conference of the Parties 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.

◆ **In July 2001, the COP created three new funds to further assist developing countries.** A Special Climate Change Fund and a least developed countries fund are being established under the Convention to help developing countries adapt to climate change impacts, obtain clean technologies, and limit the growth in their emissions. In addition, an Adaptation Fund is being set up under the Kyoto Protocol to finance concrete adaptation projects and programmes (The COP will guide the Fund until the Protocol enters into force). Many developed countries also pledged a combined contribution of •450 million per year by 2005 through these funds plus existing avenues to help developing countries manage their emissions and adapt to climate change.

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. However, while per-capita emissions in developed countries are likely to stabilize (at well above the world average), the developing countries' annual emissions continue to rise steadily and are expected to equal those of developed countries sometime in the early part of this century.

◆ **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 also greatly increase the transfer of low-emissions technologies. The Climate Change Convention has opened up a new channel via the government-funded Global Environment Facility (GEF). In addition, the Kyoto Protocol establishes a Joint Implementation mechanism and a Clean Development Mechanism to attract private and public sector funds for transferring technology and know-how to, respectively, countries with economies in transition and developing countries.

◆ **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.

◆ **Joint Implementation has been conceived as one way of channeling new funds into climate change activities.** JI could promote the co-development of advanced technologies and their transfer from one developed country to another. In practice, JI will normally be carried out through partnerships between investing companies in highly industrialized countries and counterparts in countries making the transition to a market economy. The investing partner may provide most of the

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required technology and financial capital while the host-country partner may provide the site, the principal staff, and the organization needed to launch and sustain the project.

◆ **The Clean Development Mechanism aims to help developing countries achieve sustainable development and contribute to the Convention's goals.** It will be guided by the Parties to the Kyoto 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 have measurable and long-term affects on the host country's emissions. Energy efficiency, renewable energy, and forest sink projects can qualify, but developed countries are to refrain from using nuclear facilities in the CDM.

◆ **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."

DATA on greenhouse gas emissions and sources

Table 1: Examples of greenhouse gases affected by human activities

	CO_2 (carbon dioxide)	CH_4 (methane)	N_2O (nitrous oxide)	CHC-11 (Chlorofluoro-carbon-11)	HFC-23 (Hydrofluoro-carbon-23)	CF_4 (Perfluoro-methane)
Pre-industrial concentration	About 280 ppm	About 700 ppb	About 270 ppb	Zero	Zero	40 ppt
Concentration in 1998	365 ppm	1745 ppb	314 ppb	268 ppt	14 ppt	80 ppt
Rate of concentration change[b]	1.5 ppm/yr[a]	7.0 ppb/yr[a]	0.8 ppb/yr	-1.4 ppt/yr	0.55 ppt/yr	1 ppt/yr
Atmospheric lifetime	5 to 200 yr[c]	12 yr[d]	114 yr[d]	45 yr	260 yr	>50.000 yr

Notes:

a Rate has fluctuated between 0.9 ppm/yr and 2.8 ppm/yr for CO_2 and between 0 and 13 ppb/yr for CH_4 over the period 1990 to 1999.

b Rate is calculated over the period 1990 to 1999.

c No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.

d This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.

Source: "Climate Change 2001, The Scientific Basis, Technical Summary of the Working Group I Report", p.38.

*Table 2: CO_2 emissions from fuel combustion, 1998**

Largest emitters: Annex I and non-Annex I Parties (Million of tonnes of CO2)

	Top ten: Annex I & non-Annex I Parties		% world	**Top ten: Annex I Parties**		% World	**Top ten: non-Annex I Parties**		% World
1	United States	5,410	24%	United States	5,409.75	24%	China	2,893.15	13%
2	China	2,893	13%	Russian Federation	1,415.78	6%	India	908.2	4%
3	Russian Federation	1,416	6%	Japan	1,128.34	5%	Republic of Korea	370.14	2%
4	Japan	1,128	5%	Germany	857.05	4%	Mexico	356.3	2%
5	Germany	857	4%	United Kingdom	549.51	2%	South Africa	353.67	2%
6	India	908	4%	Canada	477.25	2%	Brazil	295.86	1%
7	United Kingdom	550	2%	Italy	425.99	2%	Saudi Arabia	270.73	1%
8	Canada	477	2%	France	375.5	2%	Iran	259.77	1%
9	Italy	426	2%	Ukraine	358.78	2%	Indonesia	208.47	1%
10	France	376	2%	Poland	320.16	1%	Dem People's Republic Korea	199.66	1%
	Total	14,441		*Total*	11,318.11		*Total*	6,115.95	
	% of world total	64%		*% of world total*	50%		*% of world total*	27%	
				% of Annex I total	85%		*% of non-Annex I total*	71%	

Groups	**total emissions**	**% of world total**	**t CO2 per capita**
World#	22,726	na	3.87
Annex I Parties	13,383	59%	11.00
Annex II Parties	10,792	47%	12.00
European Union	3,171	14%	8.47
EIT Parties	2,592	11%	8.18
non-Annex I Parties	8,622	38%	1.85

Note: World includes all Parties and non-Parties to the UNFCCC.

Source: IEA CO2 emissions from fuel combustion 1971-1998, Paris, 2000. Data from IEA has been used as the UNFCCC secretariat database does not contain data for all Parties. However, the IEA data is broadly comparable to that reported to the UNFCCC secretariat by Parties.

Table 3: Greenhouse gas emissions from developed countries 1990 – 1999

All figures gigagrams or percentage change. The 1990 figures for all GHGs without sinks offer reasonable approximations to the 'assigned amounts' against which the Kyoto targets will be measured; however, there are various inconsistencies – e.g. implications of Protocol Article 3.7 not reflected, some base years for HFCs/PFCs/SF_6 differ – and the figures are likely to be revised.

COUNTRY	All GHGs 1990 w/o sinks	All GHGs 1999 ° w/o sinks	Percent Change	Kyoto Target (%)
Australia	423 237	484 699	+14.5	+8
Austria	75 452	80 315	+6.4	-8 (-13)
Belgium	136 463	145 372	+6.5	-8 (-7.5)
Bulgaria*§	157 090	84 317	-46.3	-8
Canada	611 770	692 230	+13.2	-6
Czech*	189 837	147 777	-22.2	-8
Denmark	69 567	76 144	+9.5	-8 (-21)
Estonia*	40 719	21 756	-46.6	-8
Finland	75 202	76 315	+1.5	-8 (0)
France	553 778	558 726	+0.9	-8 (0)
Germany	1 208 807	1 019 745	-15.6	-8 (-21)
Greece	105 346	124 315	+18.0	-8 (-25)
Hungary*§	101 633	83 677	-17.7	-6
Iceland	2 576	a 2 696	+4.7	+10
Ireland	53 497	63 718	+19.1	-8 (-13)
Italy	518 502	541 542	+4.4	-8 (-6.5)
Japan	1 213 262	b 1 330 555	+9.7	-6
Latvia*	35 669	11 504	-67.7	-8
Liechtenstein	260			-8
Lithuania*	51 548	23 851	-53.7	-8
Luxembourg	13 448	a 10 223	-24.0	-8 (-28)
Monaco	111	142	+28.4	-8
Netherlands	217 882	236 251	+8.4	-8 (-6)
New Zealand	73 068	74 886	+2.5	0
Norway	52 141	56 148	+7.7	+1
Poland*§	564 286	402 477	-28.7	-6
Portugal	63 858	74 870	+17.2	-8 (-27)
Romania*§	264 879	c 164 026	-38.1	-8
Russian Fed.*	3 040 062	1 962 441	-35.4	0
Slovakia*	76 304	52 818	-30.8	-8
Slovenia*	19 212	-8		
Spain	305 746	369 856	+21.0	-8 (-15)
Sweden	69 399	73 842	+6.4	-8 (-4)
Switzerland	53 005	53 706	+1.3	-8
Ukraine*	919 220	454 934	-50.5	0
UK	741 489	679 850	-8.3	-8 (-12.5)
US	6 048 786	6 726 997	+11.2	-7
Annex I °	18 147 110	16 982 195	-6.4	-5
Annex II °	12 686 651	13 553 405	+6.8	- -
EIT °	5 460 459	3 428 790	-37.2	- -

Notes:

Annex I: includes all the countries listed in the table, which are the Parties with quantified emissions targets under the Kyoto Protocol.

Annex II: includes the most industrialized countries only, listed here without asterisks.

EIT: the countries with economies in transition, indicated here by asterisks.

Gigagram = 1,000 tons

All greenhouse gases: includes emissions of the six gases addressed by the Kyoto Protocol (where reported): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), HFCs, PFCs, and sulphur hexafluoride (SF_6). Expressed as CO_2 equivalents. Carbon removals by sinks are excluded.

Kyoto targets: expressed as a percentage increase or decrease from 1990 levels (or other reference period). The European Union as a group is committed to –8%; the national rates allocated through an internal EU agreement are indicated here in parentheses. The targets are to be achieved in the five-year period 2008–2012.

§ Some Parties with economies in transition use base years other than 1990: Bulgaria (1988), Hungary (average of 1985-87), Poland (1988) and Romania (1989). These base years are given in this table in lieu of 1990.

° Values for 1998 based on the latest available data for each country.

a Latest available data is from 1998;

b Latest available data is from 1994;

c Latest available data is from 1996;

Source: Climate Change Secretariat, "National Communications from Parties Includes in Annex I to the Convention: Greenhouse Gas Inventory Data from 1990 to 1999", Document FCCC/SBI/2000/13 and Add 1. Please see original document for the complete set of footnotes.

*Table 4: World Energy Consumption (Mtoe) ***

	1971	1977	2010	2020	1997-2020*
Total Final Consumption	3,627	5,808	7,525	9,117	2.0
Coal	620	635	693	757	0.8
Oil	1,888	2,823	3,708	4,493	2.0
Gas	608	1,044	1,338	1,606	1.9
Electricity	377	987	1,423	1,846	2.8
Heat	68	232	244	273	0.7
Renewables	66	87	118	142	2.2

* Average annual growth rate, in percent

** Million tones of oil equivalent

Source: International Energy Agency, "World Energy Outlook 2000", p.61.

Table 5: Per-capita CO_2 emissions (metric tons): 10 indicative rates

Brazil	**1.7**
China	2.7
Czech Republic	12.3
India	1.1
Japan	9.3
Malaysia	5.8
Nigeria	0.8
Russian Fed.	10.7
UK	9.5
US	19.7

Note: 1996 figures

Source: adapted from CDIAC as cited in World Resources 2000-2001.

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Printed in France
GE.02-01874/E-September 2002 - 5 000
UNEP/IUC/2002/7

Published in September 2002
Typeset by Fontline Electronic Publishing, Harare, Zimbabwe