Presentation of

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Introduction

One of the major challenges facing humankind is to provide an equitable standard of living for this and future generations: adequate food, water and energy, safe shelter and a healthy environment (e.g., clean air and water). Unfortunately, human-induced climate change, as well as other global environmental issues such as land degradation, loss of biological diversity and stratospheric ozone depletion, threatens our ability to meet these basic human needs.

The overwhelming majority of scientific experts, whilst recognizing that scientific uncertainties exist, nonetheless believe that human-induced climate change is inevitable. Indeed, during the last few years, many parts of the world have suffered major heat waves, floods, droughts, fires and extreme weather events leading to significant economic losses and loss of life. While individual events cannot be directly linked to human-induced climate change, the frequency and magnitude of these types of events are predicted to increase in a warmer world.

The question is not whether climate will change in response to human activities, but rather how much (magnitude), how fast (the rate of change) and where (regional patterns). It is also clear that climate change will, in many parts of the world, adversely affect socio-economic sectors, including water resources, agriculture, forestry, fisheries and human settlements, ecological systems (particularly forests and coral reefs), and human health (particularly diseases spread by insects), with developing countries being the most vulnerable. The good news is, however, that the majority of experts believe that significant reductions in net greenhouse gas emissions are technically feasible due to an extensive array of technologies and policy measures in the energy supply, energy demand and agricultural and forestry sectors. In addition, the projected adverse effects of climate change on socio-economic and ecological systems can, to some degree, be reduced through proactive adaptation measures. These are the fundamental conclusions, taken from already approved/accepted IPCC assessments, of a careful and objective analysis of all relevant scientific, technical and economic information by thousands of experts from the appropriate fields of science from academia, governments, industry and environmental organizations from around the world.

Decision-makers should realize that once carbon dioxide, the major anthropogenic greenhouse gas, is emitted into the atmosphere, it stays in the atmosphere for more than a century. This means that if policy formulation waits until all scientific uncertainties are resolved, and carbon dioxide and other greenhouse gases are responsible for changing the Earth's climate as projected by all climate models, the time to reverse the human-induced changes in climate and the resulting environmental damages, would not be years or decades, but centuries to millennia, even if all emissions of greenhouse gases were terminated, which is clearly not practical.

This presentation, which briefly describes the current state of understanding of the Earth's climate system and the influence of human activities; the vulnerability of human health, ecological systems, and socio-economic sectors to climate change; and approaches to mitigate climate change by reducing emissions and enhancing sinks, is based on accepted and approved conclusions from the IPCC Second Assessment Report (SAR) and a series of Technical Papers and Special Reports (e.g., the Special Reports on Emissions Scenarios; Land-Use, Land-Use Change and Forestry; and Methodological and Technological Issues in Technology Transfer) and, supplemented by recent information that is being assessed in the draft IPCC Third Assessment Report (TAR). The Working Group I and II reports of the TAR have already been distributed to governments for final review, while the Working Group III report will be distributed to governments for final review within a couple of weeks. The Working Group Reports will be approved/accepted at a series of plenary meetings between January and March, 2001. The Synthesis Report of the TAR, which addresses a series of policy-relevant questions, will be approved/adopted in September 2001. None of the conclusions presented in this report are taken from the TAR, but are consistent with the draft conclusions, which are subject to change until final government approval and acceptance early next year.

Part I: The Earth's Climate System: The Influence of Human Activities

The Earth's climate is changing: The Earth's climate has been relatively stable since the last ice age (global temperature changes of less than 1 degree Centigrade over a century during the past 10,000 years). During this time modern society has evolved, and, in many cases, successfully adapted to the prevailing local climate and its natural variability. However, the Earth's climate is now changing. The Earth's surface tem-

perature this century is clearly warmer than any other century during the last thousand years, i.e., the climate of the 20th century is clearly atypical **(figure 1)**. The Earth has warmed by between 0.4 and 0.8 degree centigrade over the last century, with land areas warming more than the oceans **(figure 2)**, and with the last two decades being the hottest this century **(figure 3)**. Indeed, the three warmest years during the last one hundred years have all occurred in the 1990s and the twelve warmest years during the last one hundred years have all occurred since 1983. In addition, there is evidence that precipitation patterns are changing **(figure 4)**, that sea level is increasing, that glaciers are retreating world-wide, that Arctic sea ice is thinning, and that the incidence of extreme weather events is increasing in some parts of the world.

The atmospheric concentrations of greenhouse gases are changing due to human activities: The atmospheric concentrations of greenhouse gases have increased because of human activities, primarily due to the combustion of fossil fuels (coal, oil and gas), deforestation and agricultural practices, since the beginning of the pre-industrial era around 1750: carbon dioxide by nearly 30% **(figure 5)**, methane by more than a factor of two **(figure 5)**, and nitrous oxide by about 15%. Their concentrations are higher now than at any time during the last 420,000 years, the period for which there are reliable ice-core data, and probably significantly longer. In addition, the combustion of fossil fuels has also caused the atmospheric concentrations of sulfate aerosols to have increased. Greenhouse gases tend to warm the atmosphere and, in some regions, primarily in the Northern Hemisphere, aerosols tend to cool the atmosphere.

The weight of scientific evidence suggests that the observed changes in the Earth's climate are, at least in part, due to human activities: Climate models that take into account the observed increases in the atmospheric concentrations of greenhouse gases, sulfate aerosols and the observed decrease in ozone in the lower stratosphere, in conjunction with natural changes in volcanic activity and in solar activity, simulate the observed changes in annual mean global surface temperature quite well. This, and our basic scientific understanding of the greenhouse effect, suggests that human activities are implicated in the observed changes in the Earth's climate. In fact, the observed changes in climate, especially the increased temperatures since the around 1970, cannot be explained by changes in solar activity and volcanic emissions alone as shown in **figure 6a**. Where-as **figure 6b** shows that the observed changes in temperature, especially those since around 1970, can be simulated quite well by a climate model that takes into account human-induced changes in greenhouse gases and aerosols. Not only is there evidence of a change in climate at the global level consistent with climate models, but there is observational evidence of regional changes in climate that are consistent with those predicted by climate models. For example, climate models predict an increase in intense rainfall events over the United States of America consistent with the observations **(figure 7)**.

Emissions of greenhouse gases are projected to increase in the future due to human activities: Future emissions of greenhouse gases and the sulfate aerosol precursor, sulfur dioxide, are sensitive to the evolution of governance structures world-wide, changes in population and economic growth, the rate of diffusion of new technologies into the market place, energy production and consumption patterns, land-use practices, energy intensity, and the price and availability of energy. While different development paths can result in quite different greenhouse gas emissions, most projections suggest that greenhouse gas concentrations will increase significantly during the next century in the absence of policies specifically designed to address the issue of climate change (IPCC Special Report on Emission Scenarios - SRES). Some projections suggest that an initial increase in emissions could be followed by a decrease after several decades if there was a major transition in the worlds energy system due to the pursuit of a range of sustainable development goals. The SRES reported, for example, carbon dioxide emissions from the combustion of fossil fuels are projected to range from about 5 to 35 GtC per year in the year 2100: compared to current emissions of about 6.3 GtC per year **(figure 8)**. Such a range of emissions would mean that the atmospheric concentration of carbon dioxide would increase from today's level of about 365 ppmv (parts per million by volume) to between about 550 and 1000 ppmv by 2100.

Latest projections of carbon dioxide emissions are consistent with earlier projections, but projected sulfur dioxide emissions are much lower: While the SRES reported similar projected energy emissions for carbon dioxide to the 1992 projections, it differed in one important aspect from the 1992 projections, in-so-far-as the projected emissions of sulfur dioxide are much lower **(figure 9)**, because of structural changes in the energy system and because of concerns about local and regional air pollution (i.e., acid deposition). This has important implications for future projections of temperature changes, because sulfur dioxide emissions lead to the formation of sulfate aerosols in the atmosphere, which as stated earlier can partially offset the warming effect of the greenhouse gases.

Global mean surface temperatures are projected to increase by about 1.5 to 6.0oC by 2100. Based on the range of climate sensitivities and the plausible ranges of greenhouse gas and sulfur dioxide emissions reported in the SRES, a number of climate models project that the global mean surface temperature could increase by about 1.5 to 6.0 °C by 2100 **(figure 10)**. This range compares to that reported in the IPCC SAR of 1.0 – 3.5 °C. The revised higher estimates of projected warming arise because the lower projected emissions of sulfur dioxide result in less offset of the warming effect of the greenhouse gases. These projected global-average temperature changes would be greater than recent natural fluctuations and would also occur at a rate significantly faster than observed changes over the last 10,000 years. Temperature changes are expected to differ by region with high latitudes projected to warm more than the global average, and during the next century land areas are projected to warm more than the oceans, and the northern hemisphere is projected to warm more than the southern hemisphere **(figure 11)**[1]. However, the reliability of regional scale predictions is still low.

Seasonal and latitudinal shifts in precipitation with arid and semi-arid areas becoming drier: Model calculations show that evaporation will be enhanced as the climate warms, and that there will be an increase in global mean precipitation and an increase in the frequency of intense rainfall. However, not all land regions will experience an increase in precipitation **(figure 12)**, and even those land regions with increased precipitation may experience decreases in run-off and soil moisture, because of enhanced evaporation. Seasonal shifts in precipitation are also projected. In general, precipitation is projected to increase at high latitudes in winter, while run-off and soil moisture is projected to decrease in some mid-latitude continental regions during summer. The arid and semi-arid areas in Southern and Northern Africa, Southern Europe, the Middle East, parts of Latin America and Australia are expected to become drier.

Sea level projected to rise about 15-95 cms by 2100: Associated with changes in temperature, sea level is projected to increase by about 15 - 95 cm by 2100 (IPCC SAR), caused primarily by thermal expansion of the oceans and the melting of glaciers. The revised temperature projections are not likely to result in significantly different projections of changes in sea level over the next century because of the large thermal inertia of the oceans, i.e., the temperature of the oceans responds very slowly to a change in greenhouse gas concentrations. However, recent more advanced models are tending to project somewhat lower values of sea level rise. It should be noted that even when the atmospheric concentrations of greenhouse gases are stabilized, temperatures will continue to increase by another 30-50% over several decades, sea level will continue to rise over hundreds of years and ice sheets will continue to adjust for thousands of years. **Figure 13** shows how sea level increases by more than a factor of 5 over hundreds of years after the atmospheric concentration of carbon dioxide is stabilized.

The frequency and magnitude of ENSO events may increase: Long-term, large-scale, human-induced changes in climate are likely to interact with natural climate variability on time-scales of days to decades (e.g., the El Nino-Southern Oscillation (ENSO) phenomena). Recent trends in the increased frequency and magnitude of ENSO events **(figure 14)**, which lead to severe floods and droughts in regions of the tropics and sub-tropics, are projected to continue in many climate models.

Incidence of some extreme events projected to increase: While the incidence of extreme temperature events, floods, droughts, soil moisture deficits, fires and pest outbreaks is expected to increase in some regions, it is unclear whether there will be changes in the frequency and intensity of extreme weather events such as tropical storms, cyclones, and tornadoes. However, even if there is no increase in the frequency and intensity of extreme weather events there may be shifts in their geographic location to places less prepared and more vulnerable to such events.

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[1] While projected changes in climate vary from among climate models, results from the UK Met Office have been used in this paper to illustrate potential changes in climate because the climate sensitivity of this model is in the center of the range from all models and the broad patterns of projected changes in climate are similar to the ensemble of all general circulation models.

Part II: The Vulnerability of Water Resources, Agriculture, Natural Ecosystems, and Human Health to Climate Change and Sea Level Rise

The IPCC has assessed (IPCC SAR and the IPCC Special Report on the Regional Impacts of Climate Change: An Assessment of Vulnerability) and is continuing to assess (IPCC TAR) the potential consequences of changes in climate for socio-economic sectors, ecological systems and human health for different regions of the world at the regional and global scale. Because of uncertainties associated with regional projections of climate change, the IPCC assesses the vulnerability of these natural and social systems to changes in climate, rather than attempting to provide quantitative predictions of the impacts of climate change at the regional level. Vulnerability is defined as the extent to which a natural or social system is susceptible to sustaining damage from climate change, and is a function of the magnitude of climate change, the sensitivity of the system to changes in climate and the ability to adapt the system to changes in climate. Hence, a highly vulnerable system is one that is highly sensitive to modest changes in climate and one for which the ability to adapt is severely constrained.

Most impact studies have assessed how systems would respond to a climate change resulting from an arbitrary doubling of atmospheric carbon dioxide concentrations. Very few studies have considered the dynamic responses to steadily increasing greenhouse gas concentrations; fewer yet have been able to examine the consequences of increases beyond a doubling of greenhouse gas concentrations or to assess the implications of multiple stress factors. Thus there is a need for the increased development and use of time-dependent integrated assessment models.

The IPCC SAR concluded that human health, terrestrial and aquatic ecological systems, and socioeconomic systems (e.g., agriculture, forestry, fisheries, water resources, and human settlements), which are all vital to human development and well-being, are all vulnerable to changes in climate, including the magnitude and rate of climate change, as well as to changes in climate variability. Whereas many regions are likely to experience the adverse effects of climate change—some of which are potentially irreversible—some effects of climate change are likely to be beneficial. Hence, different segments of society can expect to confront a variety of changes and the need to adapt to them.

There are a number of general conclusions that can be easily drawn: (i) human-induced climate change is an important new stress, particularly on ecological and socio-economic systems that are already affected by pollution, increasing resource demands, and non-sustainable management practices; (ii) the most vulnerable systems are those with the greatest sensitivity to climate change and the least adaptability; (iii) most systems are sensitive to both the magnitude and rate of climate change; (iv) many of the impacts are difficult to quantify because existing studies are limited in scope; and (v) successful adaptation depends upon technological advances, institutional arrangements, availability of financing and information exchange, and that vulnerability increases as adaptation capacity decreases. Therefore, developing countries are more vulnerable to climate change than developed countries.

The range of adaptation options for managed systems such as agriculture and water supply is generally increasing because of technological advances, thus reducing the vulnerability of these systems to climate change. However, some regions of the world, i.e., developing countries, have limited access to these technologies and appropriate information. The efficacy and cost-effectiveness of adaptation strategies will depend upon cultural, educational, managerial, institutional, legal and regulatory practices that are both domestic and international in scope. Incorporation of climate change concerns into resource-use and development decisions and plans for regularly scheduled investments in infrastructure will facilitate adaptation.

The issues of climate variability and climate change need to be integrated into resource use and development decisions: Many sectors are currently not optimally managed with respect to today's natural climate variability because of the choice of policies, practices and technologies. Decreasing the vulnerability of socio-economic sectors and ecological systems to natural climate variability through a more informed choice of policies, practices and technologies will, in many cases, reduce the long-term vulnerability of these systems to climate change. For example, use of seasonal climate forecasts into management decisions can reduce the vulnerability of the water and agricultural sectors to floods and droughts caused by the ENSO phenomena.

Let me now briefly discuss the implications of climate change for a representative number of systems: water resources, agricultural productivity and food security, natural ecosystems (forests and coral reefs), human health and sea level rise.

Water Resources

Climate change could exacerbate water stress in arid and semi-arid areas, and most regions will experience an increase in floods: Currently 1.3 billion people do not have access to adequate supplies of safe water, and 2 billion people do not have access to adequate sanitation. Today, some nineteen countries, primarily in the Middle East and Africa, are classified as water-scarce or water-stressed. Even in the absence of climate change, this number is expected to double by 2025, in large part because of increases in demand from population and economic growth. Unfortunately in many regions of the world a significant fraction of water is wasted, largely through inefficient irrigation in the agricultural sector. **Figure 15** shows projected changes in run-off due to climate change, which are closely linked to projected changes in precipitation. Hence, climate change could further exacerbate the frequency and magnitude of droughts in some places, in particular central Asia, northern and southern Africa, the Middle East, the Mediterranean and Australia where droughts are already a recurrent feature. Developing countries are highly vulnerable to climate change and increased water stress because many are located in arid and semi-arid areas. In addition, it should be recognized that the frequency and magnitude of floods in most regions of the world are expected to increase because of the projected increase in heavy precipitation events.

Agricultural Productivity and Food Security

Agricultural productivity is projected to decrease in many countries in the tropics and sub-tropics: Currently, 800 million people are malnourished; as the world's population increases and incomes in some countries rise, food demand is expected to double over the next three to four decades. Studies show that on the whole, global agricultural production might be relatively unaffected by small changes in climate, i.e., global mean surface temperature changes of less than 2 degrees Centigrade, but is projected to decrease with greater warming. Crop yields and changes in productivity due to climate change will vary considerably across regions and among localities, thus changing the patterns of production. In general, productivity is projected to increase in middle to high latitudes, depending on crop type, growing season, changes in temperature regime, and seasonality of precipitation. However, in the tropics and subtropics, where some crops are near their maximum temperature tolerance and where dryland, non-irrigated agriculture dominates, yields are likely to decrease for even small changes in climate, especially in Africa and Latin America, where decreases in overall agricultural productivity of up to 30% are projected during the next century **(figure 16)**. Therefore, there may be increased risk of hunger in some locations in the tropics and subtropics where many of the world's poorest people live.

Natural Ecosystems

Biological systems have already been affected by changes in climate during the last several decades: There are a number of instances where changes in biological systems, e.g., earlier flowering of trees and egg-laying in birds, lengthening of the growing season, and the pole-ward and altitudinal shifts in insect ranges, have been associated with regional changes in climate. While these biological systems are subject to numerous stresses that can alter their behavior, it should be noted that in many cases these observed changes in biological systems are consistent with well-known biological responses to climate.

Climate change is projected to alter the structure and functioning of ecological systems and decrease biological diversity: The structure, composition and geographic distribution of many ecosystems will shift as individual species respond to changes in climate and disturbance regimes, but these ecological changes are likely to lag behind the changes in climate by decades to centuries. There will likely be reductions in biological diversity and in the goods ecosystems provide society, e.g., sources of food, fiber, medicines, recreation and tourism, and ecological services such as controlling nutrient cycling, waste quality, water run-off, soil erosion, pollination services, detoxification and air quality.

Forests are vulnerable to projected changes in climate: The distribution of forests and forest species are projected to change in response to changes in temperature, precipitation, extreme events, pest outbreaks and fires, altering the ecosystem goods and services provided. Boreal systems are most the vulnerable, primarily due to changes in fire regime and pest outbreaks, leading to forest die-back, a change in age structure and a decrease in carbon content. The global terrestrial biosphere is currently sequestering about 0.7 Gt C per year, the difference between a global uptake of 2.3 Gt C per year and an emission of about 1.6 Gt C per year

from tropical deforestation (IPCC Special Report on Land-Use, Land-Use Change and Forestry - LULUCF). The majority of the uptake is estimated to occur in the temperate forests (about 1 - 2 Gt C per year, in response to management practices, carbon dioxide fertilization, nitrogen deposition and climate change), with little net uptake in Boreal regions. This terrestrial uptake will likely diminish with time and forest ecosystems may even become a source of carbon emissions. Net carbon emissions are very sensitive to the El-Nino Southern Oscillation phenomena, with the terrestrial biosphere being a net source during ENSO years to a net sink in non-ENSO years, albeit with large regional variations.

Coral reefs are threatened by increases in temperature: Coral reefs, which are the most biologically diverse marine ecosystems, are important for fisheries, coastal protection, erosion control and tourism. Coral reef systems, which are already being threatened by pollution, unsustainable tourism and fishing practices, are very vulnerable to changes in climate. While these systems may be able to adapt to the projected increases in sea level, sustained increases in water temperatures of 3-4 degrees Centigrade above long-term average seasonal maxima over a 6-month period can cause significant coral mortality; short-term increases on the order of only 1-2 degrees Centigrade can cause shorter-term "coral bleaching".

Human Health

Human health is sensitive to changes in climate because of its impact, in particular, on changes in food security, water supply and quality, and the functioning and range of ecological systems. These impacts **(figure 17)** are likely to be mostly adverse, and in many cases would cause loss of life. Direct health effects would include increases in heat-related mortality and illness resulting from an anticipated increase in heatwaves, although offset to some degree in temperate regions by reductions in winter mortality. Indirect effects would include extensions of the range and season for vector organisms (e.g., mosquito, water snails, black and tsetse flies), often increasing the likelihood of transmission of vector-borne infectious diseases (e.g., malaria, dengue, yellow fever and encephalitis). Projected changes in climate could lead to an increase in the number of people at risk of malaria of the order of tens of millions annually, primarily in tropical, subtropical, and less well protected temperate-zone populations. Some increases in non-vector-borne infectious diseases such as salmonellosis, cholera and other food- and water-related infections could also occur, particularly in tropical and subtropical regions, because of climatic impacts on water distribution and temperature, and on micro-organism proliferation. The impacts of climate change on food production within food-insecure regions and the consequences of economic dislocation and demographic displacement (e.g., sea level rise) would have wide-ranging health impacts.

Sea Level Rise

Sea-level rise is projected to have negative impacts on human settlements, tourism, freshwater supplies, fisheries, exposed infrastructure, agricultural lands and wetlands, causing loss of land, economic losses and the displacement of tens of millions of people: It is currently estimated that about half of the world's population lives in coastal zones. Changes in climate will affect coastal systems through sea-level rise and an increase in storm-surge hazards and possible changes in the frequency and/or intensity of extreme events. Impacts may vary across regions, and societal costs will greatly depend upon the vulnerability of the coastal system and the economic situation of the country. Sea-level rise will increase the vulnerability of coastal populations to flooding. An average of about 50 million people per year currently experience flooding due to storm surges; a 50 cm sea-level rise could double this number. The estimates will be substantially higher if one incorporates population growth projections. A number of studies have shown that small islands and deltaic areas are particularly vulnerable to a one-meter sea-level rise. In the absence of mitigation actions (e.g., building sea walls), land losses are projected to range from 1.0% for Egypt, 6% for Netherlands, 17.5% for Bangladesh, to about 80% of the Marshall Islands, displacing tens of millions of people, and in the case of low-lying Small Island States, the possible loss of whole cultures **(figure 18)**. Many nations face lost capital value in excess of 10% of GDP. While annual adaptation/protection costs for most of these nations would be relatively modest (about 0.1% GDP), average annual costs to many small island states could be as high as several percent of GDP, assuming adaptation is possible.

Part III: Approaches to Mitigate Climate Change by Reducing Emissions and Enhancing Sinks

Significant reductions in net greenhouse gas emissions are technically, and economically, feasible: Cost-effective reductions in greenhouse gases can be achieved by utilizing an extensive array of technologies:

- *energy supply* -- more efficient conversion of fossil fuels; switching from high to low carbon fossil fuels; decarbonization of flue gases and fuels, coupled with carbon dioxide storage; increased use of modern renewable sources of energy (e.g., plantation biomass, micro-hydro, wind, and solar); and increasing the use of nuclear energy (subject to addressing safety, environmental and other concerns);
- *energy demand* -- industry, transportation, and residential/commercial buildings;
- *agricultural and forestry* -- afforestation, reforestation, slowing deforestation, improved forest, cropland and rangeland management, including restoration of degraded agricultural lands and rangelands, promoting agroforestry, and improving the quality of the diet of ruminants; and
- *waste management and reductions in halocarbon emissions.*

Policy instruments can be used to facilitate the penetration of lower carbon intensive technologies and modified consumption patterns. By the year 2100, the world's commercial energy system will be replaced at least twice because of the natural lifetime of energy systems offering opportunities to change the energy system without premature retirement of capital stock. However, full technical potential is rarely achieved because of a lack of information and cultural, institutional, legal and economic barriers. The optimum mix of policies to facilitate the penetration of lower carbon intensive technologies and encourage the efficient use of energy will vary from country to country as policies need to be tailored for local situations and developed through consultation with stakeholders. Policies include: energy pricing strategies (e.g., carbon taxes and reduced energy subsidies); reducing or removing subsidies that increase greenhouse gas emissions (e.g., agricultural and transport subsidies); internalization of environmental extranalities (e.g., incorporating the health costs associated with particulates caused by the combustion of coal into the price of coal); incentives such as provisions for accelerated depreciation and reduced costs for the consumer; domestic and international tradable emissions permits and joint implementation; voluntary programs and negotiated agreements with industry; utility demand-side management programs; regulatory programs including minimum energy efficiency standards; market pull and demonstration programs that stimulate the development and application of advanced technologies; and product labeling.

Energy services are critical to poverty alleviation and economic development: It is quite clear that increased energy services in developing countries are critical in order to alleviate poverty and underdevelopment, where 1.3 billion people live on less than $1 per day, 3 billion people live on less than $2 per day, and 2 billion people are without electricity. Hence the challenge is to assist developing countries expand their production and consumption of energy in the most efficient and environmentally benign manner.

Co-benefits can lower the cost of climate change mitigation: The long term challenge of stabilizing the atmospheric concentrations of greenhouse gas concentrations as required by Article 2 of the UNFCCC (Article 2) will eventually require global emissions of greenhouse gases to be significantly lower than today **(figure 19)**. **Figure 19** shows two different pathways for stabilizing carbon dioxide concentrations for each stabilization level between 450ppm and 750ppm and one for 1000ppm. The figure clearly shows that for any of these stabilization levels emissions must be lower than IS92a (often called the business-as-usual scenario) within the next few decades. Given the challenges of improving indoor and outdoor air quality in many parts of the world, and the goals to reduce acid deposition, land degradation and protect biodiversity, policies, practices and technologies that can simultaneously address these local and regional environmental issues, while reducing net greenhouse gas emissions are particularly attractive. Estimates of the costs of mitigating climate change should take into account the co-benefits of switching from a fossil fuel based economy to a lower-carbon intensity energy system. Co-benefits from energy sector interventions could include lower levels of local and regional pollution, including particulates, surface ozone and acid rain. Such interventions would have both social and economic benefits. **Figures 20 and 21**, respectively, show the high levels of pollution in many developing country cities and the health costs associated with total suspended particulates in China. Co-benefits from the agricultural and forestry sector could include increased soil fertility and reduced loss of biodiversity.

Significant reductions in greenhouse gases can be accomplished by pursuing sustainable development goals. A future world with greenhouse gas emissions comparable to those of today can either be achieved through the adoption of specific polices, practices and technologies to limit greenhouse gas emissions or, as

shown in **figure 8**, through the adoption of a range of policies, practices and technologies to achieve other sustainable development goals (SRES). It should be noted that a major oil company, Shell, has suggested that the mix of energy sources could change radically during the next century. Non-fossil energy sources (solar, wind, modern biomass, hydropower, geothermal and nuclear) could account for as much as half of all energy produced by the middle of this century **(figure 22)**. Such a future would be consistent with the lower projections of greenhouse gas emissions and would clearly eliminate the highest projections of greenhouse gases from being realized. However, an energy efficient and low-carbon energy world is considered by many to be unlikely to occur without significant policy reform, technology transfer, capacity-building and enhanced public and private sector energy R&D programs.

Technology transfer is a critical issue: The recent IPCC Special Report on Methodological and Technological Issues in Technology Transfer examined the flows of knowledge, experience and equipment among governments, private sector entities, financial institutions, NGOs, and research and education institutions, and the different roles that each of these stakeholders can play in facilitating the transfer of technologies to address climate change in the context of sustainable development. The report concluded that the current efforts and established processes, i.e., business-as-usual, will not be sufficient to meet this challenge. The report concluded that enhanced capacity is required in developing countries and that additional government actions can create the enabling environment for private sector technology transfers within and across national boundaries. Government actions could include, inter-alia, reforming legal systems, protecting intellectual property rights and licenses, encouraging financial reforms, promoting competitive and open markets for environmentally sound technologies, and knowledge sharing. Mechanisms for technology transfer include National Systems of Innovation, Official Development Assistance, the Global Environmental Facility, Multilateral Banks and the Kyoto Protocol Mechanisms (Clean Development Mechanism) and the UNFCCC.

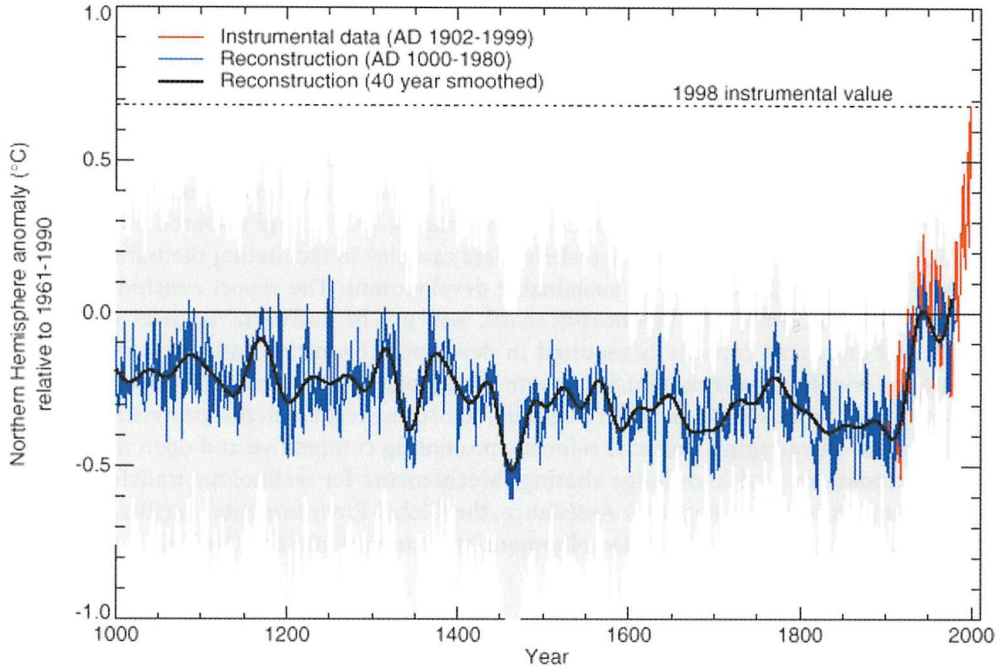
Summary

Without action to limit greenhouse gas emissions the Earth's climate will warm at a rate unprecedented in the last 10,000 years: If actions are not taken to reduce the projected increase in greenhouse gas emissions, the Earth's climate is projected to change at a rate unprecedented in the last 10,000 years with adverse consequences for society, undermining the very foundation of sustainable development.

Policymakers are faced with responding to the risks posed by anthropogenic emissions of greenhouse gases in the face of significant scientific uncertainties. They may want to consider these uncertainties in the context that climate-induced environmental changes cannot be reversed quickly, if at all, due to the long time scales (decades to millennia) associated with the climate system. Decisions taken during the next few years may limit the range of possible policy options in the future because high near-term emissions would require deeper reductions in the future to meet any given target concentration. Delaying action would increase both the rate and the eventual magnitude of climate change, and hence adaptation and damage costs.

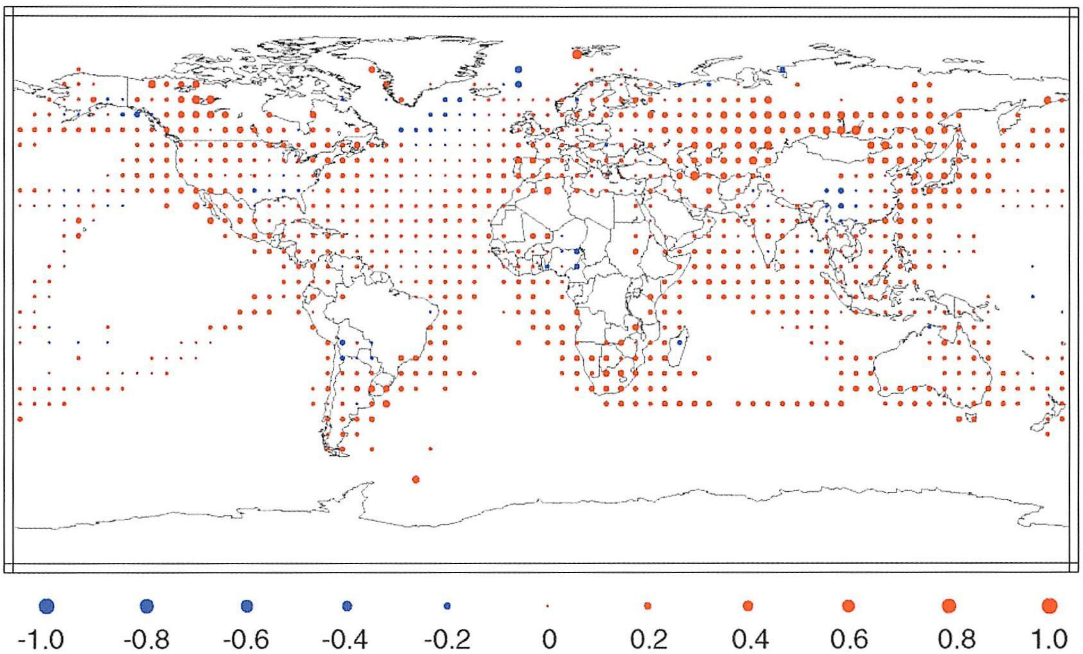
Policymakers will have to decide to what degree they want to take precautionary measures to limit anthropogenic climate change by mitigating greenhouse gas emissions and enhancing the resilience of vulnerable systems by means of adaptation. Uncertainty does not mean that a nation or the world community cannot position itself better to cope with the broad range of possible climate changes or protect against potentially costly future outcomes. Delaying such measures may leave a nation or the world poorly prepared to deal with adverse changes and may increase the possibility of irreversible or very costly consequences. Options for mitigating change or adapting to change that can be justified for other reasons today and make society more flexible or resilient to anticipated adverse effects of climate change appear particularly desirable.

Figure 1: Millennial Northern Hemisphere (NH) Temperature Reconstruction (blue) and Instrumental Data (red) from AD 1000-1999



Source: Mann et al. 1999.

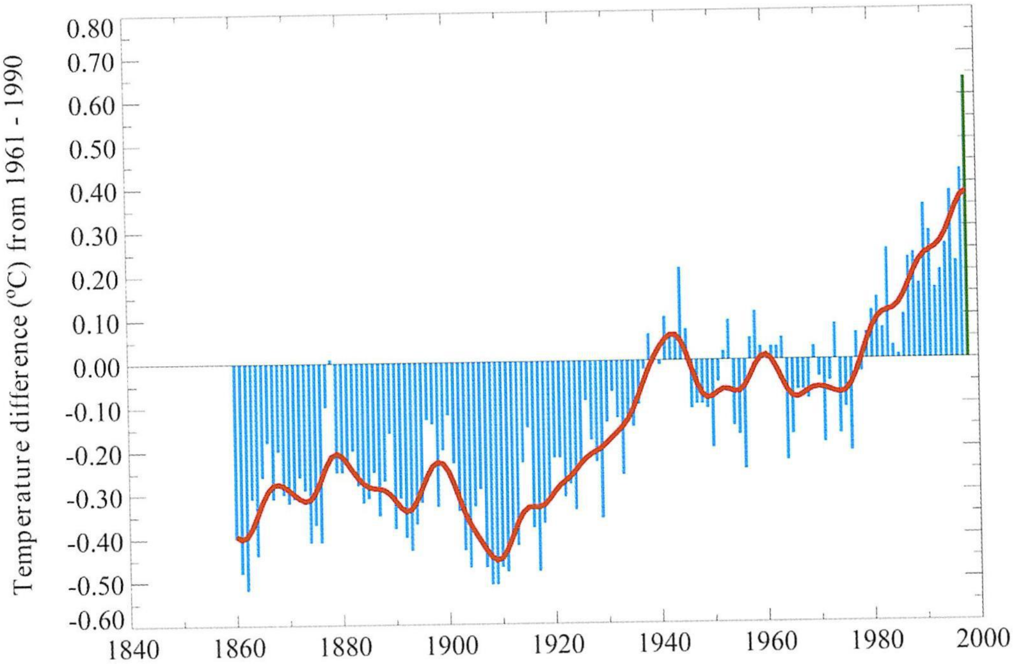
Figure 2: Annual Temperature Trends, (°C / century) 1901-1999



Source: P. Jones, et. al. 2000.

Figure 3: Global Observed Temperatures

Combined global land, air, and sea surface temperatures 1860 to August 1998 (relative to 1961–1990 average)



Source: The U.K. Meteorological Office. 1997. *Climate Change and Its Impacts: A Global Perspective.*

Figure 4: Precipitation Trends (%) per Decade (1900-1994)

Green = increasing / Brown = decreasing

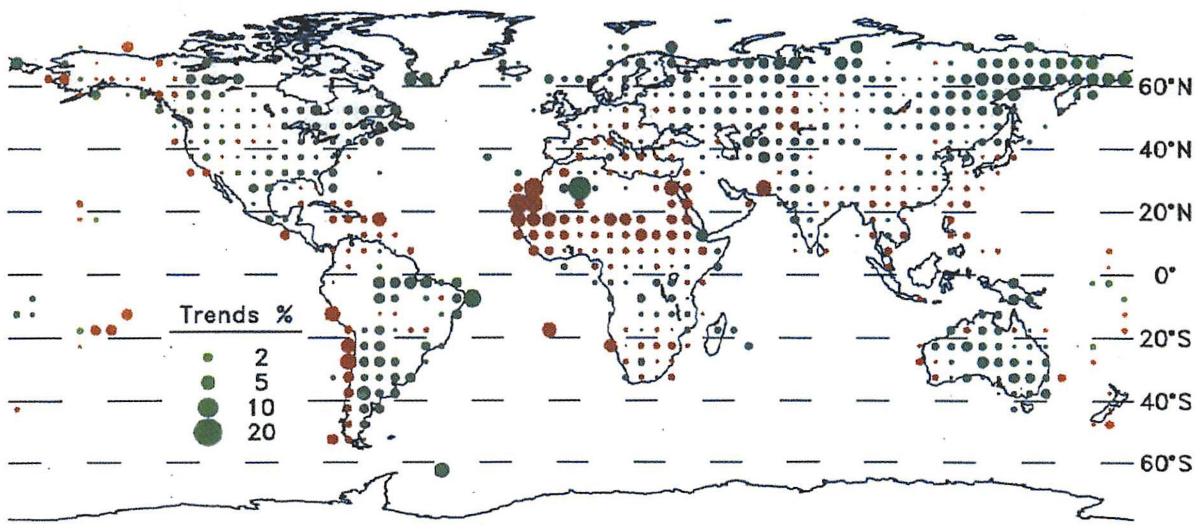


Figure 5: Concentration of Carbon Dioxide and Methane Have Risen Greatly Since Pre-Industrial Times

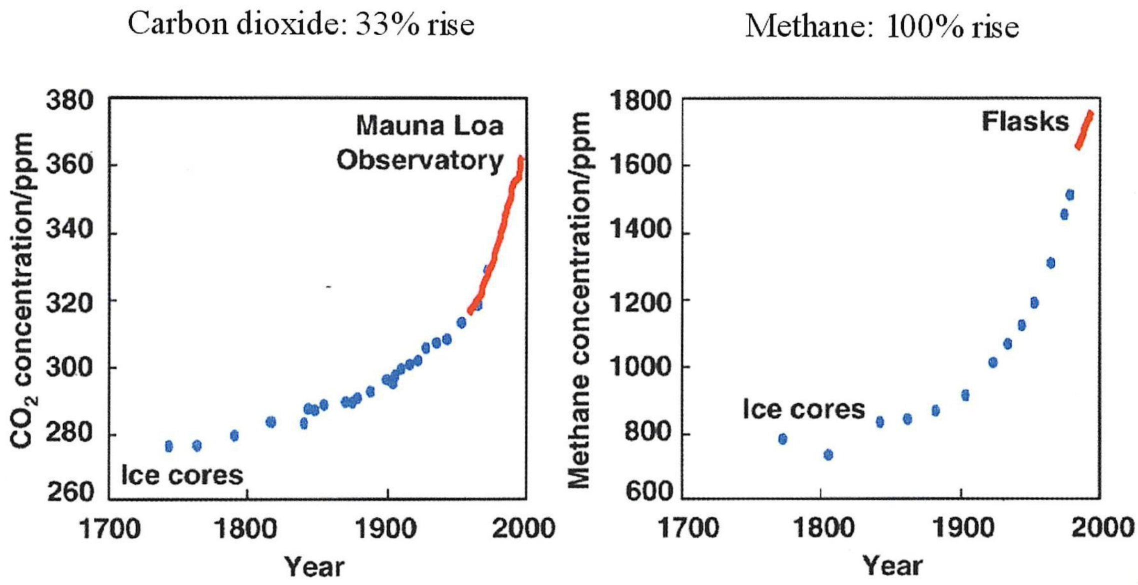


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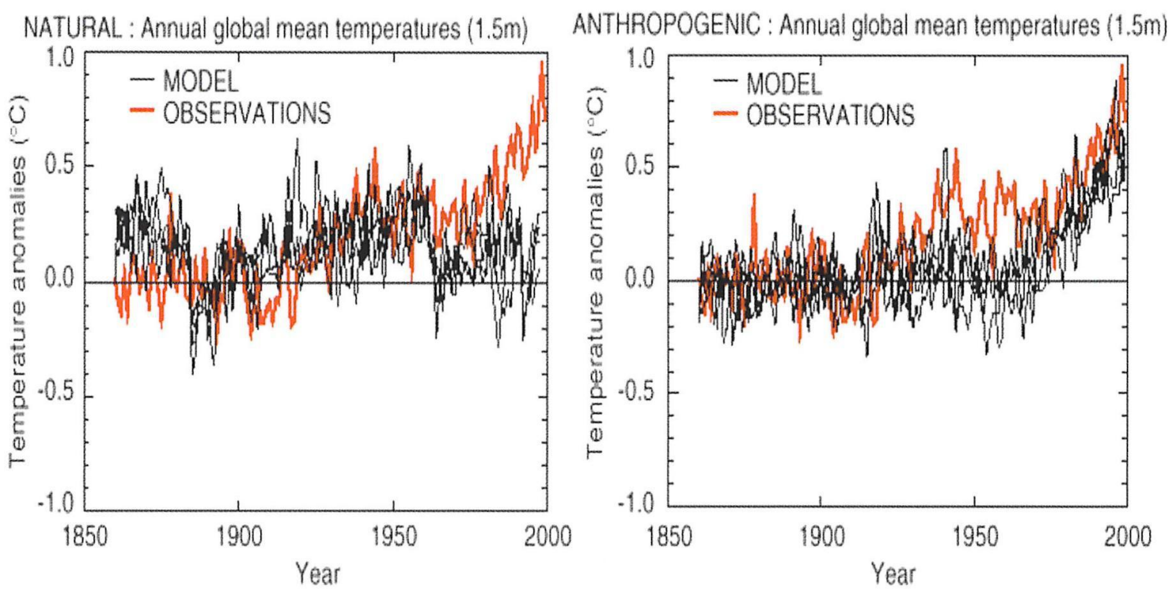
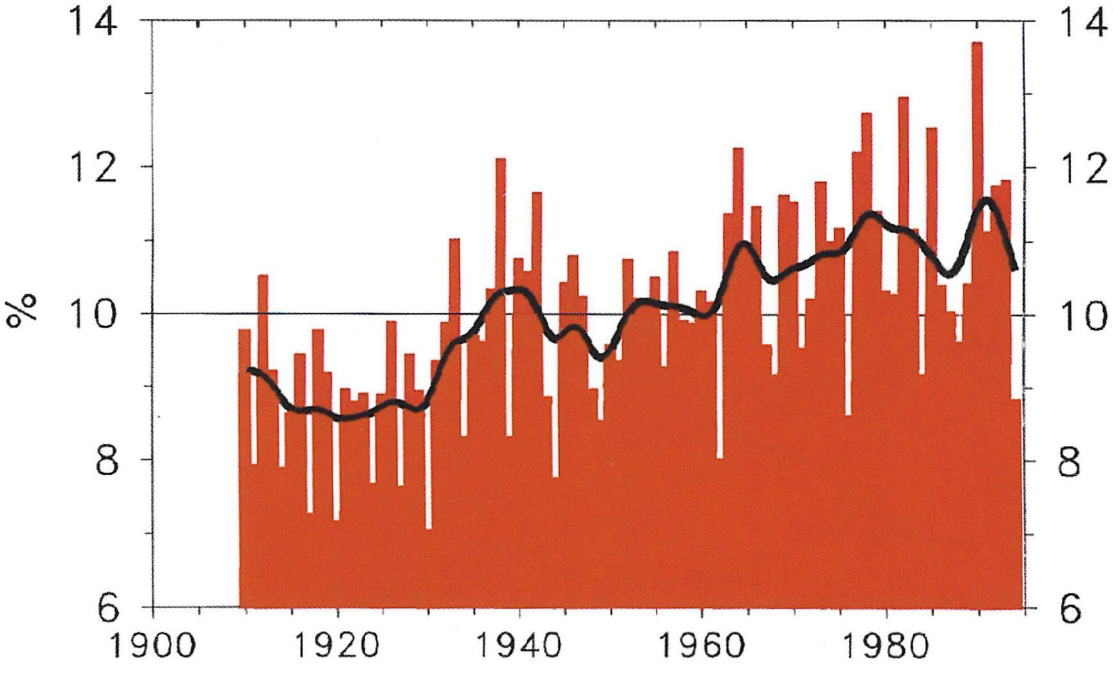
Figure 6: Comparison of Temperature Observations and Model Simulations



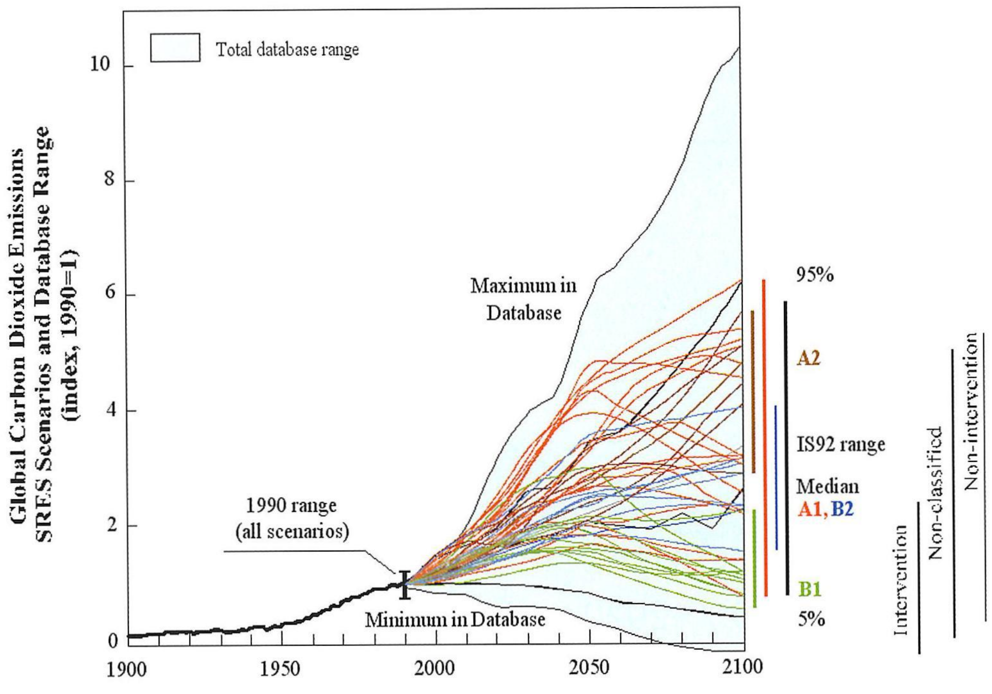
Source: Tett, et.al., 1999.

Figure 7: Percent of the Continental U.S. with A Much Above Normal Proportion of Total Annual Precipitation from 1-day Extreme Events (more than 2 inches or 50.8mm)



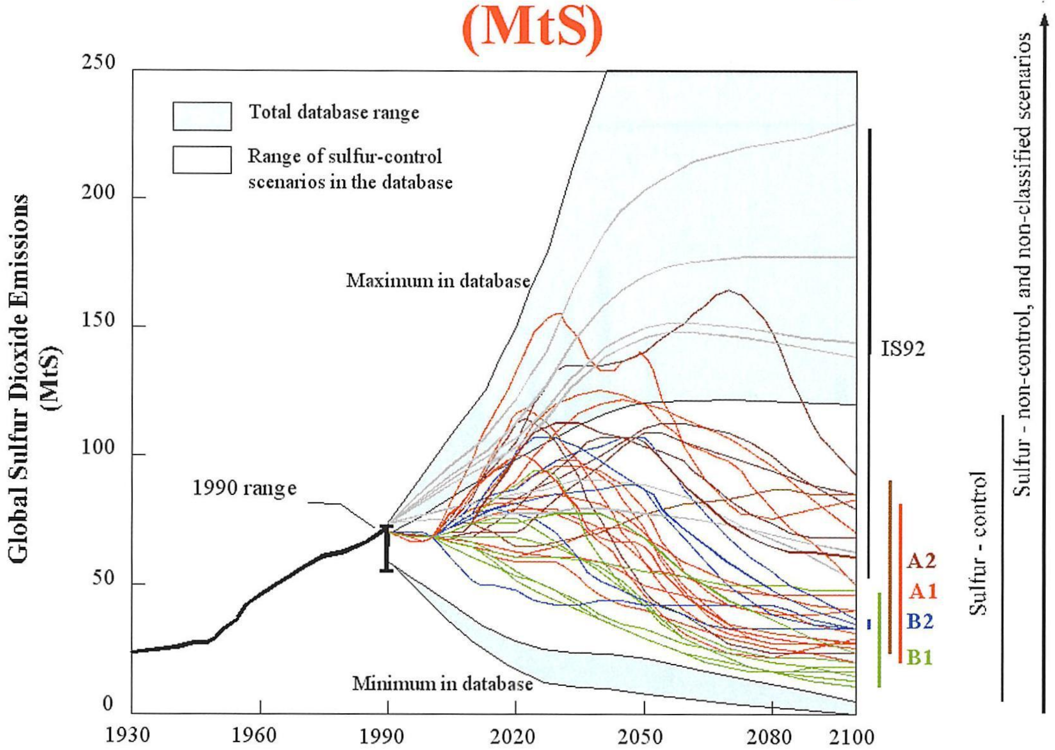
Source: Karl, et.al. 1996.

Figure 8: Global CO_2 Emissions from Energy & Industry



Source: IPCC. 2000. *Emissions Scenarios. Working Group III.* Cambridge.

Figure 9: Global Anthropogenic SO_2 Emissions (MtS)



Source: IPCC. 2000. *Emissions Scenarios. Working Group III*. Cambridge.

Figure 10: Projected Change in Global Mean Surface Temperature from Models using the SRES Emissions Scenarios

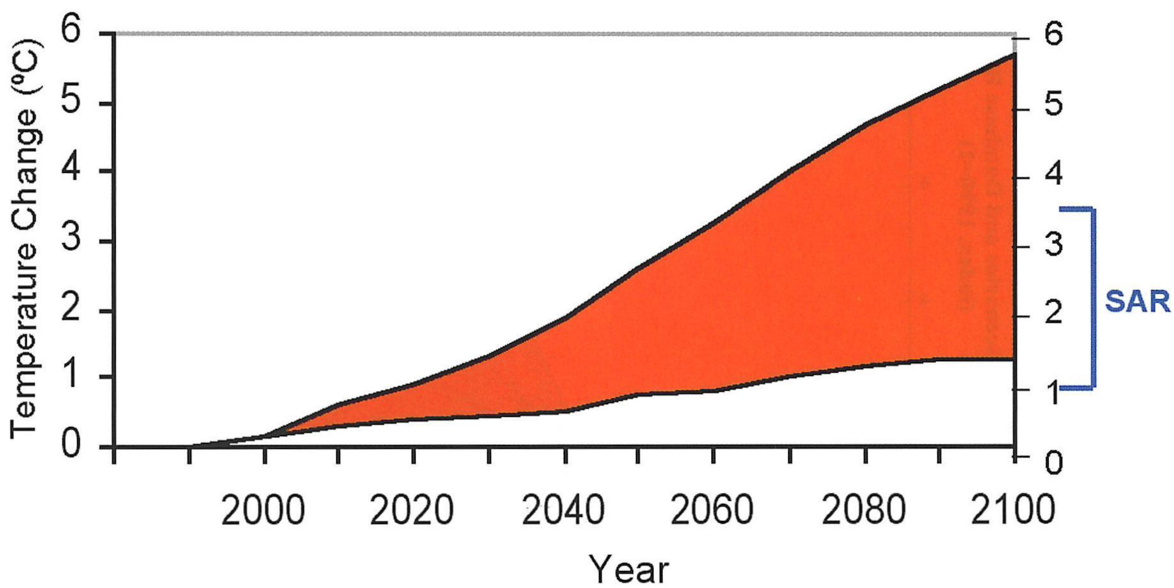
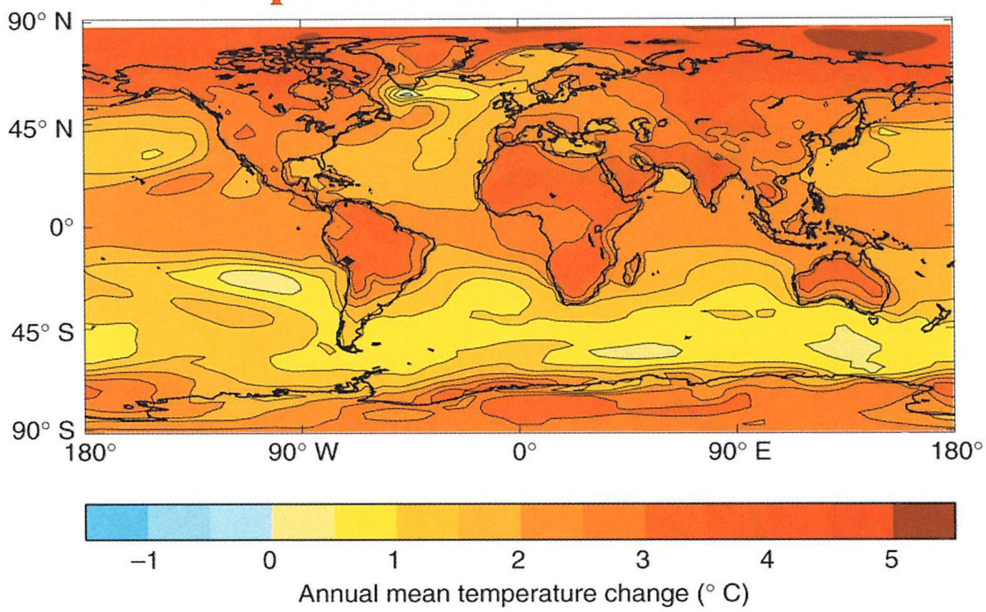


Figure 11: Projected Changes in Annual Temperatures for the 2050s



The projected change in annual temperatures for the 2050s compared with the present day, when the climate model is driven with an increase in greenhouse gas concentrations equivalent to about a 1% increase per year in CO_2.

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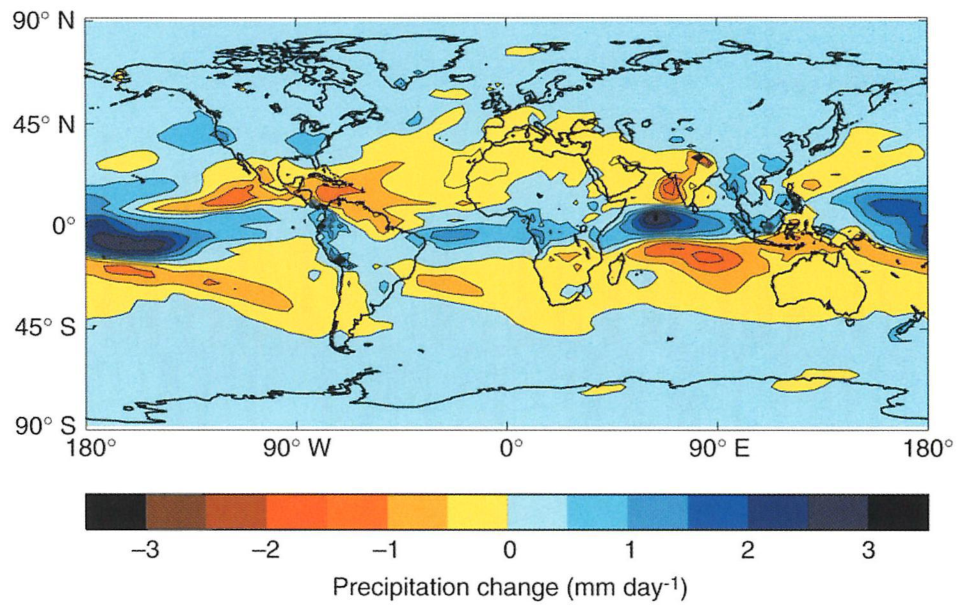
Figure 12: Projected Changes in Annual Precipitation for the 2050s



The projected change in annual precipitation for the 2050s compared with the present day, when the climate model is driven with an increase in greenhouse gas concentrations equivalent to about a 1% increase per year in CO_2.

The Met Office - Hadley Centre for Climate Prediction and Research.

Figure 13: Sea Level Rise Commitment

Thermal expansion and land ice melt after an initial 1% increase in CO_2 for 70 years

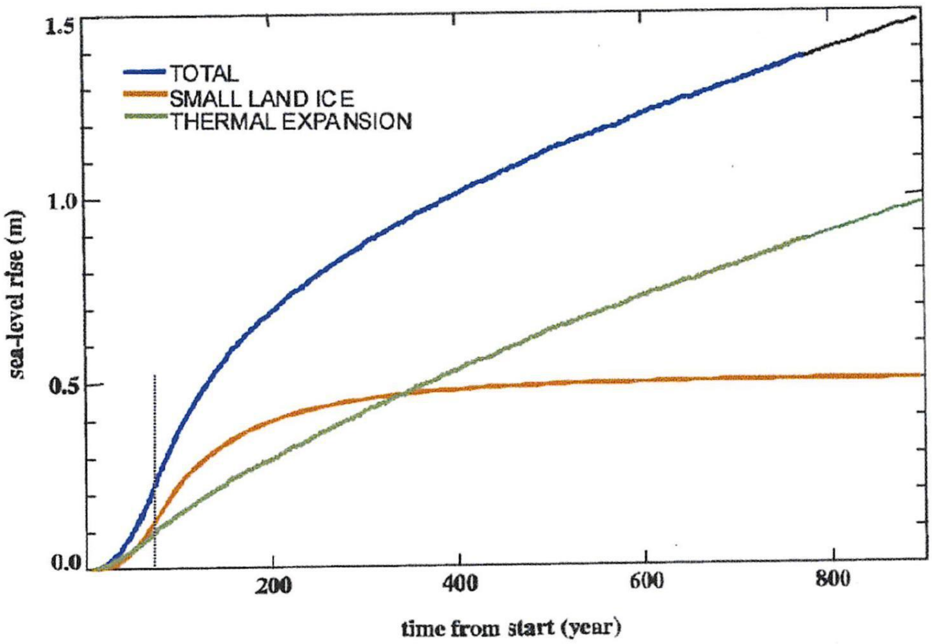


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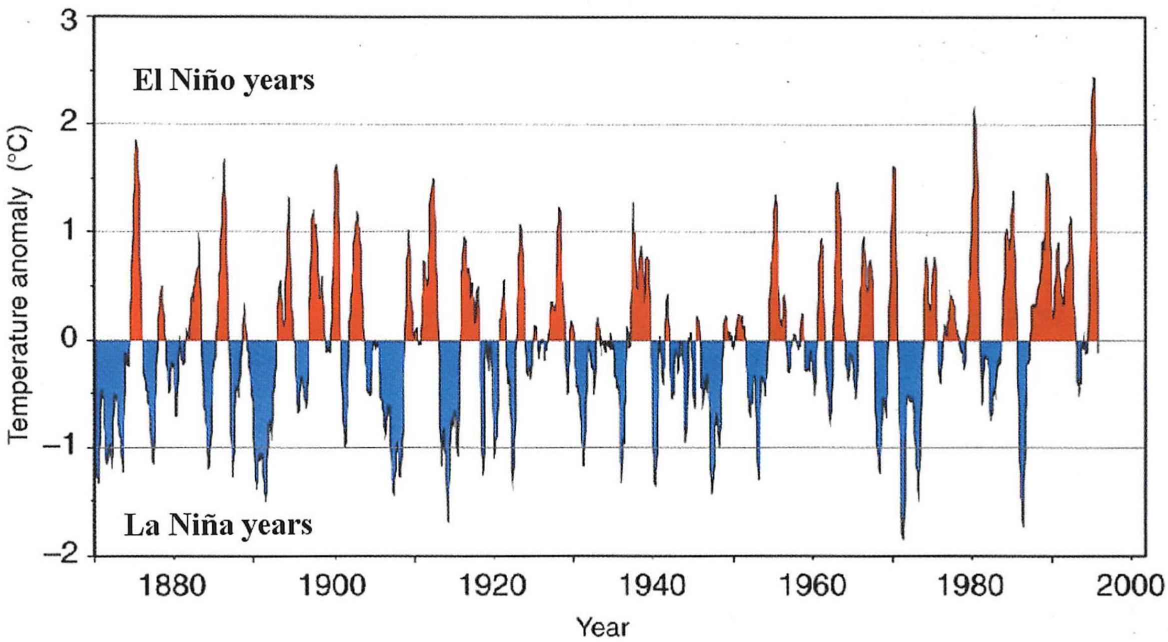
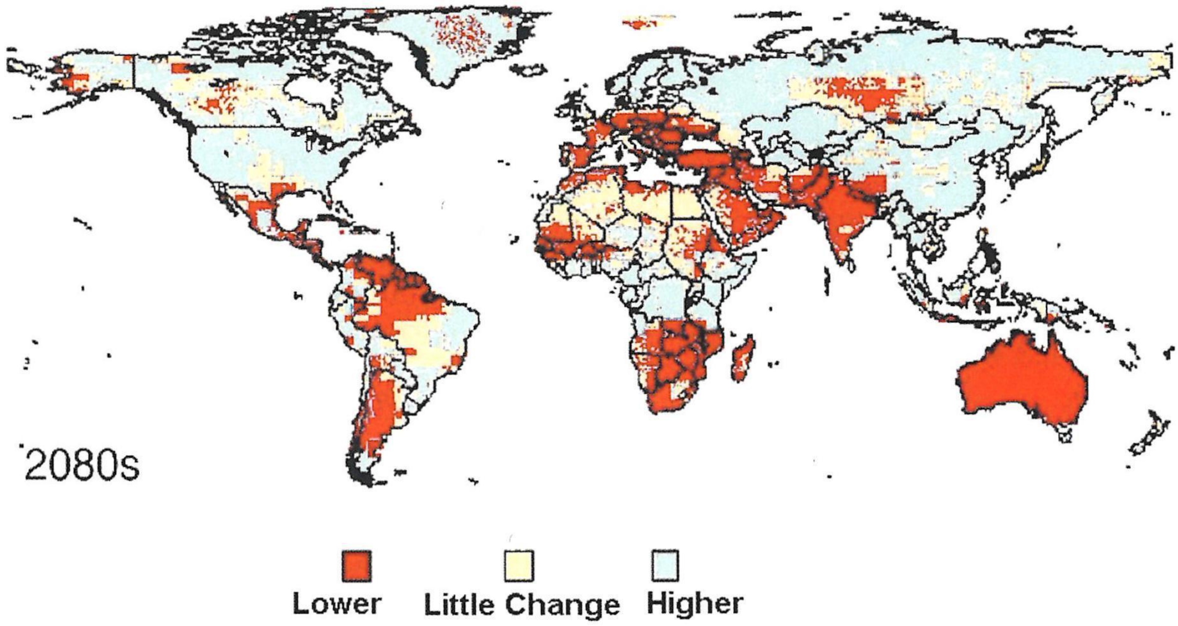
Figure 14: The 1997/98 El Niño Strongest on Record*



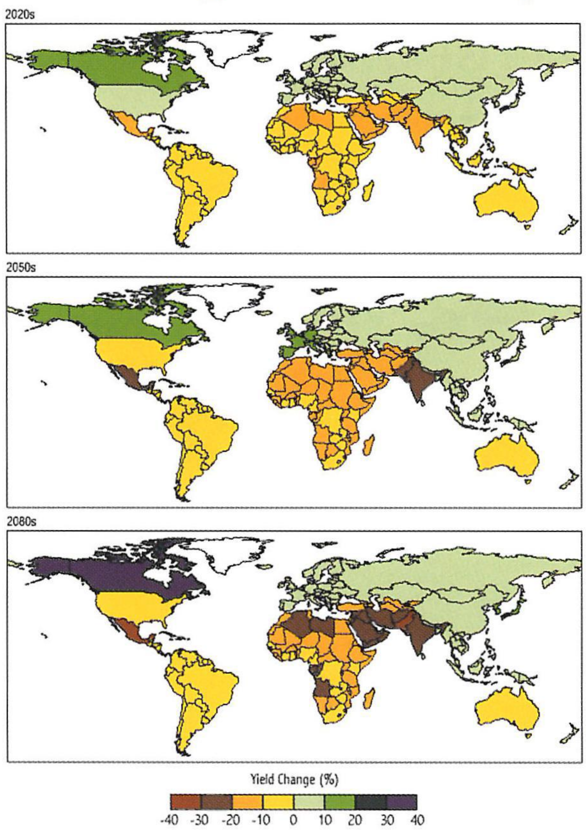
*As shown by changes in sea-surface temperature (relative to the 1961-1990 average) for the eastern tropical Pacific off Peru

Figure 15: Annual Runoff



Percentage change in 30-year average annual runoff by the 2080s.
University of Southampton.

Figure 16: Crop Yield Change



Percentage change in average crop yields for the climate change scenario. Effects of CO_2 are taken into account. Crops modeled are: wheat, maize and rice.

Jackson Institute, University College London / Goddard Institute for Space Studies / International Institute for Applied Systems Analysis

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Figure 17: Vector (insect)-borne Diseases

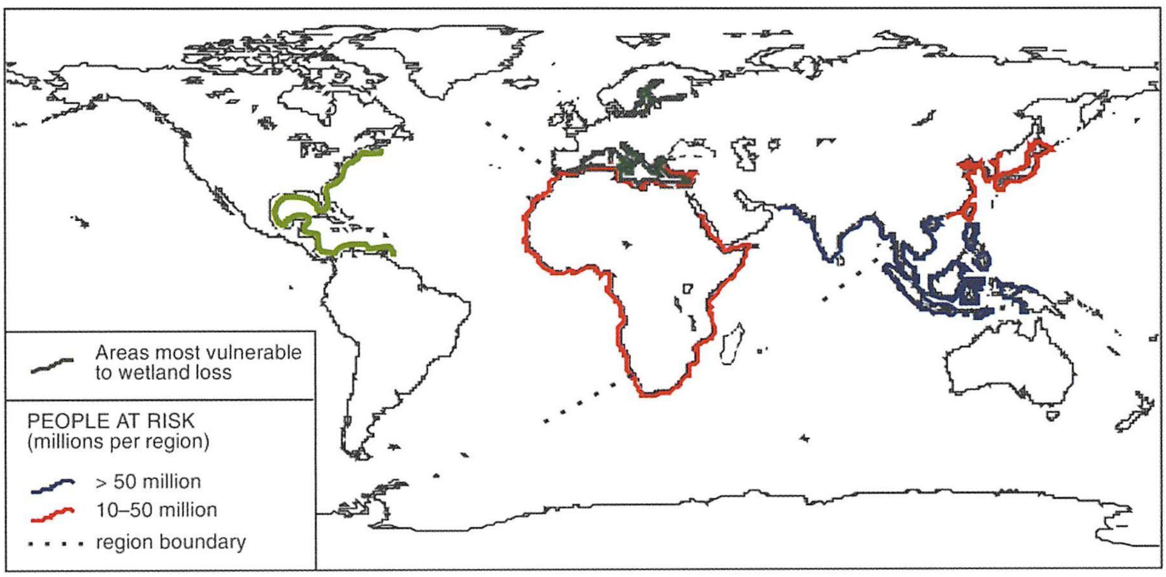
Disease	*Vector*	*Population at risk (millions)*	*Present distribution*	*Likelihood of altered distribution with warming*
Malaria	mosquito	2,100	(sub)tropics	✓✓
Schistosomiasis	water snail	600	(sub)tropics	✓✓
Filariasis	mosquito	900	(sub)tropics	✓
Onchocerciasis (river blindness)	black fly	90	Africa/Latin America	✓
African trypanosomiasis (sleeping sickness)	tsetse fly	50	tropical Africa	✓
Dengue	mosquito	unavailable	tropics	✓✓
Yellow fever	mosquito	unavailable	tropical South America & Africa	✓

Likely ✓
Very likely ✓✓

Source: Modified WHO, as cited in Stone (1995).

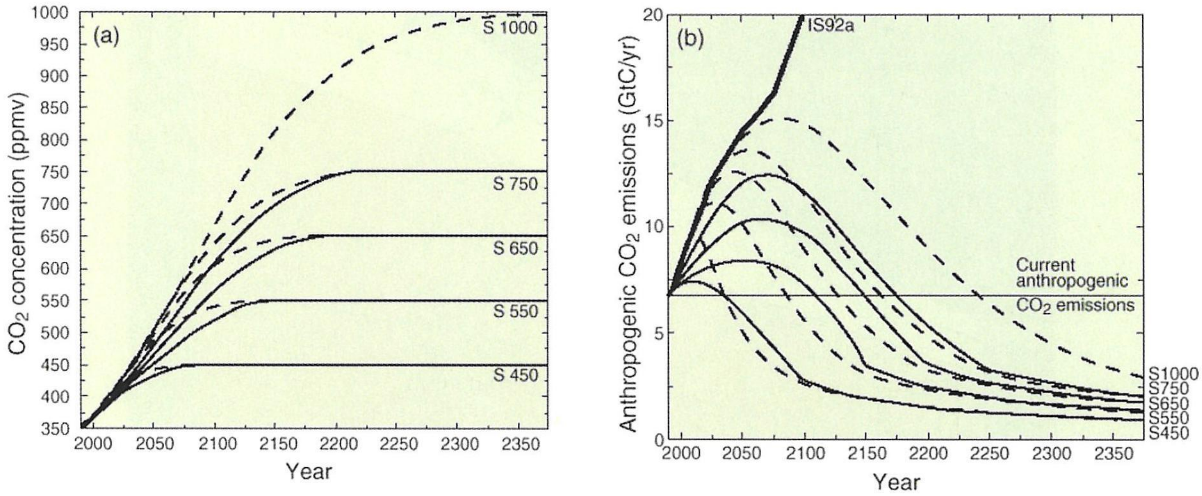
Figure 18: People at Risk from a 44 cm sea-level rise by the 2080s

Assuming 1990s Level of Flood Protection



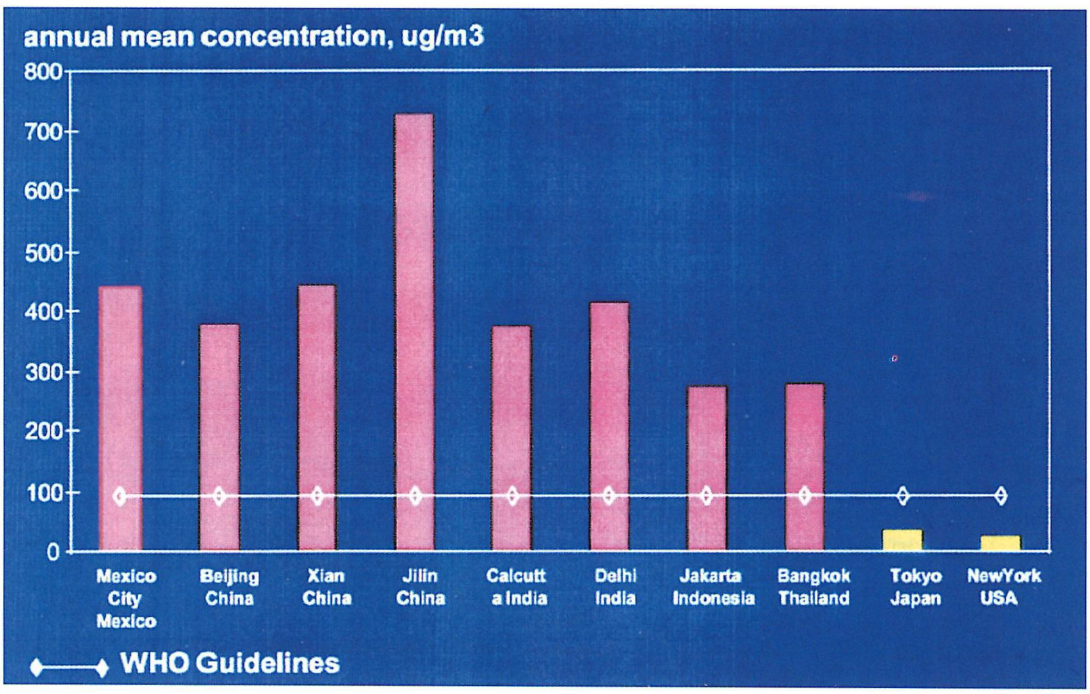
Source: R. Nicholls, Middlesex University in the U.K. Meteorological Office. 1997. *Climate Change and Its Impacts: A Global Perspective.*

Figure 19: Energy Emission Pathways and Stabilization Concentrations



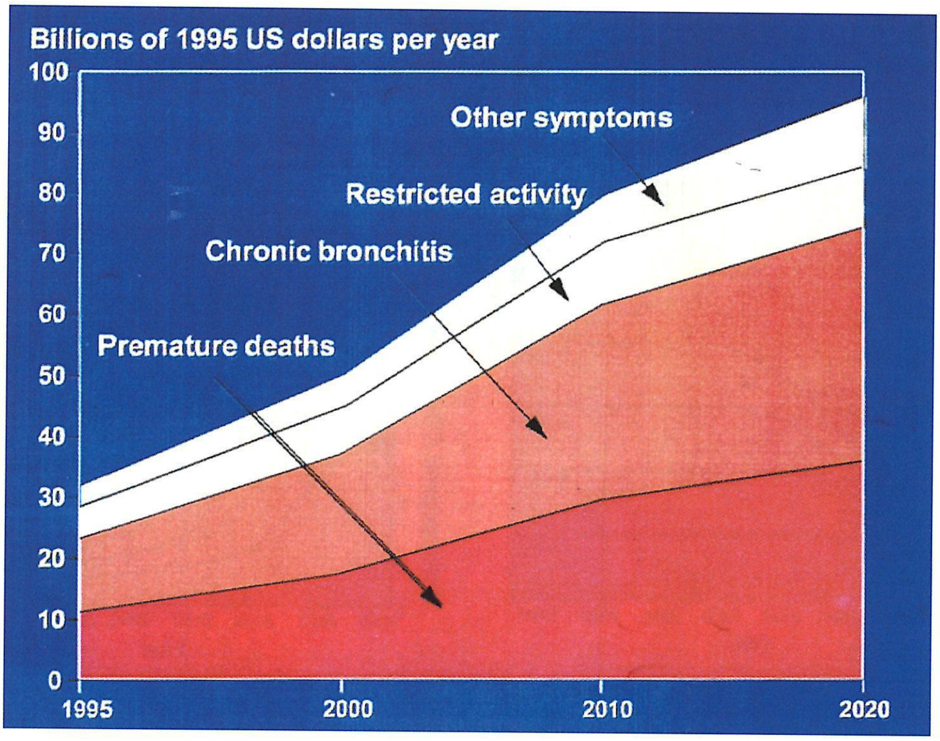
Source: IPCC. 1995. *Second Assessment Report. Working Group I*. Cambridge.

Figure 20: Pollution in Selected Cities (TSP)



Source: OECD Environmental data 1995; WRI China tables 1995; Central Pollution Control Board, Delhi. "Ambient Air Quality Status and Statistics, 1993 and 1994"; Urban Air Pollution in Megacities of the World, WHO/UNEP, 1992; EPA, AIRS database.

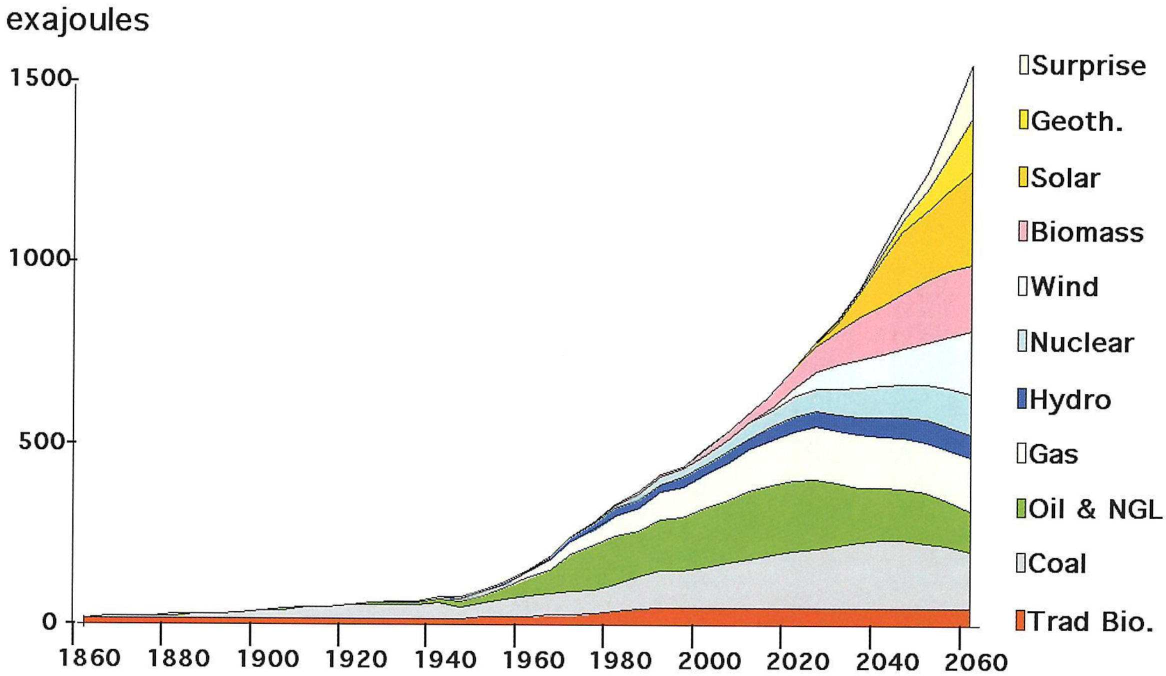
Figure 21: Health Costs (TSP in China)



Source: Clear Water, Blue Skies; China's Environment in the New Century, World Bank, 1997.

Figure 22: Energy Supply

Sustained Growth Scenario



Source: Shell International Limited.