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Review

Global warming and climate change: Realities, uncertainties and measures

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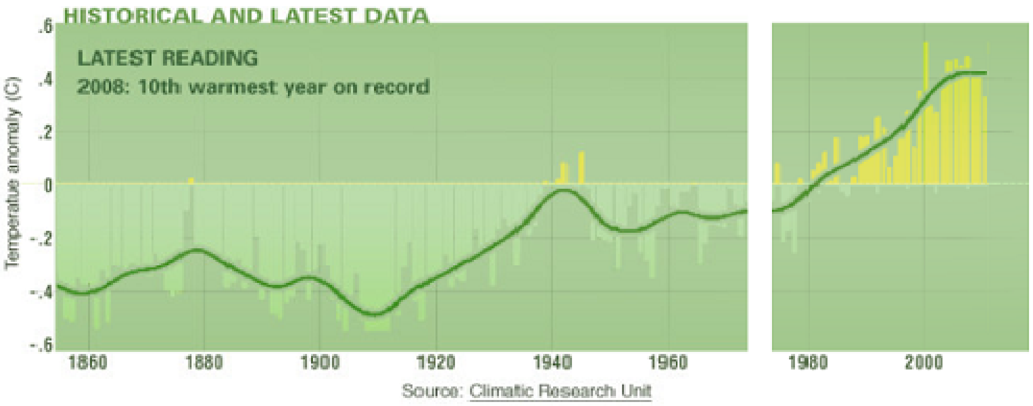
This paper is an attempt to show that global warming and climate change are real, and are greatly affecting the biosphere. Evidences suggesting that the increasing concentration of atmospheric greenhouse gases due to human activities is mainly responsible for global warming and climate change are presented. Uncertainties about the future course of global warming and climate change centred on the role of two important mechanisms, forcings and feedback processes, and their influence on earth's surface temperature are also discussed. Suitable and innovative geo-engineering measures that could make effective and efficient use of the scarce resources and maximize returns from the resources invested to limit the emissions of greenhouse gases are evaluated. Preferred actions to control and stabilize global warming and climate change which can be widely applied to reorient economic developmental policies in developing countries are examined.

Key words: Global warming, climate change, greenhouse gases, uncertainties, feedback mechanisms, measures.

INTRODUCTION

The exponential increase in surface temperature of the earth and the global sea level in the last few decades is a major aspect of climate change that has attracted both researchers and policy makers in recent times. The earth's atmosphere creates natural greenhouse effect which keeps the earth's surface warmer than it would have been otherwise. Life is an integral part of the earth system and all living things influence the composition of greenhouse gases in the atmosphere by "inhaling" and "exhaling" carbon dioxide and oxygen, thereby maintaining a chemical balance in the atmosphere. A range of human activities, which include majorly the burning of fossil fuels, industrial activities and the cutting down of forest for agricultural purposes and urbanization, are substantially increasing the concentrations of greenhouse gases in the atmosphere, thereby upsetting this atmospheric chemical balance. The details of our complex climate systems are not sufficiently known to enable us predict the exact consequences of the increasing greenhouse gases on global temperature in particular and climate change in general. Our ability to accurately quantify human influence on global climate change is therefore limited; the expected signals are still emerging from the noise of natural climate variability and uncertainties. These include the magnitudes and patterns of long term natural variability and the time-evolving patterns; and responses to changes in the concentrations of greenhouse gases and aerosols, and land surface changes.

However, not everyone agrees that the surface temperature of the earth is on the increase, and if global warming is real, not all accept the fact that human activities are mainly responsible to it. Also, not all accept that climate change is bad. Thus, sceptics and opponents of global warming do not see the need to take measures to slow down or reverse global warming and climate change. Some have argued that such actions to curb global warming and climate change are too premature and are not cost effective. An international environmental treaty, called Kyoto Protocol, linked to the United Nation Framework Convention on Climate Change (UNFCCC) mandated the governments of industrialized nations to take appropriate measures that would control and stabilize global warming by reducing greenhouse gas emissions to a level that would prevent dangerous anthropogenic interference with the climate systems. But this accord, which was adopted in Kyoto, Japan on December 11, 1997 and entered into force on February 16



Source: Climatic Research Unit

Figure 1. Global mean annual temperature obtained by combining air temperature measured at weather stations on continents and sea temperature measured along ship tracks on the oceans. This time series is the direct, instrumental record of global warming from 1850 to 2008; the year 2007 was the eight warmest year on record, exceeded by 2005, 2003, 2002, 2004, 2006, 2001 and 1998 (Climate Research Unit, 2009).

16, 2005, has been largely contested by opponents. The increasing energy demand by the growing population, the need for economic growth and improved standard of living in the developing countries, lack of political will and institutional weakness to make and implement appropriate environmental policies, as well as lack of related information and misinformation are the major factors that have militated against measures to reduce greenhouse gases emissions and mitigate the effects of climate change.

What then should we do? Should we all pretend that all is well with our "beloved planet Earth", and that global warming and climate change does not matter much? Should we seek for greater knowledge of our complex climate system and more evidence of global warming? Should we continue to do "business as usual" by emitting more greenhouse gases into the atmosphere or should we evolve possible mitigation measures to combat the adverse effects of global warming and maintain stability in the climate? This paper attempts to show that global warming in particular and climate change in general are real, and are greatly affecting the biosphere. Evidences suggesting that increasing atmospheric greenhouse gases concentrations due to human activities on earth is mainly responsible for global warming and climate change are presented. Uncertainties about the future course of global warming and climate change centred on the role of two important forcings and feedback mechanisms, and their influence on surface temperature are also discussed. Suitable and innovative measures that would make effective and efficient use of the scarce resources and maximize returns from the resources invested to limit the emissions of greenhouse gases are evaluated. Preferred actions to solving the problems and effects of global warming and climate change, which can be widely applied to reorient economic developmental policies in developing countries, are examined.

EVIDENCES OF GLOBAL WARMING FROM INDEPENDENT MEASUREMENTS

Results from the analysis of three independent sets of observations namely, surface air temperature measurements, sea level changes and temperature profiles in boreholes all shows that the surface temperature of the earth is on the increase there by warming up the globe. Results obtained from each of these sets of observations confirm and complement each other. In addition, images from satellite observations of the earth surface and lower atmosphere reveals details of the effects of the increasing concentration of greenhouse gases on global warming and climate system.

Surface temperature

Analysis of the routine measurements of the earth's surface temperature reported daily from thousands of weather stations across the globe, both on land and at sea, suggests that the surface of the earth has warmed by an average of 1.0℃ (1.8℉) in the last 100 years (IPCC, 2007a). The daily temperature measurements are combined to produce mean weekly, monthly and annually temperatures. Thus, the averaged annual temperature change from year to year can easily be tracked. The mean annual temperature measurement for a period of over 150 years (from 1850 to 2008) is shown in Figure 1. Measurements of air temperature made at weather stations were integrated with measurements of sea temperature to produce mean annual temperature for the entire globe. The graph shows a gradual increase in temperature

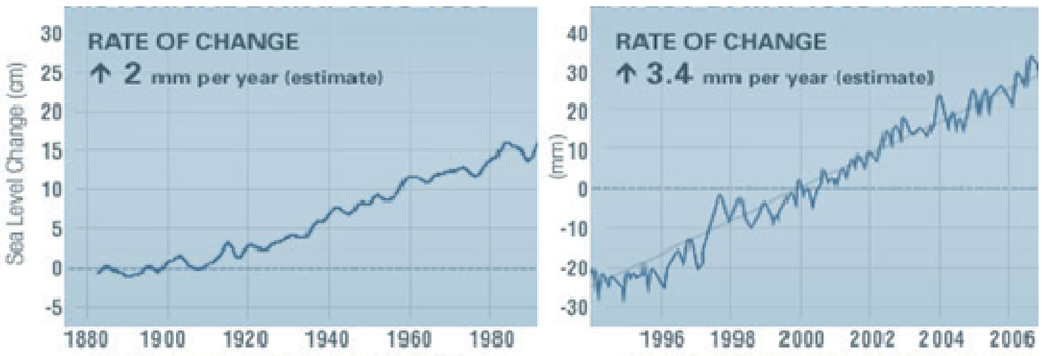


Figure 2. Mean annual sea level rise associated with the thermal expansion of sea water due to warming and widespread melting of ice sheets. Left chart: Historical sea level data derived from 23 tide-gauge measurements. Right chart: Average sea level since 1993 derived from global satellite measurements (NASA, 2009).

with a minimum anomaly of about -0.5°C to a maximum of about +0.5°C. The graph indicates a steady increase in surface temperature between 1860 and 1910 and a rapid increase between 1910 and 1945, stabilizing for about 3 decades and increasing rapidly again after 1975.

In the last two decades, the global mean temperature has increased by 0.1°C per decade, with 2005 being the warmest year on record (NASA, 2005; 2009). Statistical methods are used to close the gaps in the measurements. The effects of large population centres on the global mean temperature, called "urban heat island effect" are computed and corrected for; however, this account for less than 15% of the observed global warming. Global warming is not uniform across the globe, both in time and in space; high latitude regions generally experience more warming than low latitude regions (Hinzman et al., 2005). All regions of the earth have experienced years of cooler temperature imbedded within the warming trend. The observed spatial and temporal irregularity in global warming is an indication of a chaotic nature of global warming and climate change.

Sea level rise

Another pointer to global warming and climate change comes from a completely independent set of observations (the measurements of sea level changes). The volume of water in the oceans is increasing due to thermal expansion of water in the oceans, and the melting of glacier and polar ice, resulting from increasing warming of the earth. As in temperature measurements, daily sea level observations are made at many locations; daily sea level fluctuations, mainly due to tides and storms, are averaged out to obtain mean sea level over a given period of time. The mean annual sea level change between 1880 and 2008 is shown in Figure 2. The mean sea level rose by about 18 cm in the last century (IPCC Report, 2007b); it rose by an estimated average of 2 mm per annum between 1880 and 1990 (left chart in Figure 2) and is currently rising at the rate of about 3.4 mm per annum (right chart in Figure 2). Like global temperature changes, sea level changes are not steady and the detailed changes are not exactly synchronous with surface temperature measurements. The thermal expansion of the water column tends to come later than the corresponding change in surface temperature; the differences are affected by ocean currents. The observed irregularity in sea level changes is another indication of the complexity and chaotic character of the interactions being witnessed by our planet resulting in climate change.

Borehole temperature profile

A third confirmation of global warming and climate change comes from an unlikely source – the thermal history of the earth's subsurface. The subsurface retains records of temperature changes over a period of time that can be linked to the prevailing climatic conditions about the time. This geothermal history can be accessed by measuring temperature profiles with depth in boreholes, tunnels and deep mines using sensitive thermometers. Expected temperature increase due to the upward flow of heat from the earth's interior, heat generated by crustal rocks, temperature anomalies due to geological features and fluctuations in groundwater movement are usually corrected for. The downward propagation of surface temperature oscillation attenuates with depth, with short period fluctuations attenuating more rapidly than longer ones. Thus, only long period variations of heat penetrate great depths, with seasonal variations penetrating about 15 m before the signals eventually die out. In contrast to seasonal variations, century long variations can penetrate to depths of about 150 m and millennial cycles can be observed to a depth of about 500 m or more. These depths can easily be achieved by inexpensive drilling. The

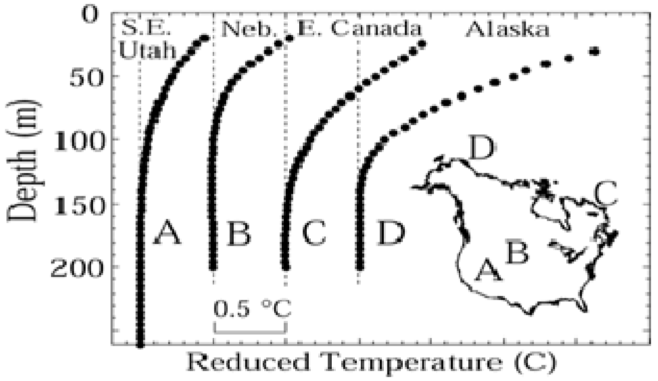


Figure 3. Borehole temperature profiles from sites in North America showing warmer temperatures within near-surface depths of 100-150 metres. The temperature profiles suggest substantial warming in the last century from 0.6 ˚C in southeast Utah to more than 2.0 ˚C in Alaska. Curves are arbitrarily offset for display purposes (after Chapman and Davis, 2007).

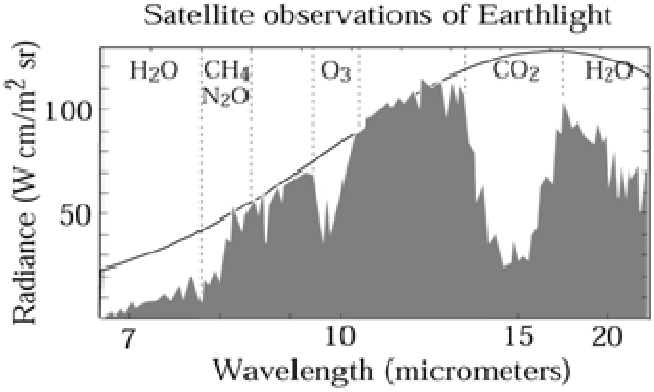


Figure 4. Earthlight confirms greenhouse effect; thermal radiation emitted from the earth's surface as observed by satellite instrument looking down the earth (irregular line). In the absence of greenhouse effect, the radiance would follow the solid smooth curve (Houghton, 1997).

inexpensive drilling. The subsurface acts like a selective filter which discriminates against short period temperature variations, thereby retaining excellent records of global warming and hence climate change.

Figure 3 shows evidence of surface temperature changes from the analysis of several geothermal data sets from North America. The temperature profiles of boreholes spread across a length of about 500 km of northern Alaska shows anomalous warming of 2 to 5℃ in the upper 100 to 150 m of the permafrost and rocks (Lanchenbruch and Marshall, 1986). Similarly, borehole temperature profiles in eastern Canada (Nielsen and Beck, 1989; Wang and Lewis, 1992) shows a less rapid warming of about 1.0℃. A warming of about 0.5 and 1.0℃ are observed in Nebraska sites (Deming and Bore, 1993) and Utah sites (Harris and Chapman, 1995), respectively. These results clearly show that geothermal data mimicked the geographic variations of warming as observed in weather stations data. Past centuries baseline temperature can be inferred from geothermal data, thus making it possible to connect the beginning of the industrial revolution to the present century and thereby access the impact of industrialization on global warming and climate change.

SATELLITES OBSERVATIONS OF EARTHLIGHTS

The solar radiation from the sun is balanced by the thermal radiations emanating from the earth; this energy balance determines the surface temperature of the earth. The incoming solar radiation depends on the solar output and the distance between the sun and the earth, and is independent of the surface temperature of the earth. On the other hand, the outgoing thermal radiation from the earth strongly depends on the earth's surface temperature. If the atmosphere was composed only of nitrogen and oxygen molecules, which do not absorb thermal radiation, the surface temperature of the earth would be controlled to about -6℃ by the energy balance. This surface temperature would render much of the planet frozen. The presence of greenhouse gases, majorly water vapour, carbon dioxide and methane, in their natural abundance in the atmosphere would cause some of the outgoing thermal radiation to be trapped, thereby establishing a new energy balance with a surface temperature of about +15℃. This phenomenon, which amounts to 21℃ of warming of the earth's surface, is usually called natural or beneficial greenhouse effect.

Details of the effect of greenhouse gases in the atmosphere are confirmed by satellite observations of the earthlight (Figure 4), the outgoing thermal radiation from the earth. Without an atmosphere to absorb thermal radiation, the atmospheric radiance is mapped by a smooth curved called the spectrum which peaks at a wavelength of about 20 µm, almost 40 times the wavelength of the incoming visible light. But not all the thermal radiation gets out, as much of the thermal radiation is absorbed by greenhouse gases: water vapour (45%), carbon dioxide (30%), methane (20%), and other minor greenhouse gases that account for the remaining 5%. This shows that most of the outgoing thermal radiation is absorbed by water vapour and carbon dioxide. But the change that occurs in the amount of water vapour in the atmosphere due to human activities is negligible. The greenhouse gases (Figure 5) that are changing rapidly as result of human activities are carbon dioxide, methane, nitrous oxide, ozone and chlorofluorocarbons (CFCs), and carbon dioxide is the most worrisome. The irradiative forcing increases with increasing atmospheric concentration of the human-derived greenhouse gases. The five gases shown in Figure 5 account for about 97% of the direct climate change forcing by long-lived greenhouse gas increases since 1750 and the remaining 3% is contributed by an assortment of 10 minor halogen gases

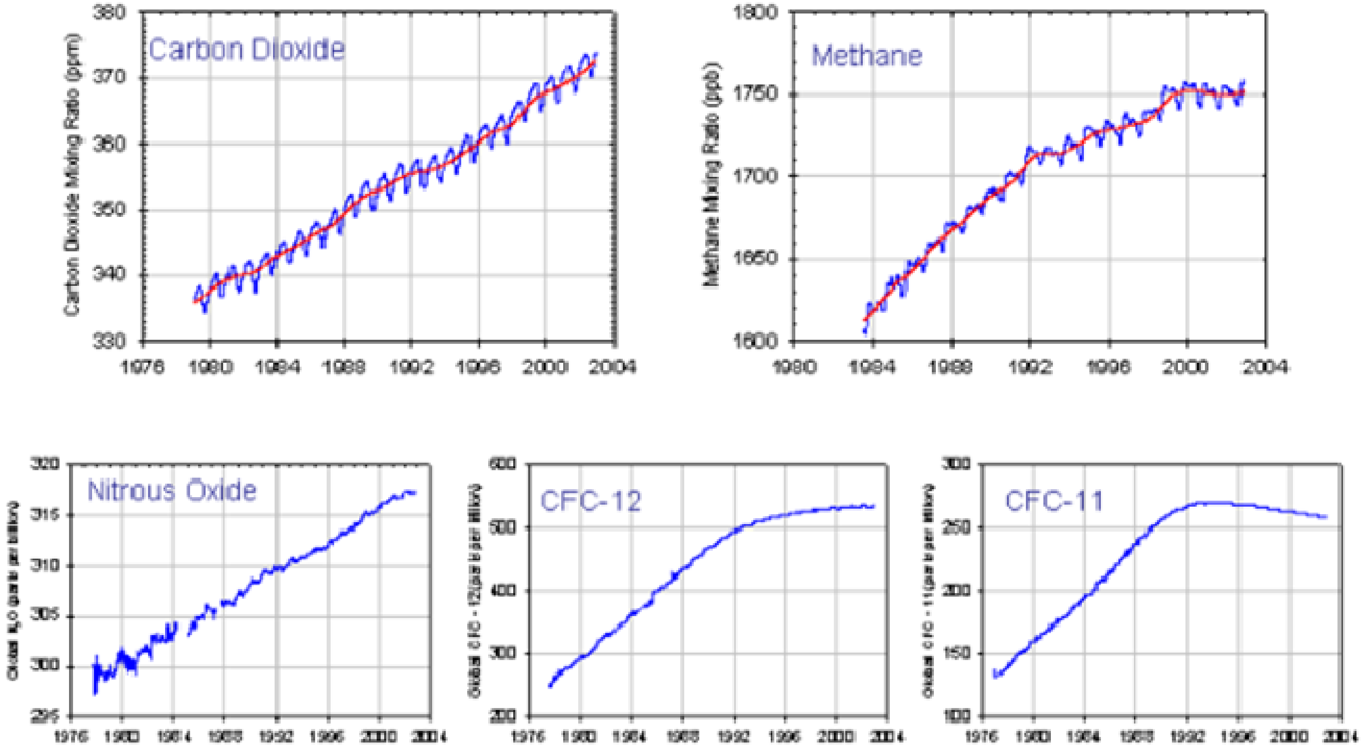


Figure 5. Global trends in major long-lived greenhouse gases between 1997 and 2003. The five gases shown account for about 97% of the direct climate change forcing by long-lived greenhouse gas increases since 1750 and the remaining 3% is contributed by an assortment of 10 minor halogen gases (Source: NOAA, 2005).

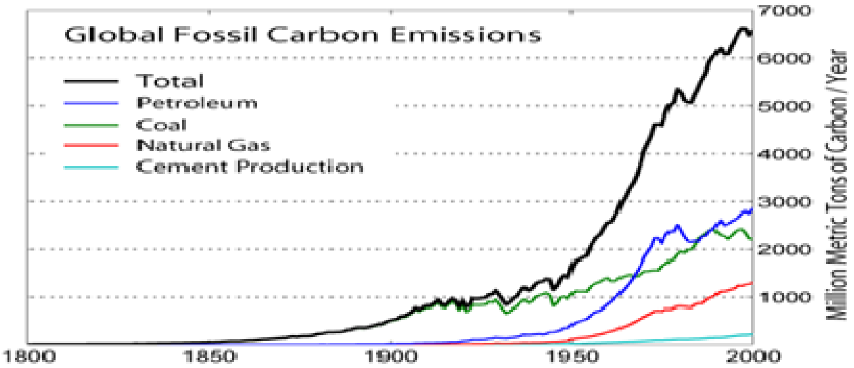
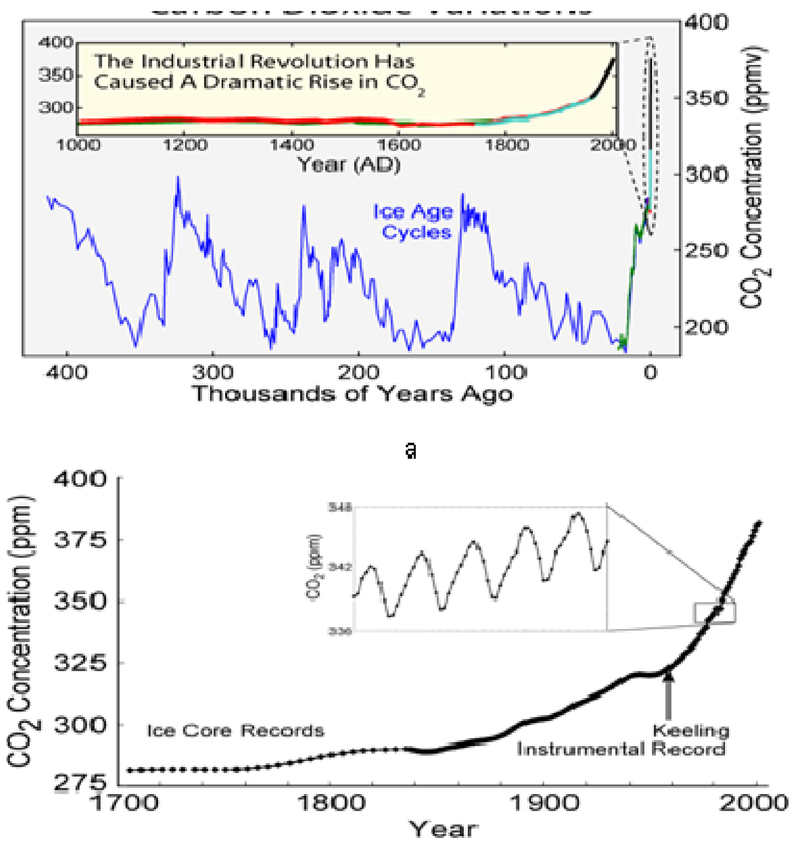


Figure 6. Global annual fossil fuel carbon dioxide emissions in million metric tons of carbon (Marland et al., 2003).

(After NOAA, 2005).

The major sources contributing to the increasing concentration of carbon dioxide in the atmosphere include the burning of fossil fuels, cutting down of forest for agricultural purposes and industrial activities. About 5.4 billion metric tons of carbon is released into the atmosphere annually from the burning of fossil fuel. About 1.6 billion metric tons of carbon is in addition emitted into the atmosphere by deforestation for agricultural and other land use purposes. Figure 6 shows the global annual fossil fuel carbon dioxide emissions in million metric tons of carbon (Marland et al., 2003). The data for the plots in Figure 6 were originally presented in terms of solid (coal), liquid (petroleum) and gas (natural gas) fossil fuel sources, and separates terms for cement production and gas flaring (natural gas lost during exploitation of oil and gas). The plot for gas flaring is the smallest of all the categories and was added to the total emission of carbon dioxide from burning of natural gas. The carbon dioxide from cement production results from



a

b

Figure 7. Variations in the concentration of atmospheric carbon dioxide: (a) in the last 400 thousand years, the largest changes that occurred can be related to glacial/interglacial cycles within the current ice age; and (b) between 1700 and 2000, the concentration of carbon dioxide in earth's atmosphere increased steadily from 270 to 385 ppmv since 1700 (Source: Mauna Loa Observatory, NOAA).

the thermal decomposition of limestone into lime, thus are technically not a fossil fuel sources.

Variations in the concentration of carbon dioxide in the last 400 thousand years are given in Figure 7a. The largest changes that occurred can be related to glacial/interglacial cycles within the current ice age. Glacial cycles are mainly caused by changes in the earth's orbit; these changes also influence the carbon cycle which in turn feeds back into the glacial system. Since the industrial revolution in 1900, the burning of fossil fuels has caused a dramatic increase in carbon dioxide concentration in the atmosphere, reaching levels unprecedented in the last 400 thousand years. This increase has been largely implicated as the primary cause of global warming and climate change.

The combined emissions of carbon dioxide from fossil fuel sources and deforestation amount to about 30% increase in the concentration of carbon dioxide in the atmosphere from 280 to 385 parts per million by volume (ppmv) since 1860 as revealed by results of the experimental observation made at Mauna Loa Observatory in Hawaii (Figure 7b). The results show a rise and fall of carbon dioxide in the atmosphere to about 6 ppmv per annum, indicating the growing and dormant seasons for plants; but the annual maximum and minimum carbon dioxide increases by about 1.5 ppmv. This annual growth in the concentration of carbon dioxide in the atmosphere poses a major threat to global warming and climate change because the average lifetime of carbon dioxide in the atmosphere is 100 to 150 years.

Carbon dioxide can only be depleted by dissolution in the oceans over time, but much of it is spewed back to the atmosphere as a result of warming.

UNCERTAINTIES IN THE FUTURE COURSE OF GLOBAL WARMING AND CLIMATE CHANGE

Observations made from surface temperature measurements at weather stations, sea level rise and borehole temperature profiles show that the earth's surface has warmed significantly in the last century. Global climate change – desert encroachment, deforestation, more turbulent weather, increased flooding and drought, and many more – attributed to the global warming are being witnessed across the globe. The most likely explanation of the observed warming and consequently climate change is enhanced greenhouse effect due to increasing concentration of greenhouse gases in the atmosphere. The concept of global warming and the consequent climate change has not been generally accepted by all players; most governments have not made reasonable efforts to reduce the emissions of greenhouse gases. This is because the following hypothesis could explain global warming and climate change: possible variations in solar radiation or natural variations in earth's temperature independent of human activities, which are yet to be understood, may be responsible for the observed warming and climate change; the complexity in earth's climate system may exceed the complexity in human behaviour and reaction to change; and genuine scientific uncertainties about global warming and climate change prediction has made the concept of global warming and climate change difficult for policy makers and planners, and a major weapon of attack for sceptics with varying agenda (Pollack, 2003).

A helpful analysis of the uncertainties in the predictions of global warming both in terms of the magnitude and changes, and the related climate effects was provided by Mahlman (1997). According to him, issues that are more certain about global warming include:

- Atmospheric abundance of greenhouse gases is increasing due to human activity.
- Increased concentration of greenhouse gases in the atmosphere leads to warming at the earth's surface.
- Carbon dioxide build up is particularly serious because it remains in the atmosphere for decades to centuries.
- Build up of aerosols, anthropogenic or natural, inhibits incoming solar radiation and thus tends to offset global warming by cooling.
- The earth's surface has warmed on the average by 1°C over the past century.
- The global mean amount of water vapour in the atmosphere will increase with increasing global mean temperature.

Other predictions of Mahlman, which are less curtained but have greater than ninety percent chances of being true, include:

- The 20th century global warming is consistent with model predictions of expected greenhouse warming.
- Doubling carbon dioxide concentration in the atmosphere from 270 to 540 ppmv will lead to a total warming of about 1.5 to 4.5°C.
- Sea level could rise by 25 to 75 cm by the year 2100 caused mainly by thermal expansion of sea water, and melting of ice sheets could lead to a further sea level rise.
- Higher latitudes of the northern hemisphere will experience temperature changes much more than the global experience temperature changes much more than the global mean increase.

The range in the above predictions is caused by the uncertainties in modelling based on two important mechanisms: forcings and feedbacks, which determine the direction of changes in the climate system. Climate forcings are the initial drivers of climate change. Solar irradiance is one important climate forcing that scientists are not too confidence about. The sun has a well known eleven year irradiance cycle that produces 0.08% variations in output (IPCC 2007c) which have been incorporated into climate models. Evidences from proxy measurements show that solar output also varies over long periods of time; these longer terms solar variations are not well understood and cannot be relied on. Aerosols forcing is another substantial uncertainty in the prediction of climate change. Aerosols from both natural and man-made sources have different effects on climate. Sulphate aerosols from the burning of fossil fuels and volcanic eruption tend to cool the earth, but other kinds of atmospheric particles have opposing effects. The global distribution of aerosols has only been tracked for about a decade, from the ground and satellites, and these measurements cannot accurately distinguish between particulates.

Climate feedbacks are processes that change as a result of a small change in forcing, and cause additional climate change. Feedbacks that amplify a small change in a particular direction are called positive feedbacks, while those that attenuate an initial response are negative feedbacks. An example of a positive climate feedback is water vapour; increased water vapour in the atmosphere from a warmer climate implies increased evaporation will enhance greenhouse effects which will lead to more evaporation. The reflectivity of ice sheets is another climate positive feedback process. Increased melting of ice sheet will decrease the reflectivity of light rays from the sun. This will lead to more warming which results in more melting of ice sheets and consequently more sea level rise.

Clouds radiation system is a much more complex climate feedback process which has enormous impact on the climate. Cloud sometimes cools the earth's surface by blocking or reflecting back into space the incoming solar radiation which would have otherwise results in warming. Cloud system can also act like a thermal blanket which absorbs the outgoing thermal radiation resulting in warming of the earth. Warming can significantly change cloud patterns and this would alter the amount of solar radiations absorbed or reflected by the clouds. A small change in the cloud pattern – amount, location and type – could speed, slow or reverse warming. The ocean system is another complex climate feedback that has significant influence on climate. The ocean system provides most of the water vapour in the atmosphere, modulates weather by redistributing heat around the globe through internal circulation. The ocean structure and dynamics should therefore be included in any accurate prediction modelling of climate change. Global ocean data set became available only from early 1990s, so the prediction of future changes in the ocean is largely uncertain. Carbon cycle is another climate feedback process that is not clearly understood. Natural processes remove about 50% of the carbon dioxide emissions from the atmosphere each year. The major repository of this carbon dioxide are oceans and land biota, but what is not clearly understood is which of them absorbs more. The ability of the earth system to continue to absorb carbon dioxide from the atmosphere may decline with increasing warming.

The incomplete understanding of the climate forcings and feedback mechanisms has limited the ability to predict the exact timing, magnitude and the regional patterns of climate change. This has made planning difficult for policy makers. Complexity in the system is a clear indication that surprises in the effects of global warming on climate change cannot be ruled out. The complexity in understanding global warming and climate change as well as the element of genuine scientific uncertainties does not preclude the reality of global warming and consequent effects of climate change.

POSSIBLE MEASURES TO REDUCE GLOBAL WARMING AND MITIGATE CLIMATE CHANGE

In order to effectively control global warming and climate change, the emission of greenhouse gases into the atmosphere should be drastically reduced. This can be achieved by improving energy conservation and efficiency as well as the production and efficient utilization of non-fossil fuels. The use of non-fossil fuels can be greatly improved by unleashing our engineering, economic and political entrepreneurs. This could help us in moving towards greater use of renewable energy resources and non-fossil fuels. Technological development geared towards energy efficiency, renewable sources and non-fossil fuels could allow developing countries to skip the carbon intensive energy production stage of industrialization. This approach could simultaneously reduce the excessive energy consumption in developed countries, thereby controlling global warming and climate change in the short-to-medium term. Other ways carbon dioxide emission could be reduced include establishment of stringent standards for power plants, development and marketing of high efficiency but cost effective automobiles, and provision of financial incentives for energy efficiency in industries and homes.

Apart from reducing the emission of greenhouse gases, a number of innovative geo-engineering models have been proposed so as to achieve a cooler planet and thereby control climate change and other effects of global warming. One of the most interesting proposed techniques that could be used to control and stabilize carbon dioxide in the atmosphere is iron fertilization. According to John Martin, an oceanographer, the intentional introduction of iron to the ocean will fertilize the water which will stimulate the growth of phytoplankton (microscopic marine plants) that uses carbon dioxide to synthesis their food. Iron fertilization is intended to enhance biological productivity that can be beneficial to the marine food chain and sequester carbon dioxide from the atmosphere. Thirteen international researches have been used to confirm Martin's hypothesis since 1993 (Boyd et al., 2007; Buersseler et al., 2008).

The planting of more trees is a more direct and practical way of combating global warming and climate change because forests sequester a large amount of carbon dioxide in the leaves and soil. However, this would require vast regions and would compete for lands needed for agricultural purposes to feed the growing population. Improvement in agricultural technology and productivity for crops like rice, wheat, maize and barley is required to best make use of the limited crops lands. Storing carbon in forest and agricultural areas is an important and cost effective part of the bigger strategy that should be used to control carbon dioxide emission into the atmosphere.

Pollution model is another proposed technique that could be used to combat global warming and climate change. Sulphur could be injected into the stratosphere so as to block incoming solar radiation and thereby produce cooling at the earth's surface. Other sunscreen schemes envision sending Mylar balloons or thousands of small, reflective particles into orbits around the earth to block partially the incoming solar radiation. Changing the reflectivity of the land and ocean surface could also increase the amount of solar radiation reflected back into space. The oceans could be made to absorb more carbon dioxide by increasing its alkalinity. These proposed methods are not cost effective and could alter rainfall pattern across the globe, cause more damage to the ozone layer, and have other unexpected environmental draw backs on the long run.

Preferred actions

To continue to do business as usual in terms of the emission of greenhouse gases would be a dangerous course to follow. This assertion is based on the reality of population growth, energy consumption as it relates to standard of living, and energy production to meet the demand of the growing population. The world population has continued to increase (Figure 8) and currently stands at about 6.8 billion with an annual growth rate of about 1.39%. Much of the growth in world population is in the developing countries as shown in the insert of Figure 8, which compares the rapid growth of five-year age brackets in Kenya of about 20% to the slow growth rate in USA of about 7%. The global population growth rate indicates a global predicament as rapid growth countries (developing countries) still significantly outnumber slow growth countries (developed countries); thus global

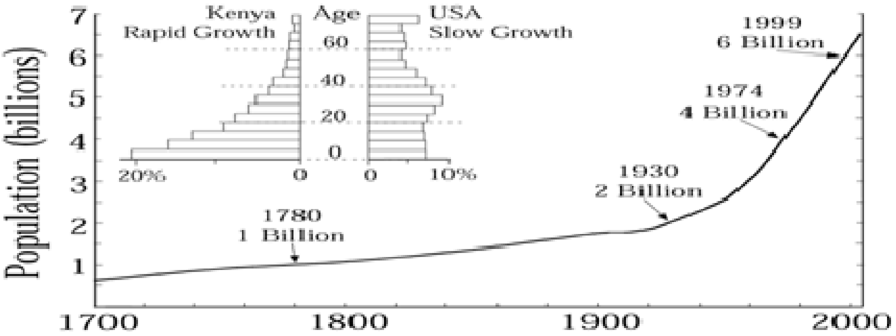


Figure 8. The global population growth traced from 1700 to the present; population distributions, in five-year age brackets, are shown for rapid and slow growth countries (inset).

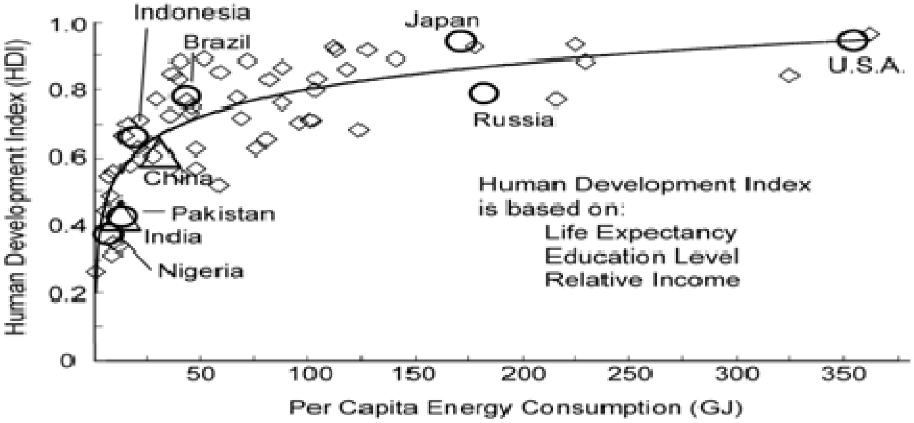


Figure 9. The human development index (HDI) for individual countries showing a strong dependence on per capita energy consumption. Different symbols indicate country populations: 1 billion or more (triangles), 100 million to 1 billion (circles) and less than 100 million (diamonds).

population will continue to rise even as birth rates decline.

The developing countries generally have a natural desire for an improved standard of living. The Human Development Index (HDI), developed by the United Nations, is a measure of the quality of life based on life expectancy, educational level and per capita gross domestic products. The HDI is measured on a scale of zero for the poorest nation to one for an ideal performance. Figure 9 shows that energy consumption plays a significant role in achieving high standard of living acceptable performance in the HDI. Current trend shows that standard of living increases with increasing per capita energy consumption. About 90% of the present global energy need is produced by burning of fossil fuels (Figure 10) – coal, oil and natural gas, which substantially increase atmospheric concentration of greenhouse gases, principally carbon dioxide and methane. Thus, the drive towards higher standard of living especially in the developing countries combined with the growing global population will aggravate the concentration of greenhouse gases in the atmosphere which will result in more severe effects of global warming and climate change.

The developing countries are still seen as relatively small players on the energy scene. They accounted for only 15% of global demand for commercial energy in 1970 and increased to 26% in 1990 despite the crippling effects of oil price rises and heavy indebtedness. Figure 11 shows the carbon dioxide emissions by regions. To expect the developing countries to cut down on fossil fuel consumption may seem unfair, given that there are enormous disparities between their stages of development and fossil fuel consumption. Also, it would be inequitable and unfair to propose that the developing countries forego opportunities for bettering their standards of living in order to solve a global problem which in any case is not of their making. As high-population countries such as Nigeria, India, Pakistan, China, and Indonesia increase their standard of living, the total global energy consumption will increase significantly. Thus, the energy consumption path these countries choose will have major implications on global energy demands and

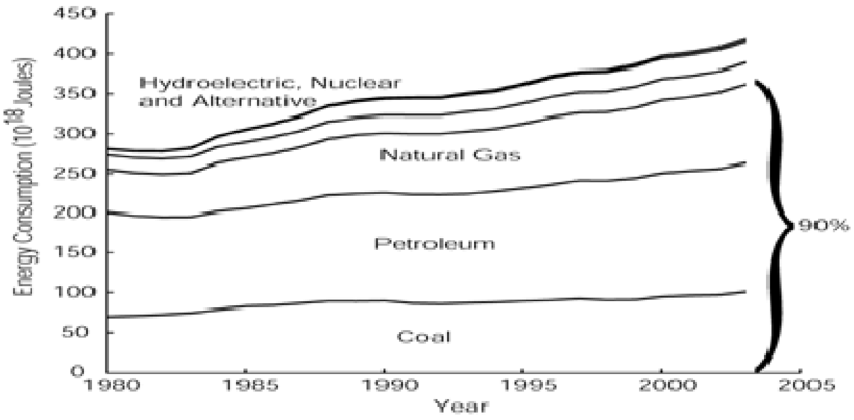


Figure 10. Global energy consumption with a growth rate of about 1.3% per year.

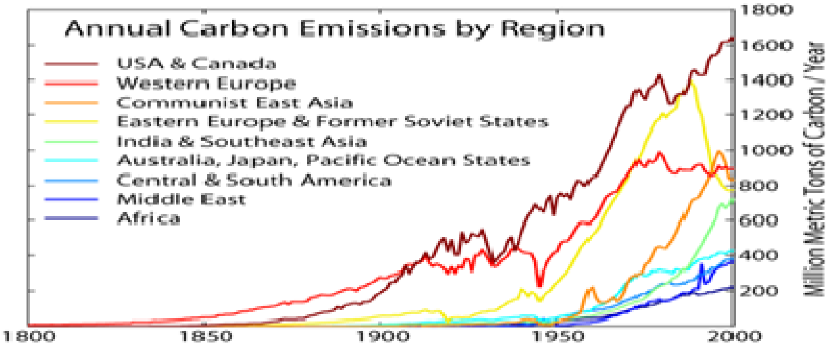


Figure 11. Global annual fossil fuel carbon dioxide emissions, in million metric tons of carbon, for a variety of non-overlapping region (Marland et al., 2003).

demands and will influence greenhouse gas emission on the long run.

Figure 12a shows carbon dioxide emission for various scenarios between the year 2000 and 2100, equivalent atmospheric carbon dioxide concentrations for each of the emission scenarios are given in Figure 12b. Differences in the emissions between the scenarios result from different assumptions about population growth, use of fossil fuel, technology, and global sustainability ethic. Scenario A2, for example, is doing “business as usual” with global population increasing to15.1 billion by 2100, and heavy reliance on fossil fuel. Emissions of greenhouse gases rise from the current 8 Mt of carbon dioxide annually to 30 Mt of carbon dioxide in 2100. This scenario results in atmospheric carbon dioxide concentrations of 800 ppmv in 2100. Scenario B1, at the other extreme, follows a “balanced” path with global population rising to 8.7 B by 2050 but decreasing to 7.0 B by 2100. Considerable emphasis is on technology, non-fossil energy sources, and a global commitment to solve environmental problems. Emissions of greenhouse gases rise slightly until mid century but decrease steadily until 2100 when the emissions are 25% less than today. Atmospheric carbon dioxide concentration increases slowly but more steadily through the next century reaching 560 ppmv or a doubling of the historic carbon dioxide level (2 × 280 ppmv) only by 2100.

The projections of global mean temperature of the earth surface to the year 2100 are shown in Figure 13 with a fluctuation of about 0.5°C amplitude and decadal periods for the last thousand years, relative to the present day surface temperature. There is a week evidence for global medieval warm period about 1100 AD a little ice age, particularly pronounced in Europe from 1500 to 1700 AD. The 1°C increase in surface temperature of the current warming episode and the prediction of a global mean temperature increase of 3°C in the next century are very unusual. This prediction is even more alarming as regional warming, for example in the arctic, is expected to be 3 times as great as the global mean.

Conclusion

To effectively control and stabilize the effects of global warming and climate change would require the integration

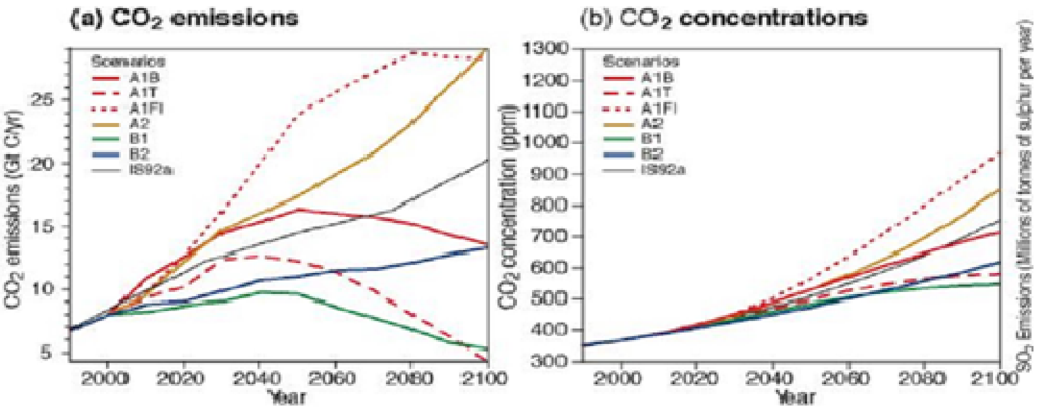


Figure 12. The atmosphere of the 21st century. Left: Seven scenarios for carbon dioxide emissions combined with projections for human population, technology, economics, and a sustainability ethic. Right: Each emission scenario results in a growth of carbon dioxide concentration for the next 100 years (After IPCC, 2007c).

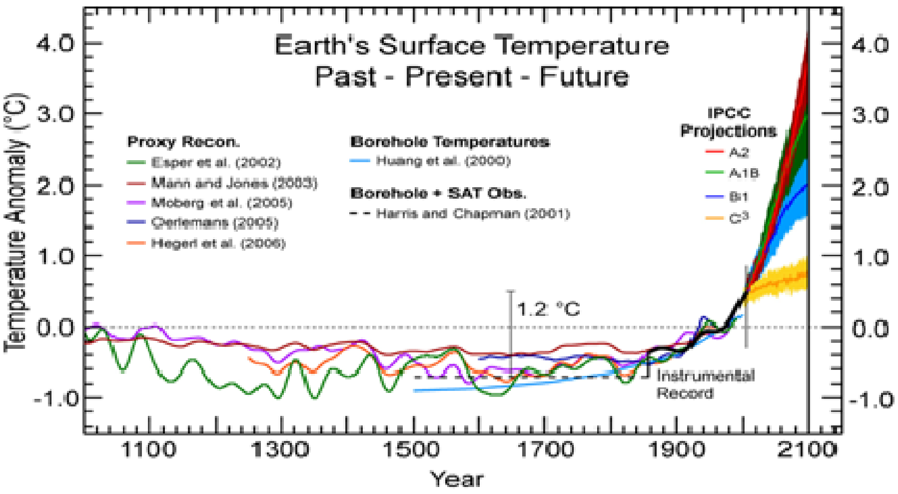


Figure 13. Projected global warming and climate change for the next century indicating continuous increase in surface temperature from 1 to 4 degrees C. Also shown are smoothed reconstructions of large-scale (Northern Hemisphere mean or global mean) surface temperature variations from seven different research teams, each with slightly different data sources, shown along with the instrumental record. However, all of the reconstructions provide a consistent picture of temperature variation over the last millennium (IPCC, 2007a).

integration of global commitments, good public leadership initiatives as well as individual actions. Changing the future projections of the curves shown in Figures 12 and 13 would be the most general solution to the dilemma of global warming and climate change. Global population growth should be brought under control (Figure 8), especially in developing countries that are already densely populated. Both the developed and developing countries should work towards achieving high standard of living within the sustainable per capita energy consumption range of 100 to 150 GJ (Figure 9). The developed nations, especially Canada, Australia and the United States should reduce their excessive energy consumption. Developing countries should strive to maximize their HDI at the least growth in energy consumption, using feasible and realistic models other than those used in the developed world. The creative talents of engineers and scientists should be harnessed and challenged to improve energy efficiency and the use of non-fossil fuel so as to reduce the dependency on fossil fuels (Figure 10).

To achieve the economic potential of improved energy efficiency and non-fossil fuel utilization, governments and policies makers should provide a combination of targets and timetables, efficiency regulations and arrays of market-based incentives that would encourage businesses to make the necessary investments on the reduction of greenhouse gases emissions. Such measures could include: mandating high energy-efficiency standards, retrofitting buildings to conserve energy, increasing subsidies that promote and encourage non-fossil and renewable energy sources, encouraging the production and use of more energy efficient vehicles, and assisting municipalities with planning that minimizes vehicle use. Other measures should include the establishment of regional, national and local warming and climate change centres, and the award of research grants to research institutes and researchers working on global warming.

Individuals can also make a difference in controlling and stabilizing carbon dioxide concentration in the atmosphere. The strategies could include using a fuel-efficient car and driving less; living closer to place of work and walking or riding a bicycle; making sure one's house is well sealed and insulated to reduce heating during cold weather and cooling during hot weather; using compact fluorescent light bulbs and/or tubes, and energy-efficient home appliances; planting trees and shrubs around homes, schools religious worship centres; and, through the democratic process, encouraging elected officials to deliver policies that properly take the environment into account. The actions we take or fail to take and the path that we choose to follow curbing greenhouse gases emissions will either break or make the earth. After all, if man could cause global warming and climate change, then man can put a stop to it. All hands must be on desk to ensure that the concentration of greenhouse gases, especially carbon dioxide, starts shrinking instead of growing; and the shrinking must continue until it reaches about half of the levels it was in 1990 in the two or three decades.

Not taken action to reduce or stabilize global warming would mean more greenhouse gases in the atmosphere, more melting of ice sheets, more turbulent weather, and more redistribution of precipitation. The redistribution of rainfall would mean more flooding and in places that previously have less of rain and more droughts in places that previously have more rain. More warming would mean more mass extinction, many species of plants and animals would go into extinction. For example, collar reefs, which have been around for about 250 millions years, are collapsing due to climate change, acidification and ocean warming; about 20% of coral reefs have already disappeared and about 24% is gravely threatened.

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