Unmasking "An Inconvenient Truth"

by

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Summary for Policymakers

An Inconvenient Truth puts Al Gore at the vanguard of a growing worldwide movement that claims there is a planetary emergency from global warming. It is claimed that the looming Armageddon is of our own doing because of the burning of fossil fuels that are causing a build-up of carbon dioxide in the atmosphere. The more developed a country's economy then the more it is to blame, and the more it behoves that country to change its profligate ways. *An Inconvenient Truth* is a call to arms for government and community action to fight a perceived emergency.

The planetary emergency is presented as a logical extension of recent climate change. Dramatic photos of glacier retreat and other graphics conjure up an image that the earth is changing as it has never changed before. It is claimed that the impacts of climate change are already being felt in biosphere responses that are leading to species loss, disease explosion and landscape destruction.

Much of Al Gore's evidence for his claims lacks credibility when examined without the emotive baggage of impending disaster, blame and simplistic political solutions.

The Science

The presentation of the science of climate change by Gore is superficial, erroneous and misleading. In contrast to Al Gore's simplistic metaphors for the greenhouse effect, what climate science demonstrates are the following:

- CO2 is almost exhausted as an agent for greenhouse global warming and increasing the concentration, including doubling from its present value, will have little impact on the earth's radiation budget.
- Water vapour is the primary greenhouse gas. Its role in the hydrological cycle is essential for balancing the excess solar radiation absorbed at the surface with the infrared radiation cooling of the atmosphere. The buoyancy of convective clouds causes overturning of the tropical atmosphere and distributes energy through the atmosphere. Convection is essential for linking and constraining the temperature of the atmosphere to the warmest ocean surface temperatures.
- The ocean and atmosphere circulations transfer excess heat from the tropics to the polar regions and so regulate surface temperatures over middle and high latitudes. More than 85 percent of the poleward transport of energy is by the atmosphere and middle and high latitude temperatures vary with the rate of transport.
- The oceans, with their much greater thermal and mass inertia, are the flywheels of the climate system. Relatively small changes in sea surface temperature pattern (for example associated with El Niño) can markedly change the atmospheric circulation and the rate of poleward transport of heat.
- Surface wind fields drive the ocean currents, including the slow meridional overturning circulations.
- The non-linear interactions between the oceans and the atmosphere are a source of internal variability of the climate system on timescales from years through millennia.

Recent Climate Change in Perspective

Al Gore focuses only on changes over the past few decades to century. He implies that the trends are unusual and will continue unabated. It is, however, a preposterous assertion that observed trends over the past few decades can be extrapolated into the future. These changes must be put in the context of the past million years.

- We have had major Ice Age conditions that have regularly recovered to Interglacial conditions with cycles of about 100,000 years. Typical impacts of the recovery are global temperature rise, ice sheet recession and CO_2 increase.
- The global temperature rise, ice sheet retreat and sea level rise during recent interglacials have had a recurring natural boundary, suggesting a natural strong constraint is imposed; CO_2 amplification of global temperatures (whether natural or anthropogenic) is an unfounded proposition.
- Fluctuations in glacier flow of the Greenland ice sheet are not unusual. Even during the Ice Age periods ice surges into the North Atlantic left glacial debris on the ocean floor at intervals covering a thousand years or more (Heinrich events).
- There is substantial evidence of global temperature fluctuations over the late Holocene on millennial timescales – eg, the Greek/Roman warm period, the Dark Ages, the Medieval Warm period, the Little Ice Age, and the modern warm period.
- The glacial retreat of the past two centuries is unremarkable and not irreversible, despite the claims of Al Gore to the contrary; surface ice sheets wax and wane on the millennial timescale.
- The claim of a 'stable climate' prior to industrialisation (the 'hockey stick' representation) cannot be sustained. The methodology of splicing low-resolution proxy data to high-resolution instrument data without a sound basis for comparing respective datum is flawed.

Interpretation of Weather Extremes

Al Gore is selective in choosing various recent severe weather events to make the case that they are unusual and due to global warming.

- Hurricane frequency and intensity are related to sea surface temperature (SST), but only in as much as hurricanes require a minimum SST to provide the necessary buoyancy of convection; evaporation from the surface (the energy source driving the systems) increases almost exponentially with SST increase.
- Atmospheric circulation characteristics must also be favourable. 1997, the year leading to the warmest year of the instrument record, was a season with record low numbers of systems in the Atlantic and Gulf of Mexico region – years of developing El Nino in the Pacific are linked to low numbers of hurricanes in the Atlantic-Gulf of Mexico.
- Internal factors inhibit intensification. As the intensity of a hurricane increases so there are natural forces that kick in to restrain development. Mass subsidence around the storm acts to warm the atmospheric environment and reduce convective buoyancy and mass overturning – both are necessary to release latent energy. Frictional drag on the surface wind increases as the cube of wind speed thus also constraining intensification.
- Storm damage statistics do not in themselves indicate an increase in hazard, only that the insurance exposure in hazardous locations has increased.

- Much is made of the damage by hurricane Katrina, a severe but not record intensity storm, but much of the loss of life and damage were due to a combination of inadequate action leading up to the storm, failure of vital infrastructure, and slow response following the storm's passage. There are lessons from Katrina, as there are after any major disaster, but cutting back on CO_2 emissions to prevent future hurricane damage is daft.
- There is no clear evidence of expanding deserts, except by poor land management practices. Shifting dunes is natural. The rainfall of semi-arid and arid regions often has decadal to centennial cycles. There is evidence that North Africa and the Middle East have been drying from a savanna-type climate that was more typical 5,000 years ago.

Polar Ice

Al Gore raises the spectre of massive ice sheet destruction from Greenland and Antarctica to raise sea levels by 10-15 m. There is every reason to believe that the Greenland and Antarctic ice sheets are stable despite some peripheral melting at low elevations during the brief summer.

- The Greenland ice sheet has been preserved despite previous Interglacials that were warmer than current temperatures. It has likely been in place for more than a million years. On the high plateau temperatures are less than minus 10C even in summer. Melting around the coastal margins and surging glaciers are not evidence of instability and there is no evidence of recent rapid sea level rise.
- Arctic sea ice has a natural rhythm of expansion and contraction between winter and summer and year-to-year variations are small in comparison to the annual cycle. It would require a strong surge of relatively warm water into the Arctic basin to prevent the formation of sea ice in the long winter darkness.
- The Antarctic Circumpolar Current driven by the westerly winds prevents the intrusion of warmer subtropical surface water to the Antarctic coastal margins. In addition, the wind stress causes upwelling of cold sub-surface water on the poleward margin of the current, further isolating the Antarctic continent. There is no compelling evidence that the Antarctic ice sheet is other than in mass balance.
- Touted warming and ice shelf destruction are mainly confined to the Antarctic Peninsula that extends equatorward towards South America, a small fraction of the total ice mass.

Geosphere and Biosphere responses

Al Gore makes much of a limited number of statistics on species change in response to recent warming. He then suggests this is happening across the biosphere and extrapolates to presumptions of species extinction.

- We would expect a change in species populations and distributions, reflecting differing adaptation and mobility characteristics, to any climate change.
- The general robustness of species is concluded from the survival from the dramatic changes that occurred as earth went through glacial to interglacial cycles over the past million years. This is especially true for those areas of North America and northern Europe over which the thick ice sheets advanced and retreated.
- Today's pristine coral reefs were but limestone cliffs during the last glacial maximum and have responded to higher sea levels and warmer tropical waters.

- Just as the boreal forests advanced poleward following the retreat of the ice sheets so too the biosphere flourished. Satellite evidence confirms the increase in plant growth over sub-Arctic regions during the past two decades of increased warmth.
- Species are not threatened by the recent global warming as conditions are not yet as extreme as the early Holocene. There is no evidence that polar bears and emperor penguins, to name two species quoted as being threatened with extinction, will not survive the current interglacial. After all, they survived previous climatic periods and there is no recent evidence that numbers are declining.
- Many species quoted as being threatened are also threatened by direct human activities. For example, algae blooms increase with land-based fertiliser run-off, sewage discharge and urban stormwater run-off. These blooms threaten coastal ecosystems but are best addressed through local management measures, not reduction in CO2 emissions.

'Collision of Earth and Humanity'

There are many examples offered by Al Gore under this theme but they are fear mongering at its worst and with no foundation in science.

- Despite Al Gore's protestations otherwise, Earth is demonstrated to be capable of providing food, clothing and housing to the present 6.6 billion population.
- There are regional hardships but these are strongly associated with recent natural disasters (eg, drought, flood or earthquake), tribal or religious warfare, or disease pandemics. These are not issues to be resolved by decarbonising the economies of developed countries.
- Cities and industrial regions of the developed countries have sensible measures in place to maintain clean air to a high standard. Regulations and market mechanisms are in place to discourage or punish real polluters. In this sense CO2 is not a pollutant and is vital to the biosphere.
- There is an acknowledged need to better manage resources, especially those becoming limited in availability. Better and more efficient utilisation of all resources, but especially energy, lowers costs and prolongs the lifetime of such resources.
- A green and sustainable future is a common objective of humankind. The disagreements surround strategies for achieving the object – either market-linked mechanisms or centrally directed government. It will not be achieved through an inefficient centrally planned and coercive regulatory environment that inhibits innovation and entrepreneurial initiative.

In Summary

- Al Gore has not substantiated a 'climate crisis' caused by human activities. The scientific basis of his claims is specious. Current climate variations are not outside the bounds of climate history. Projections of future climate are on the basis of rudimentary computer models that are unable to predict a season ahead.
- Weather and climate extremes are dangerous to humankind and improved knowledge of the climate system is required to better understand their occurrence and severity.

- Weather and climate hazards are mitigated through infrastructure planning, development of emergency response strategies, including aftermath assistance.
- Attempting to change the course of climate, especially by reducing carbon dioxide emissions will not effectively mitigate weather and climate extremes nor alter the future direction of climate.

Access to energy and material resources is changing as new reserves are discovered and existing reserves depleted. This is reflected in market prices and substitutions. It would be grossly inefficient of governments to interfere on the basis of the perceived superior knowledge of bureaucrats and unrepresentative NGOs, especially if the interference led to higher prices for essential commodities and a worldwide slowing of development.

INTRODUCTION

Global warming is an idea that became a movement. Its genesis is a discredited late 19th century hypothesis of the Swedish Nobel Laureate, Svante Arrhenius, linking past ice ages to changing concentrations of carbon dioxide in the atmosphere. Discredited because it is now generally accepted that the cyclically recurring ice ages of the past million years are linked to the characteristics of the Earth's changing orbit around the Sun. Nevertheless, before Milankovitch's orbital theory for the ice ages was widely accepted, the idea that emissions of carbon dioxide from human activities could alter the Earth's radiation processes and lead to global warming was well established.

Research in the 1950s, that showed atmospheric carbon dioxide concentration to be increasing due to widespread reliance on fossil fuels as an energy source, gave impetus to the human-caused global warming hypothesis. Analysis of air bubbles recovered from ice cores drilled over Greenland suggested that pre-industrial levels of atmospheric carbon dioxide varied between about 180 ppm[1] and 280 ppm as Earth shifted between ice age and warmer interglacial periods, such as now prevailing. Regular direct analysis of air samples showed that the concentration increased from 315 ppm in the late 1950s and reached 340 ppm by the early 1980s. The concentration is now about 400 ppm.

The development of numerical weather prediction, based on well-known equations for atmospheric motion, was one of the early applications for the emerging computer technology of the 1950s. The computer models developed for weather forecasting were adapted for studying climate processes and one of the first set of 'climate experiments' was to examine how the climate system might respond to a change in carbon dioxide concentration. These experiments suggested that the global mean surface temperature would increase between 1.5^{o}C and 4.5 °C for a doubling of the atmospheric CO_2 concentration.

The combination of increasing carbon dioxide concentration, a 'scientific' hypothesis of enhanced global warming and alarming computer projections were the ingredients for setting off what was to become a global movement to constrain fossil fuel burning and reduce emissions of carbon dioxide into the atmosphere. But the question remains, is global warming a real danger to humanity, or is it what the 19th century commentator Charles Mackay[2] might categorise as just another example of an "extraordinary popular delusion and the madness of crowds"?

The origins for the groundswell of public interest in the global warming scenario was a United Nations co-sponsored conference held in Villach, Austria in 1985. The Conference Statement, drawing on observations, theory and modelling claimed that, "As a result of increasing concentrations of greenhouse gases [carbon dioxide and other radiatively active constituents of the atmosphere] it is now believed that in the first half of the next century a rise of global mean temperature could occur which is greater than any in man's history".

For more than two decades there have been a succession of national and international conferences calling for global action to avert the perceived threat of global warming. The United Nations negotiated a Framework Convention on Climate Change with the objective of preventing 'dangerous' climate change. The Kyoto Protocol to the Convention puts limits on the allowable annual emissions of carbon dioxide by so-called developed countries. Despite the words spoken and written about the perceived dangers, and the expressed good intentions and tentative agreements for action, global emissions of carbon dioxide continue to increase.

Former US President Al Gore's 2006 book[3] and movie, both titled *An Inconvenient Truth*, has again raised the spectre of global warming as a pathway to the annihilation of humanity. Such a future is claimed to be of our own making. The more developed countries are credited with most blame because of their past unconstrained use of fossil fuels. Development is equated with decadence, and it behoves developed countries to change their profligate ways. Al Gore's is a call to arms for complementary action by governments and communities to address the perceived planetary emergency of global warming.

According to Al Gore, science and observations support his view of the coming apocalypse. Carbon dioxide concentration in the atmosphere is increasing, having reached nearly 380 ppm; the earth is warming, with melting ice sheets and rising sea levels; weather is becoming more violent and dangerous; and the biosphere is suffering stress. A planetary emergency is, therefore, a logical extension of recent climate change. Dramatic photos and graphics of glacier retreat and other perceived environmental disasters are designed to portray a vision that the earth is changing as it has never changed before. The Al Gore thesis is that, even now, climate change is being registered in dangerous biosphere responses that include species loss, disease spread and landscape destruction.

Even if partially true, Al Gore's story would be a wake-up call for concerted action. Unfortunately, much of Al Gore's evidence for his claim lacks credibility when examined without the emotive baggage of impending disaster, blame and simplistic political and technological solutions.

A measure of the superficiality of Al Gore's message is that the underlying science of human-caused global warming is covered in less than 200 words! Part of his explanation is to describe Earth as the "Goldilocks planet" – more greenhouse gases than Mars, therefore not as cold; less greenhouse gases than Venus, therefore not as hot. According to this logic, the thickening of Earth's atmosphere by 'huge quantities of human-caused carbon dioxide and other greenhouse gases' will trap more of the infrared radiation that would otherwise escape to space. Supposedly it is this retained heat that will cause the Earth's atmosphere and oceans to get dangerously warmer. If only the climate system were so simple to describe!

Al Gore's homespun metaphor for human-caused global warming is qualitative and is of itself not alarming. After all, Earth as we know it is the outcome of more than 4 billion years of evolution and unremitting change. The biosphere, of which humans are part, is a product of that evolution. Notably, over the past 100 million years the Earth's evolution has included significant variations of temperature, and atmospheric carbon dioxide concentration has steadily fallen from about 2,000 ppm. Change is not necessarily adverse to humanity and the biosphere, especially when it is recognised that expansion of human populations is closely linked to the period of massive global warming and accompanying retreat of land ice that occurred between about 20,000 years and 10,000 years ago.

A key element underpinning the alarmism of human-induced global warming is the magnitude of global temperature rise projected by computer models. The climate modelling community claim that the most likely range of global average surface temperature rise, if the growth of carbon dioxide emissions is allowed to rise unabated, is between 1.4 and 5.8C by the year 2100[4]. It is the wide range of the various model estimates of future global warming that give us a glimpse of how complex the climate system really is and how uncertain are the projections.

As portrayed by Al Gore, the projected temperature rise is a collision of Earth and humanity. The consequent melting of sea and land ice and raising of sea level, the general heating and drying of land masses and reduction in availability of essential water, the more extreme weather events and their associated destruction, and the impacts of these on the biosphere and human life are the essence of Gore's Armageddon.

Gore is not alone in his thesis of a self-destructing humanity, although his is a long-held conviction. He recounts his introduction to greenhouse theory at college and an earlier book, *Earth in the Balance*[5], is testament to his ongoing concerns and adherence to the environmental cause. Gore's thesis encompasses and is representative of the claims by environmental activists that human activity is changing the global climate. The view is that there is a coming crisis if emissions of carbon dioxide into the atmosphere are not reigned in.

Over recent decades the human-caused global warming debate has become ever shriller but the underlying scientific uncertainties have not been reduced. The Intergovernmental Panel on Climate Change (IPCC) was established as a UN entity co-sponsored by the United Nations Environment Programme (UNEP) and the World Meteorological Organization. The purpose of the IPCC was "to provide an authoritative international statement of scientific opinion on climate change". IPCC issued major assessment reports in 1990, 1995 and 2001. Each report expressed increasing confidence for an enhanced greenhouse effect with the latest report claiming that the warming of the previous 50 years was likely caused by human activities. The Fourth Assessment Report is expected in February 2007.

On the basis of the IPCC First Assessment Report, the UN members negotiated a Framework Convention on Climate Change. However the ongoing debate has become confused because the UN has defined climate change, for the purposes of the Convention, as being that change caused by human activities over and above any natural climate variability. The UN definition is at odds with conventional usage where climate change is any change whether caused by human activities or as a consequence of natural processes. The objective of the Convention is to prevent dangerous (human caused) climate change, although 'dangerous' is not defined. The Kyoto Protocol to the Convention represents the first formal steps to mandating a global reduction in carbon dioxide emissions for the purpose of preventing (human caused) dangerous climate change, albeit that in its first phase the limitations only apply to so-called developed economies.

The effectiveness of the UN objective of limiting, and ultimately reducing, human-caused emissions of carbon dioxide rests on the efficacy of the presumed causal relationship between atmospheric carbon dioxide concentration and global climate. IPCC relies on computer models to demonstrate that there is a credible causal relationship. Al Gore, and fellow alarmists, take the relationship as gospel and draw upon observed trends, particularly over the past few decades of warming, to project future catastrophe.

Concern, without unambiguous evidence, however, is not sufficient reason for humanity to discard the fundamental tools of progress. This is especially so if the proposed alternative pathway can only lead to physical hardship, intellectual poverty, and a greater exposure to the perils of natural hazards associated with weather and climate extremes. After all, it has been access to energy and the machines of industry that have alleviated much of the labour from food production, habitat construction and commerce. In turn, greater discretionary time has been the basis for free thought and the formulation of imaginative new systems for progress. Overall, progress is a measure of community protection from social disruption associated with famine, disease, widespread prolonged suffering and even death that are associated with the various destructive forces of nature.

The purpose of this paper is to examine the scientific thesis that underpins the human-caused global warming prophecy. The simplistic metaphors and representations of the climate system will be reviewed and the seemingly plausible but actually erroneous projections that are an outcome will be analysed. Climate has changed over recent times. Al Gore and his ilk have shamelessly commandeered these changes as evidence in support of their human-caused global warming hypothesis. In reality these changes are coincidental. They are neither unprecedented nor unusual and cannot be related to human cause.

The biggest danger to humanity from blindly following the human-caused climate change hypothesis is through misallocating resources and prolonging exposure of societies weakest to the hazards of weather and climate extremes. Investment of scarce resources more properly directed to saving lives and protection of property against the known range of weather and climate extremes will be diverted in a quixotic attempt to avert the chimera of human-caused climate change.

UNRAVELLING THE GREENHOUSE EFFECT

A false paradigm

Water vapour, carbon dioxide and other so-called greenhouse gases are important to the climate system because each is capable of both absorbing and emitting radiation in discrete bands of the infrared spectrum that are characteristic of each gas. In contrast, solid and liquid materials absorb and emit infrared radiation from their surfaces across the full wavelength spectrum. The greenhouse gases of the atmosphere will absorb infrared radiation emitted from the Earth’s surface within their respective bands. Independently, each greenhouse gas will emit infrared radiation across its characteristic band in all directions and with intensity that is proportional to the temperature of the emitting gas.

There is a widely held misconception that the temperature of the atmosphere is maintained by the absorption of infrared radiation emitted by the Earth’s surface. For example, Tim Flannery in his widely publicised book, *The Weather Makers*[6], claims (p 28):

> “*More importantly, they [scientists] discovered that rather than being the sole agent responsible for climate change, CO2 acts as a trigger for that potent greenhouse gas, water vapour. It does this by heating the atmosphere just a little, allowing it to take up and retain more moisture, which then warms the atmosphere further. So a positive feedback loop is created, forcing our planet’s temperature to even higher levels.*”[7]

Al Gore also has difficulty in explaining the greenhouse effect in terms easily understood by the layperson but which has scientific integrity. His explanation (*An Inconvenient Truth*, p 26):

"Under normal conditions, a portion of the outgoing infrared radiation is naturally trapped by the atmosphere – and that is a good thing, because it keeps the temperature of the Earth within comfortable bounds. ….. The problem we now face is that this thin layer of atmosphere is being thickened by huge quantities of human-caused carbon dioxide and other greenhouse gases. And as it thickens it traps a lot of the infrared radiation that would otherwise escape the atmosphere and continue out to the universe. As a result, the temperature of the Earth's atmosphere – and oceans- is getting dangerously warmer."

Both of these populist explanations contradict the well-established fact that, because of decrease of density and temperature with height, the greenhouse gases of the atmosphere emit more infrared radiation than they absorb. This is clear from the global energy budget of Kiehl and Trenberth[8], as quoted in the IPCC's Third Assessment Report (see Figure 1.2, p 90 and reproduced in Box 1). The heating of the atmospheric layer by absorption of solar radiation (67 W/m^2) and absorption of infrared radiation (350 W/m^2) are offset by emission of infrared emission back to the surface (324 W/m^2) and to space (195 W/m^2). The net loss of 102 W/m^2 represents an ongoing tendency for radiation processes associated with greenhouse gases to cool the atmosphere. Increasing the carbon dioxide concentration will not reverse this tendency for cooling of the atmosphere.

The IPCC Third Assessment Report also has an incomplete explanation of the greenhouse effect. The IPCC correctly notes that for a stable climate it is necessary for the net solar radiation absorbed by the Earth's climate system (land, ocean, ice sheets and atmosphere) to be offset by an equivalent emission of infrared radiation to space. This is no more than an expression of the conservation of energy. Also, the magnitude of the emission to space is 235 W/m^2, which equates to an average radiating temperature for the climate system of -19^oC.

The IPCC explanation of the greenhouse effect is as follows:

"The atmosphere contains several trace gases which absorb and emit infrared radiation. These so-called greenhouse gases absorb infrared radiation, emitted by the Earth's surface, the atmosphere and clouds, except in a transparent part of the spectrum called the "atmospheric window", as shown in Figure 1.2 [see Box 1]. They emit in turn infrared radiation in all directions including downward to the Earth's surface. Thus greenhouse gases trap heat within the atmosphere. The mechanism is called the natural greenhouse effect. The net result is an upward transfer of infrared radiation from warmer levels near the Earth's surface to colder levels at higher altitudes. The infrared radiation is effectively radiated back into space from an altitude with a temperature of, on average, -19^oC, in balance with the incoming radiation, whereas the Earth's surface is kept at a much higher temperature of an average 14^oC. This effective emission temperature of -19^oC corresponds in mid-latitudes with a height of approximately 5 km. Note that it is essential for the greenhouse effect that the temperature of the lower atmosphere is not constant (isothermal) but decreases with height."

A key element that is missing from this explanation is the reason why the surface temperature is maintained warmer than the atmosphere above, an acknowledged requirement of the IPCC explanation. Also, the sentence "*Thus greenhouse gases trap heat within the atmosphere*" is clearly wrong because, in the global energy budget, the net upward infrared radiation at the surface (66 W/m^2) is significantly less than the infrared radiation to space at the top of the atmosphere (235 W/m^2). There is an increase in net upward infrared radiation with height that does not accord with 'trapping of heat'. Also, the back radiation of 324 W/m^2 is considerably less than the surface emission of 390 W/m^2 and it is clearly not back radiation that is maintaining the surface temperature. Indeed, the overnight formation of temperature inversions in the atmospheric boundary layer are evidence that radiation processes will not of themselves maintain the decreasing atmospheric temperature with altitude (ie, a negative temperature lapse rate).

The sentence "*The net result is an upward transfer of infrared radiation from warmer levels near the Earth's surface to colder levels at higher altitudes"* in the IPCC explanation is also incorrect. The magnitude of upward directed emissions of infrared radiation decreases from 390 W/m2 at the surface to 235 W/m2 at the top of the atmosphere, suggesting a convergence of infrared radiation energy in the atmosphere. The reality is, as the global energy budget demonstrates, the magnitude of net infrared radiation directed to space increases with altitude; it is 66 W/m2 at the surface and increases to 235 W/m2 at the top of the atmosphere. This is not a convergence of infrared radiation in the atmosphere as IPCC implies but a net loss of infrared radiation from the atmosphere. Energy is being lost from the atmosphere at all altitudes as we expect.

The inadequacy of the IPCC explanation of the greenhouse effect is carried through to its explanation for radiative forcing:

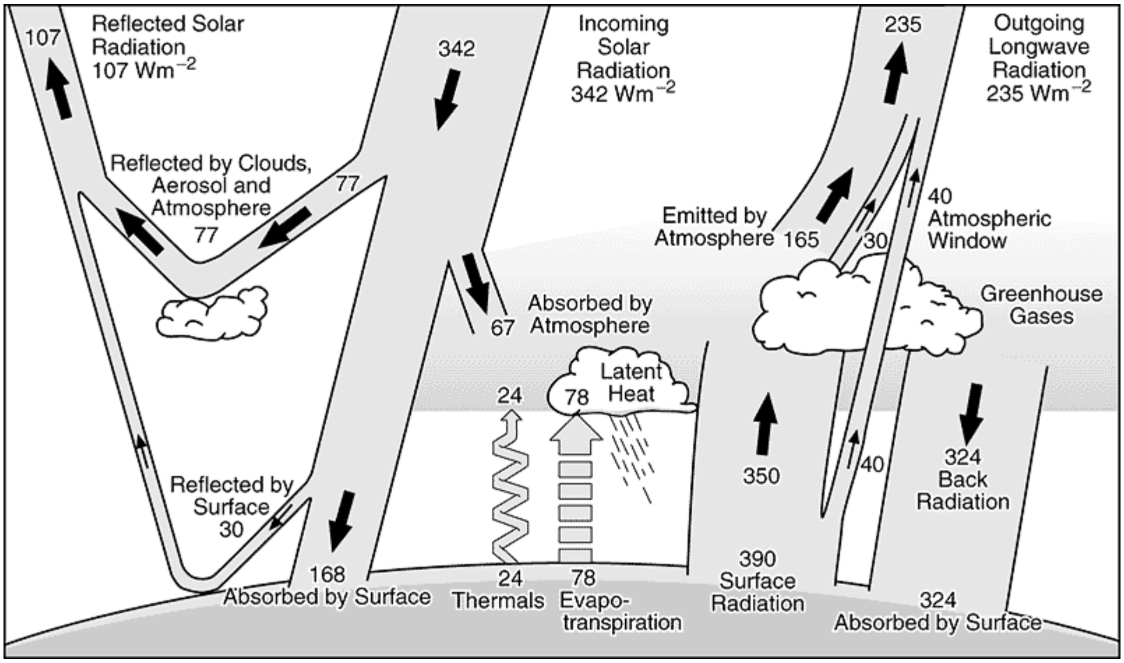
> *"In an equilibrium climate state the average net radiation at the top of the atmosphere is zero. A change in either the solar radiation or the infrared radiation changes the net radiation. The corresponding imbalance is called "radiative forcing" …… These variations may be negative or positive. In either case the climate system must react to restore the balance. A positive radiative forcing tends to warm the surface on average, whereas a negative forcing tends to cool it."*

There are two major unresolved questions in the IPCC hypothesis for human-caused climate change.

- Firstly, what maintains the surface temperature greater than -19°C, because it is clearly not because of radiation processes alone and is certainly not because of an upward transfer of infrared radiation?
- Secondly, what regulates the relationship between radiative forcing and surface temperature change?

For both of these questions, the IPCC relies on computer model representations of the climate system to provide the answers. The shift from an incomplete explanation of the greenhouse effect, essentially based on a one-dimensional annual mean global average representation of the climate system's energy budget, to a three-dimensional time varying representation of interacting fluids requires a giant leap of faith in the efficacy of formulation of computer models. The IPCC contends that such a shift is reasonable because the specifications of the processes of the climate system are adequate, and the ensuing representation of climate by the computer models is realistic. Faith in the computer models underpins the IPCC claim that the radiative forcing by human-caused carbon dioxide and other greenhouse gas emissions is translated to realistic warming of the Earth's surface temperature. This faith is misplaced.

BOX 1



THE GLOBAL ENERGY BUDGET

Source: Kiehl and Trenberth, 1997

THE GREENHOUSE EFFECT

The Earth's greenhouse effect arises because of the interplay of energy transfer processes that, in combination, raise the temperature of the surface above the effective emission temperature required for radiation equilibrium.

1. The emission of infrared radiation by greenhouse gases, clouds and aerosols elevates the Earth's effective emission layer from the surface to the atmosphere (about 5 km) but the effective emission temperature (about $-19^{o}C$) is not changed. [IPCC TAR 1.2.1 p90].
2. Greenhouse gases, clouds and aerosols emit 102 W/m^2 more radiation energy than they absorb and the net radiation deficit acts to cool the atmosphere.
3. At the surface there is a net radiation gain of 102 W/m^2 because the absorbed solar radiation exceeds the net infrared radiation loss and this radiation energy excess tends to warm the surface.
4. Overall, radiation processes cause an energy disconnect as the surface tends to warm through net accumulation of radiation energy and the atmosphere tends to cool because of net loss of radiation energy.
5. Surface temperature regulates the transfer of energy from the surface to the atmospheric boundary layer by conduction and evaporation. Evaporation increases approximately exponentially with temperature increase.
6. Convective overturning distributes heat and latent energy from the boundary layer through the atmosphere to offset the net radiation loss from greenhouse gases, clouds and aerosols (Riehl and Malkus, 1958).
7. Convective overturning requires buoyant saturated ascent in the updraughts of deep convection clouds and the temperature decrease with altitude in the convective updraughts (about $6.5^{o}C$ per km in the lower atmosphere) regulates the rate of temperature decrease with altitude of the atmosphere.
8. The extent of warming of the Earth's surface above the effective emission temperature (the greenhouse effect) is regulated by the height of the effective emission layer in the atmosphere and the temperature change with height generated by convective overturning.

Note. Most of the absorption of solar radiation takes place over the tropics but infrared emission is at all latitudes. As a consequence, it is the atmospheric overturning associated with the deep convection clouds of the equatorial trough and the tropical Hadley Cells that primarily determine the warmest temperatures of the Earth's surface. Excess energy of the tropics is transported to middle and high latitudes by the atmospheric circulation and it is the atmospheric transport that keeps surface temperatures over middle and high latitudes warmer than they would be due to local radiation processes alone.

One of the reasons that the greenhouse debate has failed to converge on a consensus view is that different simplistic metaphors are used in public discussion to explain the greenhouse effect and these give only partial descriptions of what is a complex system. The IPCC one-dimensional construct is seemingly plausible but it neither explains what maintains the lapse rate of temperature in the atmosphere nor its magnitude. Further, it is erroneous to suggest, as some commentators do, that radiation warms the atmosphere directly; and it is also erroneous to suggest, as Al Gore does, that it is the back infrared radiation emitted by the greenhouse gases that warms the surface.

The emphasis in public discussion is mostly on absorption of infrared radiation by the greenhouse gases in the atmosphere and this establishes a false paradigm. Fundamentally, it is the emission of infrared radiation by the greenhouse gases that is important to the greenhouse effect, not the absorption. As a consequence of the emission that tends to cool the atmosphere, the source of the emission to space is shifted from the Earth's surface (in the case of no greenhouse gases) to the atmosphere (when greenhouse gases are present). It is the elevation of the height of the effective emission layer that establishes the conditions for a greenhouse effect. But still the explanation of the greenhouse effect is not complete.

The simplistic explanations for the greenhouse effect that are promulgated for public use are incomplete, and thus flawed. They are no basis for projecting substantial surface warming (dangerous climate change) with increases of carbon dioxide concentration in the atmosphere. They are certainly no basis for rationalising the significant surface temperature increase projected from computer models.

At face value these simplistic but erroneous explanations give us no clue as to whether increasing carbon dioxide concentration in the atmosphere will, at one extreme, have no identifiable impact or, at the other extreme, lead to runaway global warming. It is the spectre of the latter, fuelled by alarmist rhetoric such as promulgated by Al Gore, which drives the anthropogenic global warming and dangerous climate change debate.

Solar heating of the Earth's surface

It is important at the outset to recognise a fundamental inadequacy of the one-dimensional representation of the climate system (as in Box 1). Solar energy is not distributed uniformly over the Earth's surface. On an annual average basis the daily amount of solar radiation varies with latitude and more is absorbed over the tropics than over polar regions. Over the tropics absorbed solar radiation exceeds the amount of infrared radiation emitted to space. Over polar regions the infrared radiation emitted to space exceeds the amount of solar radiation absorbed. As a consequence, the energy balance of the Earth can only be maintained by ongoing transport of energy from the tropics to the polar regions.

The transport of excess energy from the tropics to the polar regions is by the atmospheric and ocean circulations. Export of energy means that tropical surface temperatures are cooler than local radiation processes would suggest. In contrast, surface temperatures over polar regions are warmer than local radiation processes would suggest. The notion that it is possible to calculate local surface temperature on the assumption that there is radiation balance at the top of the atmosphere is fatally flawed.

The temperature differences between the equator and the poles drives the atmospheric and ocean fluids and their respective circulations are continually transporting energy in an attempt to achieve global radiation balance. The fluid motions and energy transports are further complicated by the annual cycle of solar heating. The equator to pole temperature gradient, and the ensuing poleward transport of energy, varies between winter and summer as maximum solar heating shifts between the hemispheres.

The rate of poleward transport of energy is a critical factor in regulating polar temperatures. A sustained reduction in poleward energy transport will cause a fall in polar temperatures; acceleration will result in rising polar temperatures.

An analysis of the rates of transport by Trenberth and Caron[9] quantified the magnitude and annual cycle of transport in each hemisphere. The authors estimate that between 85 percent (Northern Hemisphere) and 90 percent (Southern Hemisphere) of the transport is by the atmospheric circulation and the remainder is by the ocean circulations. The atmosphere and the oceans are fluids that interact through exchanges of momentum, moisture and heat at the sea-air interface and whose circulations vary non-linearly with changes to the equator to pole temperature gradient. There is, therefore, no expectation that the partitioning of energy transport between the atmosphere and the ocean will remain constant with time. Year to year fluctuations in the poleward energy transport by each of the fluids is to be expected. Variations of middle and high latitude temperatures on multi-year cycles are consistent with variations in the rate of energy transport, especially those due to changes in partitioning between the fluids.

The nature of the Earth’s surface, whether it be land or ocean, is also critical to how surface temperature responds to solar heating. Land surfaces have a low capacity to store heat because soils generally have a low heat conductance and seasonal heating only penetrates the upper few metres of the surface layer. Consequently, land surfaces tend to warm rapidly with seasonal solar heating and correspondingly emit infrared radiation at a high intensity; they also cool quickly because of the low capacity to store heat.

In contrast, solar radiation penetrates and is absorbed through tens of metres of the surface layer of the oceans. Mixing of the ocean surface layer by winds disperses the absorbed solar energy through the ocean surface layer to a depth of many tens of metres. The mixed layer of the ocean surface acts as a very effective energy reservoir, accumulating heat during summer and losing it through surface exchange of heat and latent energy during winter. The ocean energy reservoir is particularly important because of the ability to return heat to the atmosphere during winter and moderate overlying and downstream atmospheric temperatures of middle and high latitudes.

The partitioning of surface-atmosphere energy exchange between conduction and evaporation has important ramifications for establishing an equilibrium surface temperature over the tropics. As Priestley identified in 1966[10], surface temperatures are constrained over well-watered surfaces because of the cooling effect of evapotranspiration. In his study of worldwide land based climate data, Priestley identified a limiting upper temperature of between 33^{o}C and 34^{o}C over well-watered land surfaces. As a comment, Priestley also noted that, for the same reasons, an upper temperature limit of about 30^{o}C is to be expected for the world’s oceans. This is an important issue in the context of a constraint on human-caused global warming and will be discussed further.

Oceans cover approximately 70 percent of the Earth's surface and tropical surface temperatures are tightly constrained by the thermodynamics associated with the hydrological cycle and convective overturning. The sensitivity of tropical surface temperatures to increasing carbon dioxide concentration will be regulated by the rates at which surface energy is lost by conduction, evaporation and radiation. The rate of loss associated with each process varies with surface temperature, especially evaporation loss that approximately doubles with each 10 degrees C temperature increase. It is the combined increase in these components that will offset any increase in downward infrared radiation due to an increased concentration of carbon dioxide. Over the tropics, particularly, rise in surface temperature is constrained by the rapid rate of increase in latent energy loss as surface temperature increases.

The climate system cannot be treated as a truly steady state system because of the annual pattern of solar heating and the partitioning of energy transport between the oceans and atmosphere. At any time the global radiation budget may have an excess absorption of solar radiation or an excess emission of infrared radiation. It is the fluid characteristics of the oceans and atmosphere and their interactions that are the basis for internal variability of the climate system that causes interannual and longer duration fluctuations of surface temperatures over middle and high latitudes. The natural variability will tend to mask small very long duration trends.

The role of convection

In the IPCC explanation of the greenhouse effect it was concluded that absorption of solar radiation tends to warm the Earth's surface and net loss of radiation tends to cool the atmosphere. The global energy budget identifies that the energy exchanged between the surface and the atmospheric boundary layer by conduction of heat (24 W/m^2) and evaporation of water both (78 W/m^2) offsets the net radiation heating (solar absorption less net infrared emission) at the surface. The surface exchange is also sufficient in magnitude to offset the net radiation loss (102 W/m^2) of the atmosphere. What the budget and IPCC's construct of the energy processes do not explain are how the energy being exchanged is distributed through the atmosphere and the processes and controls over the rate of energy exchange across the surface-atmosphere interface.

Turbulent mixing will not distribute energy through the atmosphere from the boundary layer because total energy (the sum of heat and potential energy) increases with altitude. Energy does not mix up the gradient. Wind turbulence and larger scale vertical motions associated with weather systems will mix energy down the total energy gradient from high in the atmosphere to the surface.

In a seminal 1958 paper, Herbert Riehl and Joanne Simpson (nee Malkus)[11] described the role of deep convection clouds for transporting energy from the equatorial boundary layer and making the energy available through the troposphere to offset radiation loss. The deep convection clouds of the equatorial trough are an integral part of the tropical Hadley Cell circulations and provide protected pathways for buoyant ascent of boundary layer air to the high troposphere.

Within the convection clouds, the heat and latent energy of the boundary layer mass is transformed to potential energy as the air rises buoyantly to the high troposphere. As the air rises it cools and becomes saturated. Condensation releases latent energy giving the ascending air buoyancy. At the top of the cloud the updraught air spreads horizontally because it no longer has buoyancy, as it is dry and cold. The temperature and water vapour concentration is similar to the surrounding cloud.

Subsidence of the air surrounding the convection clouds is essential for mass balance and compensation for the air ascending buoyantly in the updraughts. In the subsiding air, potential energy is converted to heat as the unsaturated air mass sinks to lower height. It is the heating of descending air that provides the energy to offset the net infrared radiation loss of the atmosphere and is also a source of heat for transport to middle and high latitudes.

An important characteristic of the mass overturning of the tropical atmosphere (the Hadley Cells) is that the buoyancy forces in the protected updraughts of the convection clouds do work to overcome the natural stratification of the atmosphere. The need for buoyancy means that the air in the updraughts is always warmer than the air surrounding the cloud at the same level. Also, the rate of temperature decrease with height of the surrounding air is similar to that in the ascending air of the protected buoyant updraughts. The rate of decrease of temperature with height of ascending air in the convection clouds is well established from thermodynamics (known as the moist adiabatic lapse rate) and is approximately -6.5^{o}C/km in the lower and middle troposphere. In the colder and drier upper tropical troposphere the moist adiabatic lapse rate approaches that of the dry adiabatic lapse of -10^{o}C/km.

Active convection only occupies a small fraction of the tropical area but the associated moist adiabatic lapse rate is characteristic of the entire tropical atmosphere. This is because the tropical atmosphere is barotropic and surfaces of density and pressure tend to coincide. As a consequence, the tropical atmosphere is characterised by very weak horizontal temperature gradients and generally reflects the temperature change with height of the moist adiabatic lapse rate developed in the buoyant updraughts of deep convection.

The rate of temperature decrease with height in the tropical atmosphere is a direct outcome of the convective overturning that distributes heat and moisture from the boundary layer. Ongoing tropical convection will maintain the atmospheric temperature decrease with height at approximately the moist adiabatic lapse rate.

In 2004, Trenberth and Stepaniak[12] described the seamless transport of excess radiation energy from the tropics to polar regions by the overturning Hadley Cells of the tropics and the Rossby Waves of middle and high latitudes. The Hadley Cell overturning region approximately equates with the tropical area of solar radiation excess and the regions of Rossby Waves approximately equates with the regions of excess infrared radiation to space. In broad terms:

- tropical surface winds accumulate heat and latent energy in the boundary layer as they move toward the equator;
- heat and latent energy are converted to potential energy in the deep equatorial convective clouds;
- air flows poleward in the high troposphere and, as it subsides, potential energy is converted to heat;
- the Rossby Waves and weather systems transport excess heat poleward from the subtropics; and

- the heat being generated by subsidence is available to offset infrared radiation loss of the troposphere, both in the tropics and over polar regions.

The hydrological cycle traces the progress of water vapour between the surface and the atmosphere and its return as precipitation. Evaporation and the formation of water vapour extracts latent energy from the surface; the water vapour is entrained into buoyant convection where it cools and condenses during ascent. Latent energy is released to aid buoyancy as vapour is condensed to the liquid (rain) or solid (snow/hail) phase in the ascending air. The potential energy of the air increases during buoyant ascent. Ultimately, the potential energy is available as heat in the compensating mass subsidence and offsets infrared radiation loss by the greenhouse gases.

Radiation, convection and the greenhouse effect

Understanding radiation processes in isolation is not sufficient to explain the elevated temperature of the Earth's surface (the greenhouse effect). As has already been noted, solar radiation tends to warm the surface and infrared radiation tends to cool the atmosphere. Convection is necessary to distribute energy through the atmosphere from the boundary layer. It is the combination of radiation and convection that constitutes the greenhouse effect and keeps the surface warmer than the upper troposphere.

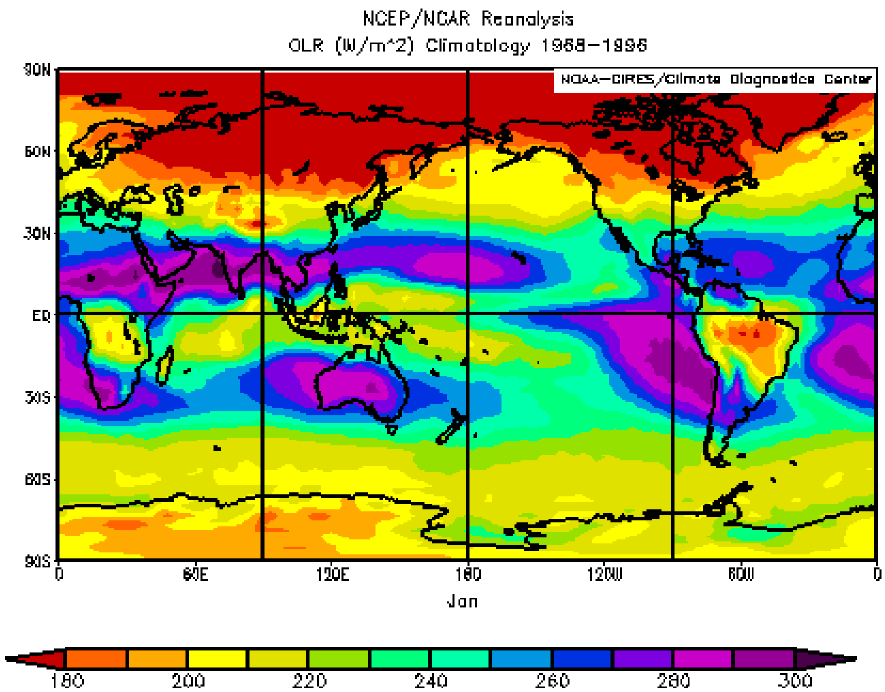
In the absence of greenhouse gases infrared radiation to space would emanate from the surface. The global radiation balance would be determined at the Earth's surface and the surface temperature would be, on average, about -19^{o}C.

When greenhouse gases, clouds and aerosols are present in the atmosphere then infrared radiation to space emanates from a layer above the surface. For global radiation balance, the infrared radiation to space must still be equivalent in intensity to the net solar radiation being absorbed within the climate system. That is, the global average temperature of the emitting layer must still be about -19^{o}C. The effect of the greenhouse gases, clouds and aerosols is to physically separate the region of the climate system where solar radiation is being absorbed (the surface) from the layer in the atmosphere where infrared radiation to space is emanating. It is convection that transfers energy from the surface to the atmosphere and maintains the effective radiating temperature of the atmosphere at -19^{o}C, the radiation equilibrium temperature of the climate system.

Buoyant convection requires a temperature decrease with height in the lower atmosphere of at least 6.5^{o}C/km. According to the IPCC, the altitude of the global average effective emission level of infrared radiation to space emanates from an altitude of approximately 5 km. The height of the emission level and the required lapse rate for convection parameters define that the surface temperature is about 32.5 degrees C warmer than that of the effective emission layer (-19^{o}C). That is, the combination of radiation and convection processes suggest a global average surface temperature of about 13.5^{o}C, very close to the estimated global average surface temperature of about 14^{o}C.

The radiation-convection construct is a more complete paradigm for the greenhouse effect. It infers that an increase in the concentration of any of the constituent greenhouse gases would lift the emitting layer to a higher colder altitude. In order to restore the global radiation balance it is necessary to restore the temperature of the emission layer. However, warming the

BOX 2



(Source: NOAA-CIRES Climate Diagnostic Center based on NCEP/NCAR Reanalysis)

Spatial Variations of Infrared Emission to Space

1. Maximum emission emanates from the regions of dry subsiding air over the subtropics.
2. Areas of reduced equatorial emission correspond to radiation from the cold tops of deep convection clouds that regularly occur over Central Africa, the Amazon Basin of South America and the maritime region extending from the Indian Ocean, through the Indonesian Archipelago, and to the western Pacific Ocean.
3. The regions with lowest emission correspond to the cold polar regions, with the Arctic having substantially lower emission than the Antarctic.

emission layer requires a warming of the surface temperature and that of the troposphere in order to maintain convective overturning. That is, increasing the concentration of greenhouse gases leads to global warming. The radiation-convection construct is qualitatively correct but still deficient because Earth's climate cannot be treated rationally as a one-dimensional system.

The effective radiating temperature of the Earth varies significantly with location and a global average value is not representative of characteristic regional processes (see Box 2). For example, across the major regions of subtropical subsidence, where the air is generally warm and dry, the effective emission temperature is about –6°C (290 W/m^2) and the emitting layer is low in the atmosphere. Across equatorial regions of deep tropical convection the emitting layer is controlled largely by the high cloud tops and is of the order of –25°C to –30°C (215-200 W/m^2). The effective radiating temperature of the cold polar regions varies from –32°C (190 W/m^2) across the Southern Hemisphere to –36°C (180 W/m^2) across the Northern Hemisphere.

The concept of a global average fails to capture the differing regional processes. In particular, deep convection, the primary process for transferring energy from the Earth's surface and which determines a local temperature decrease with height in the atmosphere, is confined to a limited region of the tropics. However the tropical atmosphere is barotropic such that density and pressure surfaces are forced by thermodynamic considerations to be approximately coincident. The vertical temperature distribution that evolves in the regions of deep equatorial convection will be reflected across the tropical atmosphere, covering nearly half of the Earth's surface.

Over the middle and high latitudes the surface and atmosphere lose energy through radiation processes. Temperatures over these regions are regulated largely by the poleward transport of energy by the atmospheric circulation and temperatures are warmer than they would otherwise be by local radiation processes alone.

Carbon dioxide as a greenhouse gas

Al Gore makes the statement that carbon dioxide is the most important greenhouse gas and that, as a result of human activities, the concentration in the atmosphere has increased. Almost as an afterthought he mentions water vapour as a natural greenhouse gas whose 'volume' increases with temperature and magnifies the effect of all 'artificial' greenhouse gases.

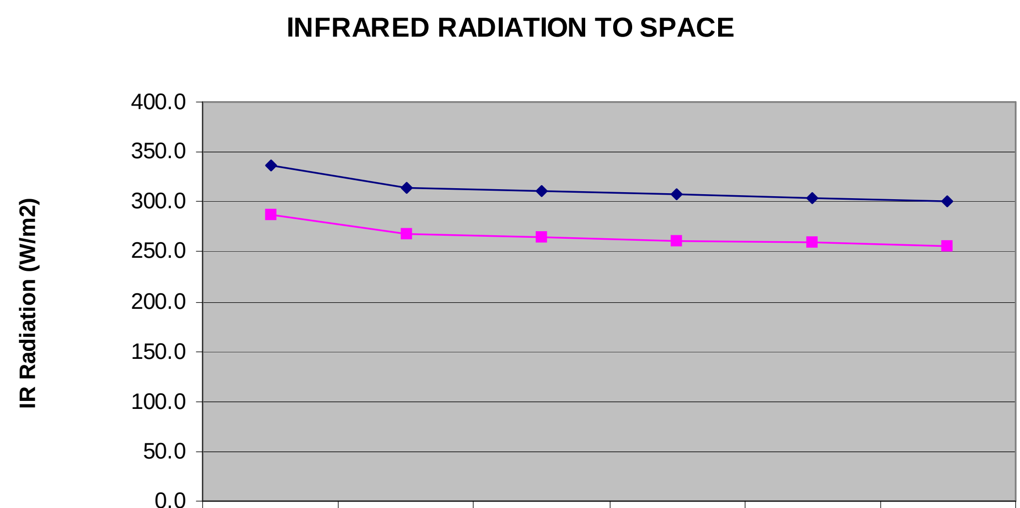
Carbon dioxide has a very important role in life on Earth. The process of photosynthesis is the conversion of carbon dioxide and water, in the presence of light and nutrients, to form plant material and oxygen. Carbon dioxide is required for growth of land and marine plants. Without carbon dioxide in the atmosphere and dissolved in the oceans there would be no life on Earth as we know it. *Carbon dioxide is not a pollutant but is essential to life.*

Life on Earth evolved over hundreds of millions of years and during most of that time carbon dioxide concentrations in the atmosphere were 2-3,000 ppm, nearly ten times current values. The extensive coalfields that are the basis of much of today's fossil fuel resources were laid down during these earlier times of high carbon dioxide concentration and plant growth. Many plants, which evolved during the earlier times, respond positively to an increase in carbon dioxide concentration. It is common to artificially enhance the carbon dioxide concentration of enclosed glass houses to promote growth of horticultural plants. An increase in carbon dioxide concentration of the atmosphere is likely to be beneficial for food production.

The reality is that water vapour and clouds dominate the Earth's greenhouse effect, not carbon dioxide. The low values of infrared radiation to space over the equatorial regions of deep convection are due to the high cloud tops and their very low temperatures (see Box 2). In those tropical regions where subsiding unsaturated air predominates and where clouds are absent or whose tops only reach low altitudes, such as the eastern Pacific Ocean, the effective emission layer is from much lower in the atmosphere and total infrared radiation to space is higher.

Even in cloud-free areas it is water vapour that dominates the radiative forcing. Calculations using an accurate radiation transfer model (MODTRAN3 available on-line from the University of Chicago[13]) shows that, for a US Standard Atmosphere profile, infrared radiation to space decreases by 50.5 W/m2 when a standard moisture profile is added and carbon

BOX 3



	0	50	100	200	400	800
Dry Air	336.7	313.5	310.1	306.8	303.5	300.1
Moisture	286.2	267.0	264.2	261.4	258.6	255.8

(Outgoing infrared radiation at 70 km altitude calculated for the US Standard Atmosphere using the MODTRAN3 radiation transfer model of the University of Chicago - *http://geosci.uchicago.edu/~archer/cgimodels/radiation_form.html*)

The radiative forcing effect of carbon dioxide (CO2) is near saturated

Radiative forcing is the reduction of infrared radiation to space due to changing concentration of greenhouse gases. (These calculations use the US Standard Atmosphere clear sky vertical profile and differ slightly from IPCC estimates based on global average vertical profiles.)

The radiative forcing due to carbon dioxide is largest for the first 50 ppm (19.2 W/m^2). For each doubling of concentration thereafter the increase in radiative forcing is only about 3 W/m^2.

The radiative forcing of the climate due to increased carbon dioxide from the last glacial maximum (near 200 ppm) to present values (near 400 ppm) is only about 3 W/m^2. Nearly 40 percent of the forcing has been since industrialisation. A doubling of the carbon dioxide concentration from present day values to 800 ppm will only increase the radiative forcing by a further 3 W/m^2.

Water vapour is the dominant greenhouse gas through the range of carbon dioxide concentration and has a radiative forcing component of about 45 W/m^2, more than double the forcing due to the introduction of carbon dioxide into the atmosphere.

dioxide is absent (see Box 3). By comparison, when the atmosphere is held dry and current carbon dioxide concentrations are added the reduction is only 33.2 W/m^2. Of the reduction attributed to carbon dioxide, 23.2 W/m^2 was due to the first 50 ppm added.

The Table and graphs at Box 3 show clearly that the radiative forcing effect of carbon dioxide is effectively exhausted after the first 50 ppm. After the initial infrared reduction of the first 50 ppm of gas there is only a small incremental reduction for each doubling of concentration.

From concentrations of carbon dioxide at the time of the last glacial maximum (about 200 ppm) to the present (about 400 ppm) the calculated reduction in infrared radiation to space, or radiative forcing, has only been about 3 W/m^2. Nearly 40 percent of this forcing is due to the increase in carbon dioxide concentration during the 20^{th} century. Even with a doubling of carbon dioxide concentration from current values to 800 ppm the radiative forcing will still only be increased by a further 3 W/m^2.

The reasons that a further increase of carbon dioxide concentration has little additional effect on infrared radiation to space are twofold; carbon dioxide is well mixed through the atmosphere, and the gas is radiatively active (high absorptivity and emissivity) in its characteristic wavelength bands. As a consequence, in those wavelengths the effective emission height for radiation to space is high in the atmosphere. At a concentration of 50 ppm the effective emission layer for the carbon dioxide bands is already in the stratosphere, where temperature changes little with height.

Satellite derived emission spectra of outgoing longwave radiation show that the effective emission temperature in the carbon dioxide bands is generally about $-52^{o}C$, a temperature characteristic of the stratosphere and in agreement with calculations. Adding more carbon dioxide to the atmosphere will elevate the height of the effective emission layer but will not appreciably change the effective emission temperature. As a consequence there will be little change in outgoing infrared radiation, or radiative forcing, relevant to the active bands when carbon dioxide concentration is increased.

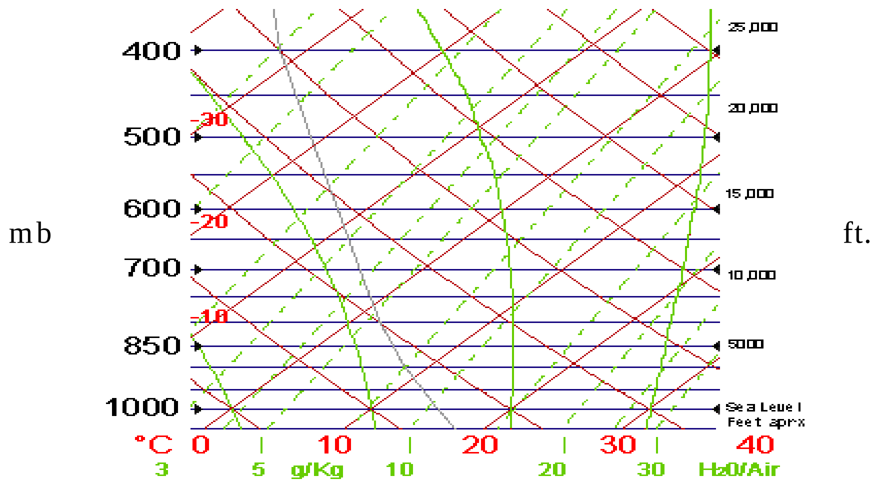
In the context of temporally and spatially varying water vapour and cloud distributions, with their large impact on infrared emission to space, the impact on infrared radiation of small changes in carbon dioxide is relatively small. This small impact may prove significant in a linear process where cloud and water vapour distributions were fixed and the carbon dioxide effect was additive. In reality, clouds and water vapour are highly variable and their radiation variations are likely to overwhelm any small impact from an increase in carbon dioxide concentration.

The magnitude of human-caused global warming

A minimalist but still realistic construct of the climate system recognises that there are differences in net radiation between the tropics and the poles and that convection and the atmospheric circulations are essential for achieving global radiation balance. The absorption of solar radiation, mainly over the tropical surfaces, is the source of energy for the simple heat engine that is the climate system. The energy sinks are the greenhouse gases, clouds and aerosols of the atmosphere and the high latitude surfaces that are net emitters of infrared radiation to space. The atmospheric circulations, especially Hadley Cell convective overturning of the tropics, Rossby Waves and weather systems, distribute excess energy from the tropical surface energy source to the atmospheric and high latitude energy sinks.

Box 4

Skew-T Log-P



Surface temperature increase is amplified in the upper atmosphere

Temperature and water vapour profiles in the atmosphere can be plotted on the Skew-T Log-P or Aerological Diagram.

1. The y-axis depicts atmospheric pressure (LHS) or standard height (RHS).
2. Temperature isotherms (^{o}C) are the straight red lines leaning right from vertical and water vapour concentration (g/Kg) are the green dotted lines also leaning right from vertical.
3. The psuedoadiabats (the temperature and water vapour concentration profile of saturated air ascending in the buoyant updraughts of convection clouds that define the moist adiabatic lapse rate) are the solid green lines curving upward from right to left.
4. The dry adiabats (the temperature profile of unsaturated air ascending or descending in the atmosphere) are the solid red lines curving upward from right to left.

Deep convection clouds cause atmospheric overturning in the tropics and distribute heat and latent energy from the surface through the atmosphere. The requirement of buoyant ascent and the barotropic nature of the tropical atmosphere cause the temperature decrease with height in the tropics to approximate a psuedoadiabat characteristic of the temperature at the Earth's surface.

The temperature difference between psuedoadiabats increases with height such that by 400 mb (24,000 ft or 7,200 m) the sea level temperature difference between psuedoadiabats has doubled; near the top of the tropical troposphere at 200 mb (40,000 ft or 12,000 m) the difference has trebled.

A temperature increase of 1^{o}C temperature at the surface in the region of active tropical convection is amplified to an increase of between 2 and 3^{o}C in the upper troposphere.

The corollary is that an increase in the upper troposphere temperature of 1^{o}C can be achieved by a temperature increase at the equatorial surface of between 0.3^{o}C and 0.5^{o}C.

The rate of distribution of boundary layer heat and latent energy to the atmosphere accounts for a large fraction of the global emission of infrared radiation energy to space. Any change in the infrared radiation loss to space through changing the concentration of greenhouse gases will be reflected as a change in the convective overturning in the tropics.

The ‘radiative forcing’ that results from increasing the concentration of atmospheric carbon dioxide affects the energy budget in a set sequence that can be used to evaluate the likely surface temperature response.

- The reduction in the rate of emission of infrared radiation from the atmosphere to space causes a reduction in net cooling of the tropical atmosphere, and thus a tendency for its stabilisation.
- The stabilisation of the atmosphere inhibits convective overturning and reduces the rate of energy transfer from the boundary layer to the atmosphere.
- The reduction in convective energy transfer causes an accumulation of energy in the boundary layer and inhibits conduction and evaporation from the surface.
- Solar energy accumulates at the surface and the surface tends to warm.
- The warmer surface temperature increases the rates of conduction and evaporation, which raises the temperature and energy of the atmospheric boundary layer and, as a consequence, enhances convective overturning.
- The higher temperature and moisture of the boundary layer means that the updraught is at a warmer psuedoadiabat (see Box 4) and buoyancy is maintained in a warmer tropical atmosphere.
- Infrared radiation loss to space is restored from the warmer atmosphere that is maintained by convective overturning from the warmer surface and a new energy balance is achieved.

IPCC calculates the 'radiative forcing', or reduction in infrared emission to space, resulting from doubling of atmospheric carbon dioxide concentrations above pre-industrial levels, to be about 4 W/m^2. At the average effective emission temperature of the Earth (-19^oC) a reduction of 4 W/m^2 in the infrared radiation emanating from the troposphere translates to a reduction in the earth's effective emission temperature of about 1^oC. A rise in temperature of 1^oC in the middle to high troposphere (the effective emission layer of infrared radiation to space) is necessary to restore the infrared radiation to space and offset the impact from doubling the carbon dioxide concentration.

A characteristic of the moist adiabatic temperature lapse rate (the rate of temperature decrease with height of air ascending buoyantly in convection clouds) is the amplification of actual temperature difference with height between adiabats. That is, as the surface temperature rises, the rise in temperature in the high troposphere is amplified by approximately 2 to 3 times (see Box 4). A temperature increase of between 0.3^oC and 0.5^oC at the surface is all that is required to achieve a rise in temperature of 1^oC in the high troposphere (the necessary compensation for the ‘radiative forcing’ from a doubling of carbon dioxide concentration).

The changes to the temperature at the surface and lower troposphere that are necessary to compensate for radiative forcing will be also cause a change in the surface energy budget. A warmer atmosphere with constant relative humidity will increase the downward infrared radiation at the surface. It is the increased back radiation from the atmosphere that provides the energy necessary to offset the enhanced conduction, evaporation and infrared emission at the warmer surface temperature.

Overall, the direct impact from a doubling of atmospheric carbon dioxide concentration above pre-industrial levels will have a relatively small impact on global temperature, and significantly less than 1^{o}C. Over middle and high latitudes, where excess infrared radiation to space prevails, any additional increase in the temperature of the troposphere by ‘radiative forcing’ is constrained by the ability of the atmospheric circulation to transport additional energy from the tropics.

Climate feedbacks

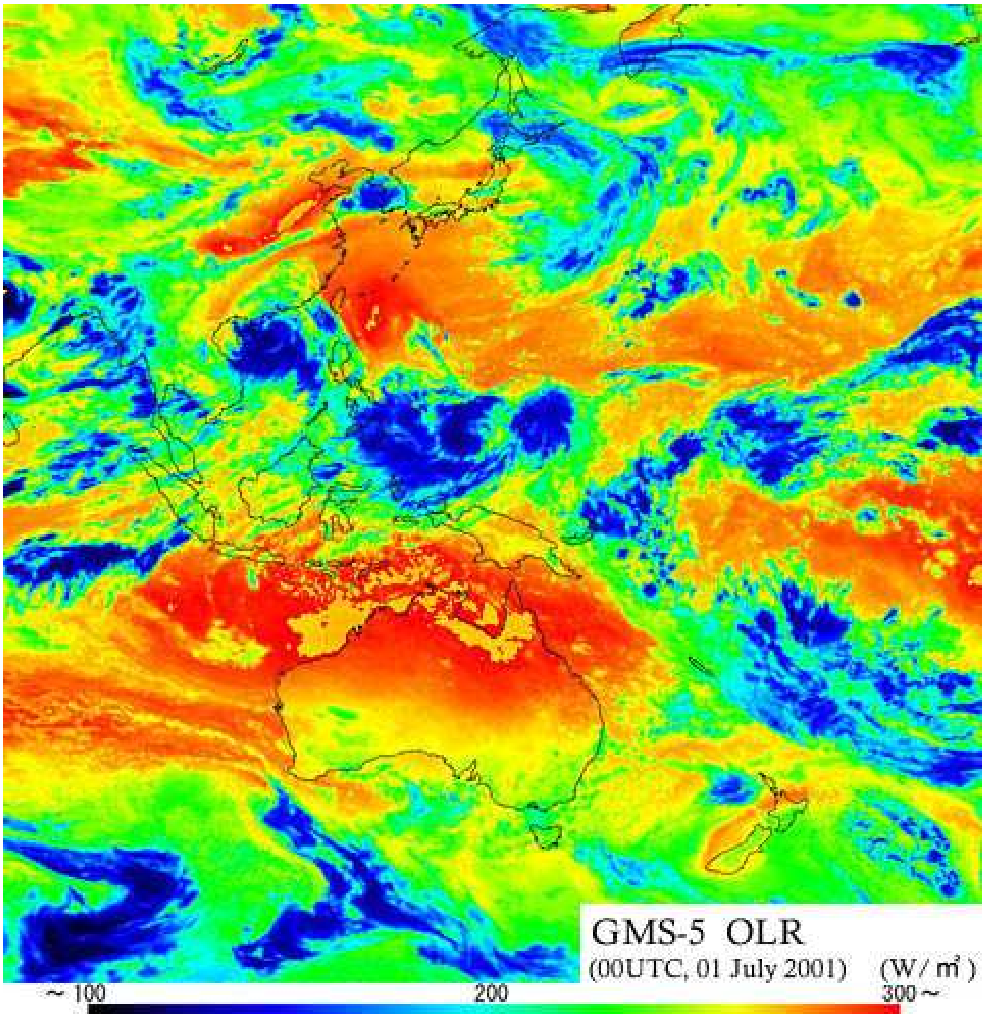
The structure of computer models of the climate system or General Circulation Models (GCM) has changed significantly since the early experiments of the 1970s. The early models were equilibrium models, where the response was the change of the ‘experimental’ simulation with imposed forcing from the ‘control’ without forcing. Also, these early models had no ocean circulation. The computer models have progressed to represent interacting ocean and atmosphere circulations, land surface processes and ice sheet growth and decay. The forcing of the computer model is applied as a growth function and the response is the change in the ‘experimental’ simulation from the initial climate state.

It is not possible to directly compare early projections of climate change made using equilibrium models with current projections using models that evolve under changing forcing functions, except in general terms. The current models depend on the time dependence of the growth in forcing, a factor which relates back to estimates of future global fossil fuel usage. Notwithstanding, there is a general similarity in the earlier estimates of a 1.5^{o}C to 4.5^{o}C from a doubling of carbon dioxide concentration and the current estimates of 1.4^{o}C to 5.8^{o}C by 2100. Each represents a significant amplification from the 0.3^{o}C to 0.5^{o}C from the direct radiative forcing from a doubling of carbon dioxide concentration.

The rationalisation by the IPCC for these enhanced sensitivities is that processes of the climate system (‘positive feedbacks’) act to amplify the direct radiative forcing due to carbon dioxide. The proposed amplification methods are hypotheses and not backed by observation.

One mechanism proposed for enhancing the climate sensitivity to radiation forcing by carbon dioxide is through the role of clouds. In this scenario the effect of global warming is to decrease the global cloud amount. The climate system is then able to more efficiently emit infrared radiation to space and tend to cool the Earth. It is suggested that this cooling effect is more than offset by the increased absorption of solar radiation because the amount of reflected radiation from cloud tops would be diminished. This hypothesis depends on whether there are more or less clouds at low, middle and high altitudes because clouds at different altitudes have different reflectance and impact on infrared radiation transfer. Such an hypothesis is also confounded if there is a change in the geographical distribution – tropical latitudes will be more sensitive to changing absorption of solar radiation through changing cloud patterns. Early satellite measurements from the Earth Radiation Budget Experiment did identify an in crease in infrared radiation to space over the past two decades, at least over tropical latitudes[14]. More recent evaluations of the data are more equivocal.

Box 5



Radiation to space varies in time and space

The colour image represents emission of infrared radiation to space as measured by the Japanese geostationary satellite GMS-5. The blue shadings are low emission intensities representing infrared emanating from cloud tops in the higher colder atmosphere. The red shadings represent high emission intensities emanating from the lower warmer atmosphere and generally cloud-free regions.

The same cloud patterns regulate the amount of solar radiation that reaches the Earth's surface.

The patterns of cloud heights and forms are constantly changing as weather systems develop, move, intensify or dissipate. For convection clouds, the lifetime is comparable to the frequency of satellite observations.

Because of the constantly changing cloud patterns it is difficult to measure and assess emitted infrared radiation and reflected solar radiation, and their variation with time, to a high degree of precision. Consequently it is not possible to draw conclusions about overall trends in radiation and cloud characteristics. Nor is it possible to draw conclusions about potential cloud feedbacks from anthropogenic global warming.

It has also been proposed that a warmer atmosphere will be capable of sustaining a higher water vapour concentration. Water vapour is a powerful greenhouse gas and the hypothesis is that an increased concentration could be expected to reinforce and amplify the forcing effect of increased carbon dioxide concentration. This argument has superficial appeal because, as previously noted, saturation vapour pressure of water increases approximately at an exponential rate with increase of temperature. Satellite observations support the view that the increase in atmospheric water vapour concentration over the past two decades is consistent with relative humidity remaining constant[16]. There is, therefore, potential for significant increase in the global water vapour concentration and amplification of the carbon dioxide forcing signal as the global temperature increases.

Notwithstanding the superficial appeal of the water vapour feedback hypothesis, it is difficult to assess the magnitude of water vapour amplification due to radiative forcing from an increase of carbon dioxide concentration. Water vapour, unlike carbon dioxide, is not well mixed through the atmosphere but is constrained to the lowest layers. This is because saturation vapour pressure, and the capacity of air to hold water vapour, decreases near exponentially with temperature. The temperature of the atmosphere decreases with height and any increase in atmospheric water vapour will be largely in the lower warmer layers.

It has already been noted that the greenhouse effect comes about because the effective infrared emission layer is lifted to a higher altitude as the concentration of radiating gases increases. In the case of carbon dioxide the gas is well mixed through the atmosphere and the effective emission altitude is raised as the concentration of the gas increases. In contrast, water vapour, as noted, is primarily confined to the warmer temperatures of the lower atmosphere. A warming of the atmosphere (at constant relative humidity) will ensure that there is more water vapour held in the atmosphere but the depth of the water vapour layer, and the effective emission altitude, are constrained by the rapid decrease in water vapour concentration with temperature.

Water vapour does act to amplify the radiative forcing of carbon dioxide but the amplification is not as great as computer models suggest. The MODTRANS3 calculations for emission to space from a cloudless tropical atmosphere produce a value of 287.8 W/m^2 at 70 km. If the surface and lower troposphere temperatures are increased by 1.0^{o}C to shift the atmospheric temperature profile, and water vapour concentration is held constant, then the infrared emission to space increases to 291.5 W/m2. If the calculation is repeated with constant relative humidity (in conformity with the radiation feedback hypothesis) the infrared radiation to space only increases to 290.0 W/m2. In these calculations the optical depth of the water vapour increased by 6 percent as a consequence of the increased temperature and constant relative humidity.

Calculations such as these can only give approximate first order effects. They do confirm that the increase in surface and tropospheric temperature will tend to increase the infrared radiation to space but that the restoration is reduced when water vapour is able to increase at constant relative humidity. It is not until the surface and lower troposphere temperatures are increased by 1.7^{o}C with constant relative humidity that the emission of infrared radiation to space returns to the same magnitude (291.5 W/m^2) as a 1^{o}C rise of temperature but with no increase in water vapour concentration.

Water vapour feedback is a positive amplification of the surface temperature rise due to increased carbon dioxide concentration. However it is also clear that the amplification is bounded, and probably less than a doubling of the direct forcing. The estimated direct warming of $0.3^{o}C$ to $0.5^{o}C$ from doubling the carbon dioxide concentration is not likely to to exceed $1^{o}C$ when water vapour feedback is taken into account.

It is also worth noting that the calculated downward infrared radiation at the surface increases by nearly 8 W/m^2, from 348.2 W/m^2 to 356.1 W/m^2, when the tropical surface temperature is increased by $1^{o}C$ and atmospheric relative humidity is held constant. This is a substantial increase to the net infrared radiation loss from the tropical atmosphere. The increased net radiation loss can only be offset by an increase of the energy exchange between the surface and the atmosphere, especially conduction and evaporation. Similarly, there is a requirement for enhanced convective overturning to make the additional heat available to the atmosphere. The analysed enhancement of the tropical Hadley Cell circulations during the decade of the 1990s[17], following the warmer ocean surface temperatures of the so-called Pacific climate shift of the middle 1970s, is consistent with enhanced infrared radiation loss from the atmosphere.

Water vapour and clouds are derivative properties of the climate system and cloud specification in models is especially sensitive to temperature and vertical motions. As a consequence, in computer models the accuracy of their representation is contingent upon, and sensitive to, their specification in relation to other broadscale circulation parameters. However, through their respective interactions with solar and infrared radiation they are important in regulating the energy flow through the climate system. Small biases or errors in the specification of how clouds and water vapour are represented in the computer models will amplify as errors in the projected energy and temperature states of the climate system.

The high-end computer model estimates of climate sensitivity to carbon concentration are implausible in the context of convective overturning of the atmosphere and basic thermodynamics. A projected rise in average global surface temperature of $5.8^{o}C$ translates to an increase in upper tropospheric temperature (ie, of the emission layer) of between 10 and 15 degrees C. Such a temperature increase equates to an increase in infrared radiation to space of between 40 and 60 W/m^2 if top of the atmosphere radiation balance is to be retained.

The consistent amplification, by computer models, of the global temperature response beyond that expected from the direct impact of carbon dioxide forcing is likely to be a systematic error in the specification of small scale processes rather than a real positive feedback effect in the climate system. Even the low-end amplification of $1.4^{o}C$ temperature rise during the 21^{st} century is nearly three times what might be expected from direct forcing and exceeds by fifty percent what might be expected with water vapour amplification.

A further argument against significant positive feedback process in the climate system is contained in the pattern of global warming associated with the warming phase of the major glacial cycles over the past million years. The warming phase of each cycle has consistently been more rapid than the cooling phase, and each warming phase has concluded at a global temperature that is only a few degrees C warmer than temperatures now prevailing. Without an internal temperature-dependent damping process within the system it would be highly coincidental that major global warming episodes would consistently cease at about the same climate state. Little has been written about the strong constraint on surface temperature rise due to the near exponential increase in evaporation with temperature was described by Peiestley. Evaporation and latent energy exchange that dominates the surface energy exchange at prevailing tropical temperatures.

Neither observation nor logical inference support the hypothesis that there are internal processes of the climate system that work to significantly amplify the relatively small direct radiative forcing due to human-caused increases in carbon dioxide concentration, particularly those claimed in respect of clouds and water vapour. In the absence of such evidence, it would be more profitable to look for systematic biases in the specification of derivative quantities of the computer models. Such biases will amplify with time and be misinterpreted as sensitivity to the imposed forcing, ie radiative forcing from human-caused carbon dioxide increase. The current approach of conjuring up hypothetical positive feedback processes to explain exaggerated sensitivity of the computer models is the source of concern about dangerous climate change but lacks credibility.

THE CHANGING CLIMATE

Recent climate change in perspective

Al Gore makes the statement, “It is evident in the world around us that very dramatic changes are taking place”. Gore’s inference is that Earth’s climate was stable prior to industrialisation and that the changes of recent decades are caused by human activities. Some of the cited changes, such as land clearing and mining, are an outcome of human enterprise. However the linkage of glacier retreat, ice calving, lake contraction and polar ice melting, to name a few of the examples given, to human causes is more rhetoric than science.

One of the reasons that there is so much mysticism and fear associated with climate and its recent change is that there is a dearth of unequivocal data relating to past climates. Satellites and their quantitative global coverage have only been available for about three decades. Instrument measurements of climate are only available from limited areas and few extend back more than a century. In the absence of data there is much opportunity for surmise and guesstimate as to what previous climate might have been like.

One of the tools to fill in the data void is computer simulation of the climate extending over a thousand years. The output from the long simulations supports the view that the climate system does not vary significantly unless forced by natural phenomena or by human activities. The limited ability of the computer models to fluctuate between climate states is more likely related to the formulation of the models rather than a real absence of internal variability of the climate system itself. Moreover, there is an absence of knowledge about how natural factors, such as solar variations, may have affected climate in the past.

The limited observations identify that there has been warming, changing rainfall patterns and a reduction in land ice over the past 100 years. These changes have been reflected in ecosystems. Species have migrated from former habitats and some populations have expanded while others have contracted, depending on their adaptive capacity. The question that has to be asked is whether these recent changes are unusual and the result of human influence on climate, as Al Gore would have us believe, or are they a reflection of the ongoing variability of the climate system under which species have evolved?

Fortunately there is not a complete absence of information prior to the development of instruments and the recording of information. Palaeoclimatology is the reconstruction of past climates based on the measurement and interpretation of sequential changes in geological structures or in the sequential changes in core samples extracted from the sea floor or ice sheets. Other techniques include the analysis of annual growth rings in biological materials, such as trees and corals. The dating of ancient tree lines and glacial moraines also contribute to our understanding of how climate has changed in the past.

As sedimentary layers of the Earth's crust were laid down over hundreds of millions of years the depositions left telltale signals. The very fact of layering indicates changing environmental characteristics and many of these are climate related. Within the layers the changing composition (including of organic material, soil material, isotopic ratios of component elements, etc) are interpreted, in the light of modern relationships. Analysis of these variations provides an impression of the climate at the time each layer was formed.

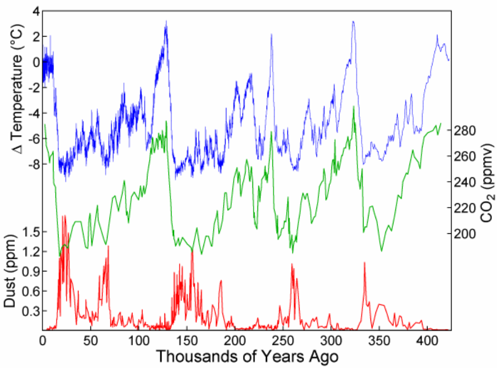
The palaeoclimatic reconstructions from all locations and across all time periods unambiguously portray a climate that is constantly changing. Some of the very long-term changes are related to tectonic movements as the continents shifted in their relative positions on the Earth's surface. Also, connections between ocean basins opened and closed and changed the circulations and heat transport, both within and between basins. These changes are slow and often their impacts span millions of years. Many of the changes in the local geological records, especially those formed in earlier times, cannot be related to specific events.

There is an expanding set of sediment cores obtained from drilling of the upper layers of the land and ocean floors that represent changes in climate that have occurred over the past several million years. Also, ice cores recovered from Greenland and Antarctica give detailed records of changes in climate that occurred over the last several hundred thousand years as the annual snow pack accumulated on the polar ice sheets.

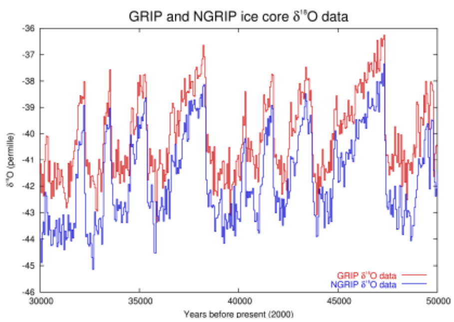
It is very clear from the sediment and ice cores that the Earth's climate has varied significantly over the past few million years and has generally been colder than the preceding hundred million years. The reason for the onset of these relatively cold conditions is not known. There are, however, plausible theories that are linked to the opening of Drake passage separating South America from Antarctica, and the establishing of the wind-driven Circumpolar Current that provides a thermal buffer between Antarctica and the warmer sub-tropical waters.

The evidence supports the view that, over the past million years, global temperatures have regularly waxed and waned with a period of about 100,000 years in accordance with the Milankovitch theory relating to the Earth's orbital periods[18] (see Box 6 – upper panel). During the extended cooling epochs the ice sheets of the polar and northern land areas expanded and thickened, and mountain glaciers advanced. The source of the expanding ice mass during these ice ages was evaporation from the oceans and, as a consequence, sea level fell. Interrupting the cooling were relatively brief intervals when large areas of the polar ice sheets melted and sea level rose.

BOX 6



Temperature, carbon dioxide and dust records over the past 400,000 years from Vostock, Antarctica (Source: Petit et al)



Isotopic oxygen data representing temperature between 30 and 50 thousand years ago from Greenland showing rapid fluctuations known as Dansgaard-Oeschger events (Source: Ice and Climate Group, University of Copenhagen)

Ice cores record climate fluctuations between ice age and warmer interglacial conditions that have repeated on approximately 100,000-year intervals (top panel). Temperature is inferred from hydrogen isotope variations and carbon dioxide is analysed from air bubbles trapped in the ice. Temperature and carbon dioxide appear to vary in tandem but detailed analysis points to temperature leading by up to one thousand years. Increased dust is recorded in those layers corresponding to the cold and presumably drier periods of the record.

The more detailed temperature record, inferred from the oxygen isotope record at two sites in Greenland (bottom panel), identifies sudden warming episodes.

Twenty thousand years ago the Earth's climate was approaching the limits of the Last Glacial Maximum. Great ice sheets covered North America and northern Europe and sea level was approximately 130 m lower than it is now. The North American ice sheets are estimated to have extended as far south as St Louis and to have been more than a kilometre thick over the Great Lakes region. Over northern Europe the ice sheet is estimated to have extended as far south as London and as far east as the Ural Mountains. Mountain glaciers extended far down the valleys of the European Alps. Although permanent ice did not accumulate over the Siberian Plains the combination of cold temperatures and reduced rainfall meant that boreal forests retreated far to the south.

The isotope ratios of oxygen and hydrogen analysed from Greenland and Antarctic ice cores suggest that high latitude temperatures were more than 10^{o}C colder at the time of the last glacial maximum than they are now. However ocean floor sediment cores obtained from near Indonesia indicate that what is now the warmest equatorial surface water temperature was only about 3^{o}C cooler at the last glacial maximum than now. This is clear evidence that the equator to pole surface temperature gradients where much stronger at the Last Glacial maximum than they are now, and that surface westerly winds over middle latitudes would have been stronger.

About 19,000 years ago Earth commenced a period of sustained and dramatic climate change that lasted about 8,000 years. Over this period the North American and northern European ice sheets melted leaving only the Greenland ice mass and remnant mountain glaciers. The melt water flowed into the oceans and sea level rose by about 130 m. The water in the surface layer of the equatorial oceans also warmed to about current temperatures.

There can be no doubt that the dramatic global warming following the Last Glacial Maximum has been beneficial for humans and for the biosphere in general. Flora and fauna expanded their domain poleward and flourished in the warmer and wetter conditions. Humans were also able to exploit the new ecosystems and settlements became established over what were previously inhospitable glacial landscapes.

One characteristic of the cyclic glacial climate fluctuations of the past million years is the apparent upper limit of temperature at the conclusion of each warming phase. The ice core data suggests that the peak polar temperature achieved about 10,000 years ago is similar to the temperature achieved at the end of each previous warming phase. Another characteristic is that the cooling phase of about 80,000 years duration is a much longer interval than the 8,000 years of the warming phase. If we accept the conventional Milankovitch view that the glacial fluctuations are related to the changing eccentricity of the Earth's orbit then it is unlikely that global surface temperature varies linearly with changes in net radiation at the top of the atmosphere – a linear relationship would lead to a cyclic temperature fluctuation rather than the marked saw-tooth pattern observed.

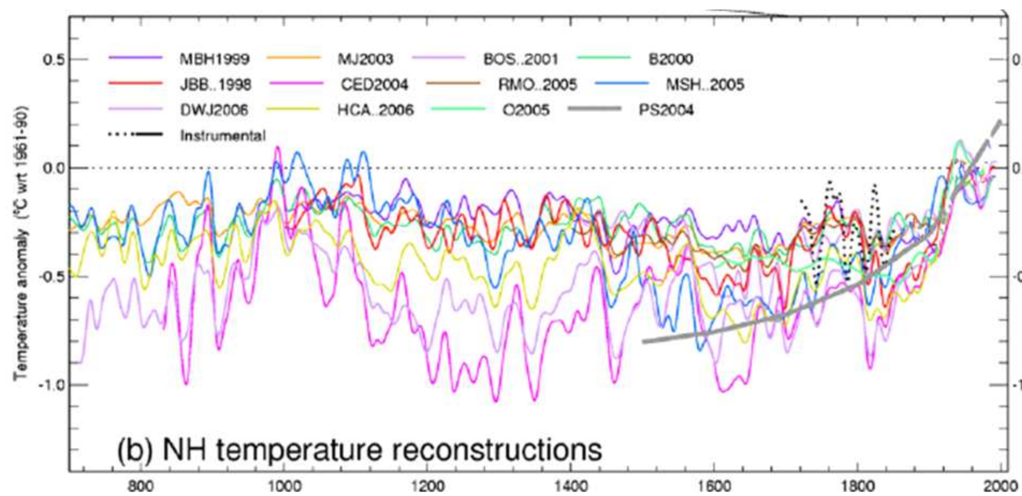
The Earth's climate also varies over periods that are less than the 100,000-year Milankovitch cycle. Signals related to the 40,000-year declination cycle and the 20,000-year precession cycle of the Earth's axis of rotation relative to the orbital plane can also be discerned from the ice core and ocean sediment records. There is strong evidence that millennial scale fluctuations pervade the last million years of the climate record[19]. These signals are departures from the orbital-forced trend and are most noticeable in the cooling phase.

The palaeoclimate record also provides strong evidence of fluctuations on millennial timescales. Sudden warming events, with temperature rises of up to 10^{o}C in Greenland temperature (known as Daansgaard-Oeschger events), are found in the ice core and ocean sediment cores over the concluding 20,000 years of the Last Glacial maximum (see Box 6 – lower panel). Over the same period, cold ocean surface temperatures in the North Atlantic correspond to periods of increased ice rafting debris on the ocean floor (Heinrich events). Ice rafting debris is fine material scoured from the land as glaciers move to the shoreline prior to calving and is then deposited on the ocean floor as the icebergs drift and melt. The material is too coarse to have been carried by ocean currents and the Heinrich events are recognised as successive layers of coarse material and finer silt.

Although there are reflections of the Daansgaard-Oeschger events in palaeodata from Europe they are almost absent from the ice cores of Antarctica. Neither the extent nor the reasons for the occurrence of the Daansgaard-Oeschger events has been established but the millennial scale fluctuations are clearly an important feature of the North Atlantic climate.

The global temperature record of the past 10,000 years is of particular interest for putting recent climate fluctuations into context. This period, known as the Holocene, has been one of prolonged warmth. The evidence is that early in the period temperatures were warmer than they currently are. Across North Africa and into the Middle East the climate was wetter than now with savannah vegetation and associated fauna prevalent across the region. Not only does

BOX 7



Proxy data have been used to reconstruct temperature histories of the past.
(Source: IPCC Fourth Assessment)

Reconstructions of past temperature have been made using various proxy data, including tree ring variations, coral growth layer variations, ice core layers and the chemical and physical variations of ocean and lake sediments. The variations in proxy data are correlated against recent temperature data.

Proxy data are not solely temperature dependent and their response variations are confounded by these other factors. We should not expect the proxy data to reflect the full amplitude of measured temperature data.

The proxy data do support the view of a warmer Medieval Period and recent temperature recovery from the Little Ice Age that extended between about 1600 and 1800. It is not possible to claim that recent temperatures are unusual or unprecedented because the proxy data cannot reflect the full amplitude of previous fluctuations.

the palaeoclimate data, particularly the ice cores of Greenland, suggest a cooling from the peak warmth of 6-9,000 years ago but it is also likely that subtropical regions have dried.

The cooling of the past 10,000 years has not been at a constant rate. The Holocene optimum prior to 5,000 years ago was succeeded by a series of climate fluctuations. These included the historically documented warmth of the Greek-Roman period of the first millennium BC, the Dark Ages of the first millennium AD, the Medieval Warm Period that straddled 800-1200 AD, the Little Ice Age that reached its peak in the period 1600-1800 AD, and the current period of rising temperatures and receding mountain glaciers.

As with the earlier millennial scale fluctuations, there is not sufficient unequivocal data to map the geographical extent or the magnitude of the fluctuations of the past 5,000 years. As demonstrated by Soon and Baliunas[20], the Medieval Warm Period and the Little Ice Age can be inferred from data covering a wide geographical distribution. Although neither the occurrences of peak warmth nor strongest cooling coincided in local records there was a broad pattern with the respective warmest and coldest periods of each record generally falling within the appropriate periods. There is a general recognition that the Little Ice Age was significantly cooler than the present but it is not possible to be categorical as to whether the Medieval Warm Period was as warm or warmer than the late 20th century. Some palaeoclimate reconstructions of the last 1,000 years are shown at Box 7 and underscore the uncertainty of quantitative reconstructions.

In comparison with the palaeoclimate record, the record of global temperature derived from instruments is relatively short. Crude thermometers were first developed in the early 17th century. However it was not until the early 19th century before instruments based on common measuring scales were deployed in networks to study the Earth's thermal properties and its climate. The middle 19th century is a generally accepted beginning of the global instrumental record for surface temperature.

Our interpretation of the climate record, and the context of recent climate, is fraught with difficulties and uncertainties. There is a high degree of uncertainty in the quantitative comparison of various palaeoclimate proxies such as obtained from sediment cores, ice cores, tree rings and coral layers, and historical chronicles. For example, rock art depicting savannah fauna in an environment that is clearly now desert is difficult to resolve. Yet such rock art is widely depicted in the now arid regions of North Africa and the Middle East, suggesting a significant reduction of precipitation. The changing structure and chemical composition of sedimentary layers and ice cores clearly have resulted from a climate influence but climate is not the only determinant. Even tree rings and coral layers, widely used as a measure of past temperatures, vary with a range of climate factors other than temperature.

Our estimate of the global temperature record covering the past few millennia is of particular interest because it provides a context for the recent instrument record that covers no more than 150 years. Notwithstanding the relative accuracy of modern thermometers, there is an ongoing problem of representative sampling. Prior to the introduction of satellite monitoring and the ability of these platforms to provide global coverage, the thermometer network density was a source of bias. Routine ocean observations were only available along shipping routes and land-based observations were biased towards more densely settled regions of developed countries. There were vast expanses of the oceans and less settled and less developed land regions for which there were no regular data. As a consequence, the global temperature record of the past 150 years reflects trade routes and changing maritime observing procedures, the effect of urbanisation on local temperature records, changing instrument technology and a bias towards the more settled land regions.

Despite the measuring limitations, it is clear that the instrument-based global temperature record of the past 150 years reflects a real warming trend that is consistent with warming from the Little Ice Age. The warm temperatures of the past two decades are the warmest of the past 400 years and are potentially as warm or warmer than those of the Medieval Warm period[21]. The generally warming temperature record is supported by observations of worldwide recession of mountain glaciers over the past 200 years and the interpretation of borehole measurements. There is uncertainty as to the magnitude of the recent global temperature rise but the direction is unambiguous.

In the context of past climate fluctuations it is misleading to imply that the warming of the past 200 years is unusual or that recent temperatures are unprecedented. Temperatures were apparently warmer early in the Holocene and rapid temperature rise occurred in the lead up to the Medieval Warm Period. It is certainly an unfounded assertion to claim, as Al Gore has done, that the Holocene has been a period of stable climate and that recent warming is unusual.

The stability of polar ice sheets

Massive destruction of the Greenland and Antarctic ice sheets, and raising of sea level by more than 6 m, are the most dramatic outcomes from human-caused global warming proposed by Al Gore and fellow alarmists. If such destruction and ice melt were to occur, and over a relatively short time span, then it would be a truly disastrous outcome for humanity and coastal ecosystems. Fortunately, there are good reason to believe that the Greenland and Antarctic ice sheets are relatively stable, and that such an outcome from human-caused climate change is extremely unlikely.

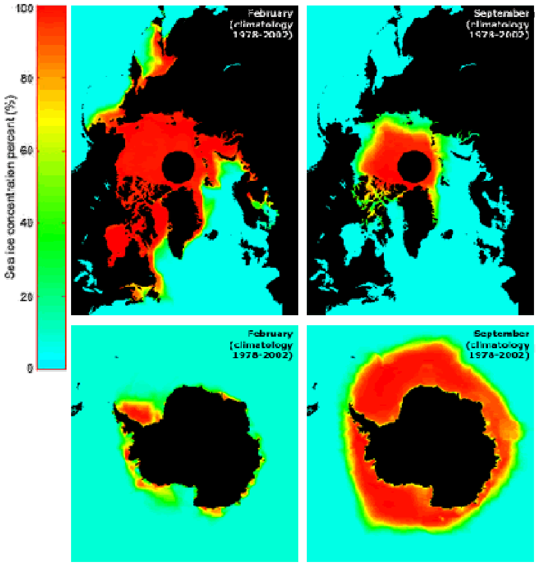
The Greenland ice sheet has been preserved, although not in its entirety, during previous interglacials. It is likely that parts of the sheet have existed for more than a million years with annual snow accumulating on the surface over the high interior plateau and with spreading and periodic melting at the margins.

There are two essential reasons for the relative stability of the Greenland ice sheet. Firstly, it is situated in a region of net radiation loss, where there is more infrared radiation emission to space than the solar energy received – energy is required to melt the ice mass. Secondly, it is only during a few months of summer, when total daily solar radiation exceeds equatorial values, that there is a net surplus of radiant energy available to melt accumulated ice and snow. Even during the brief summer, when there is a net surplus of solar radiation, temperatures across the high plateau generally remain well below melting point. Evaporation from the snow surface requires about eight times the energy required for melting, which means that at the sub-zero temperatures of the high plateau the ablation rate is low even at the height of summer.

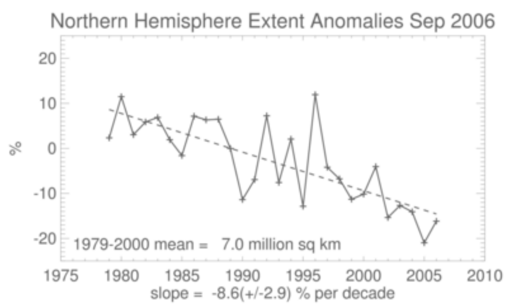
The prevailing general picture of the Greenland Plateau is one of accumulating snow over the high plateau with ice mass spreading towards the coast and melting where summer temperatures become sufficiently warm along the lower coastal margins[22]. It is likely that this has been a consistent pattern for peripheral ice melt for most of the last 10,000 years of the current interglacial. A qualification is that at the beginning of the interglacial 10,000 years ago the Earth was closest to the Sun at northern midsummer but, due to precession, the Earth is now farthest from the Sun at northern midsummer. There is continuing debate as to whether there is now net accumulation or loss of ice mass over Greenland although the peripheral melting would suggest there is a continuing slow contraction of the area.

The history of European colonisation of southern Greenland and Iceland provides some indication of how temperatures of the region have changed over the recent millennium. During the medieval period summer conditions on the coastal lowlands were sufficiently warm that the land surface thawed. Crops could be grown and pastures provided feed for grazing cattle. This was similar to other sub-Arctic lands on similar latitudes, including Norway. With fishing and trade, independent agricultural communities could be sustained. Around the year 1000 the population of Greenland was approximately 3,000 people living on 3-400 farms

BOX 8



Source: The National Snow and Ice Data Center



Seasonal variations and trends of polar sea ice

The satellite-derived climatology (top panel) demonstrates that polar sea ice extent goes through an annual cycle in response to the annual cycle of solar radiation.

Arctic sea ice varies from 6-7.5 million sq. km minimum to 15-18 million sq. km maximum. There has been an observed marked reduction in Arctic sea ice, both late for summer minimum and late winter maximum, over the period of satellite monitoring (bottom panel) Sub-surface sonar measurements indicate a general thinning of the sea ice.

Antarctic sea ice extends over a maximum area of nearly 19 million sq. km. There is no evidence from satellite monitoring of consistent change since 1979.

The climate of the North Atlantic became steadily colder during the late 13th century. Grove[23], reporting on the assessment of historical records by Ogilvie[24], describes how the climate of Iceland was severely cold in the 1280s and 1290s, became variable although generally mild during the early 14th century but with severe conditions returning after 1365. The years between 1380 and 1430 were again generally mild with occasional severe years. Then the climate got steadily colder. After 1580 the climate was particularly severe with "ice always to be found between Iceland and Greenland". Although the period 1640-1660 was remarkably mild this was followed by a prolonged period of severe cold, particularly 1690-1700 and the 1740s. Sea ice continued from the 1780s to the early 20th century, except for a brief interruption between 1840 and 1854. The warm conditions of the 20th century were only interrupted by a brief return of sea ice conditions in the 1960s

For the settlements of Greenland the growing season apparently shortened during the late 13th century and crops and pastures became more difficult to sustain. Grove, based on reconstructions by Koch[25] and Bergthorsson[26], has described how coastal sea ice formed around parts of Iceland in winter and became more extensive with time from the 14th century. It is reasonable to assume that it was the increasing extent and duration of winter sea ice that inhibited trade with the Greenland colonies because communications eventually ceased. As the winters became increasingly severe the crops and pastures deteriorated and provided less and less sustenance for the people and their animals. Without support from trade, the last of the descendants of Greenland's original European colonists perished in the early 1500s. European settlement did not resume until the establishment of a trading post in 1721.

The abandonment of farms in some fjords of Norway early in the 14th century has also been attributed to advancing cold as glaciers advanced down valleys and cold winds off the expanded ice sheet modified local temperatures. The sudden abandonment suggests rapid climate deterioration. Farm records also point to advances of glaciers in the late 15th and 16th centuries.

The cold of the North Atlantic continued until the early 20th century. Between 1600 and 1900 the records indicate that coastal sea ice formed and surrounded much of Iceland each winter. Permanent land ice accumulated on some parts of the island that were previously available for agriculture. During this period frozen rivers and coastal sea ice were not uncommon in England and parts of Europe. The freezing over of the Thames River from 23 December 1683 through middle February 1684 and the occurrence of a 'frost fair' provides a glimpse of life during the Little Ice Age. According to London diarist John Evelyn[27]:

> *"men and cattle perishing in divers places, and the very seas so locked with ice that no vessels could stir out or come in. The fowls fish and birds, and all our exotic plants and greens, universally perishing. … Here was no water to be had from the pipes and engines, nor could the brewers and divers other tradespeople work, and every moment was full of disastrous accidents."*

The cold period of the 17th and 18th centuries, as it affected the region of the European Alps, is well documented by the French historian Le Roy Ladurie[28]. A central discussion is the advance of mountain glaciers into the lower valley of the Arve River near Chamonix during the 15th and 16th centuries, and their subsequent retreat that began in the early 19th century.

Relatively accurate monitoring of Arctic sea ice has been made since appropriate satellite instruments became available about 1979. The sea ice expands and contracts with the seasons and the magnitude of the annual change is approximately 10 million sq. km (see Box 8). The data clearly identify a trend of decreasing sea ice area, both at times of maximum and minimum extent, over the short duration of observations. Sub-surface sonar measurements made over several decades also indicate that the sea ice is thinning.

Satellite measurements of the Greenland ice sheet indicate that the elevation over much of the plateau is increasing with ice accumulation but that the lower coastal periphery is thinning as ice melts. The limited accuracy of the instruments and the complex terrain prevent an accurate assessment of the ice mass balance.

The trend of reducing Arctic sea ice and the melting of ice mass from the coastal lowlands of Greenland need to be assessed in the context of the apparent millennial temperature fluctuations of the region and the evidence of behaviour during the current and previous interglacials. Although the direct measurements only cover recent decades the changes are part of a regional pattern that is most likely of global extent, given the worldwide behaviour of mountain glaciers. The warming and ice melt has its origins at the beginning of the 19th century. Moreover, the ice melt is neither unprecedented nor unusual, as there is evidence that during the previous interglacial, when temperatures were warmer, the Greenland ice sheet was less extensive than now and sea level was several metres higher.

There are suggestions that the West Antarctic ice sheet might be unstable because its base is not grounded and the ice sheet is anchored to islands with water flowing beneath it. If sea level rose the whole ice sheet may disintegrate and the parts drift into the Southern Ocean and melt, as happens from time to time on a much smaller scale with the Larsen Ice Shelf. If all of the West Antarctic ice sheet were to disintegrate it would raise global sea level by about 6 m.

The Antarctic sea ice has an annual cycle of expansion and contraction with the annual cycle of solar radiation (see Box 8). The winter extent of sea ice is nearly 19 million sq. km, slightly more than the corresponding extent of Arctic sea ice. In contrast, most of the Antarctic sea ice melts in summer and there is no appreciable reduction in extent during the period of satellite observations. Apart from over the Antarctic Peninsula, there is no variation in surface temperature evident and it cannot be concluded that ice mass over Antarctica is decreasing.

The Antarctic Circumpolar Current provides an effective physical and thermal barrier for the continent and tends to isolate the ice mass. The vertical overturning associated with the Circumpolar Current causes upwelling of cold sub-surface water on the poleward side of the current, an equatorward drift of surface waters, and downwelling of the cold surface water beneath the subtropical waters at the convergence boundary (see Box 9).

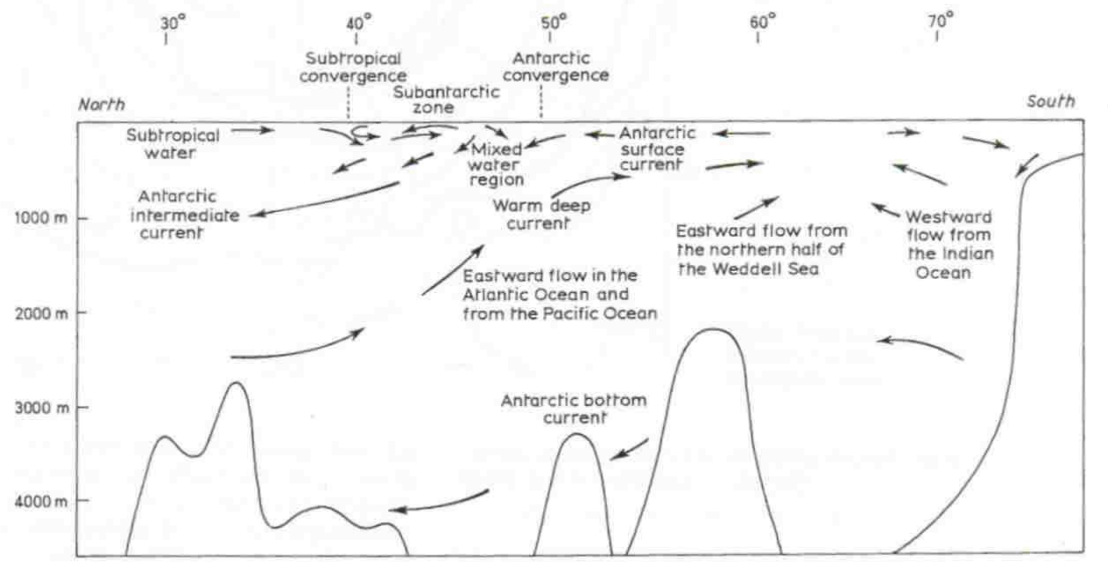
There is no evidence of instability in the West Antarctic ice mass. The wind-driven Circumpolar current protects the continent from warm water intrusion and there is no evidence of recent temperature rise except on the Antarctic Peninsular exposed to the varying westerly winds. Slow sea level rise is unlikely to destabilise and cause break-up of the West Antarctic ice sheet.

Another alarm raised in the context of polar ice sheets is the possibility that warmer temperatures will cause glaciers within the polar ice sheets to surge dramatically. We have the precedent of the Heinrich events during the last glacial periods where enormous masses of ice drifted into the North Atlantic where they melted and dropped debris to the ocean floor. Evidence of recent increases in glacier speeds over both Greenland and East Antarctica has been attributed to global warming. It is suggested that warmer temperatures are lubricating the bedrock-ice sheet interface such that the masses are beginning to surge and may break up completely, thus raising sea level. This is an unlikely scenario.

Meltwater pools do form on the lower elevations of the ice plateau during summer when the surface temperature exceeds the melting point. The meltwater follows crevasses and other weaknesses and possibly reaches the bedrock. In the process the ice layer is eroded from within and the ice layer tends to disintegrate. Such erosion has been observed prior to the break up of coastal ice shelves. Meltwater pools are observed on the lower elevations of the Antarctic Peninsula and Greenland Plateau but it is unlikely that such meltwater is of sufficient magnitude that it will contribute to the destruction of the main ice sheets.

There are more than 140 subglacial lakes beneath the Antarctic ice sheet. The biggest of these is Lake Vostok, made up of freshwater and beneath more than 4 km of ice. It is 200 km long by 50 km wide at its widest point and the depth varies between 400 m and 800 m. The water temperature averages -3^{o}C and remains liquid below the normal freezing point because of the pressure from the weight of overlying ice. The ice sheet insulates the lake from the cold

Box 9



Vertical overturning associated with the Antarctic Circumpolar Current

(Source: Scientific Committee for Ocean Research)

The schematic cross-section of the Southern Ocean shows the region of upwelling at about 65°S generated by the wind stress of the surface westerly winds.

The process of Ekman turning causes the cold surface waters to drift northward and plunge to depth under the warmer waters at the subtropical convergence.

Adjacent to the Antarctic continent the surface waters cool and, during winter, the density increases as sea ice forms and salt is expelled into the waters below. The cold salty water sinks to form Antarctic Bottom Water.

The upwelling cold subsurface water and the continuous Antarctic Circumpolar Current provide a physical and thermal barrier against the warmer subtropical water.

temperatures at the surface (colder than –80°C in winter) and geothermal heat from the Earth's interior warms the bottom of the lake.

The physical parameters of Lake Vostok and similar subglacial lakes point to why lubrication of the bedrock by surface meltwater is unlikely, except in the relatively shallow sheets of the coastal lowlands. Firstly, over the high plateau of Greenland and Antarctica the surface temperatures are too cold for surface meltwater to form in any quantity; meltwater formation is only feasible over the lower coastal ice margins. Secondly, the pressure of overlying ice compacts and closes any crevices that might form. There is no pathway from the surface to the bedrock over the thick ice sheets covering much of Greenland and Antarctica.

Nevertheless, the evidence suggests significant changes to the ice sheets are possible under the appropriate conditions. We do not know why the last interglacial was apparently warmer than the current one and led to significantly more melting and contraction of the periphery of the Greenland ice sheet than currently being experienced. However the current rates of melting are not contributing appreciably to mass loss and sea level rise. The Heinrich events during the last glacial period indicate surging of the coastal ice flow due to a build-up of ice mass in the very cold temperatures. Peripheral melting currently prevents such a build-up and there is no evidence that recently observed surging is any more than natural variations of the glacier flow.

Fears raised by Al Gore about impacts of global warming on the polar ice sheets are essentially alarmist and unfounded. The ice sheets have a very large thermal inertia and the additional energy required to melt them is enormous. Solar radiation is the energy source for summer snow and ice melt but the prevailing temperatures and the net radiation loss of the regions mean that there is only a short window of opportunity for effective ablation. The current rate of sea level rise of less than 3 mm per year, as given by satellite altimeters, indicates that polar ice is not melting at a rate that should cause alarm.

Managing weather and climate extremes

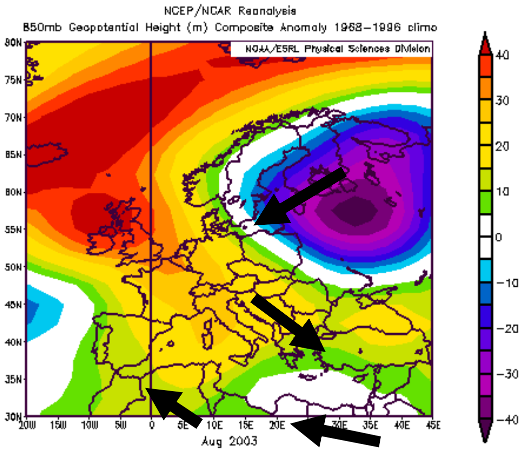
Human communities have become established in most climate regimes of the world from the humid equatorial jungles, through the hot subtropical deserts and milder temperate middle latitudes, to the harsh cold of polar latitudes. Through technology and trade they have adapted to the local climate and established lifestyles that continue to provide shelter and sustenance. Some climate regimes or local resource bases are more favourable than others are and these support more populous settlements.

Regardless of apparent wealth, all communities are exposed to the hazards of weather and climate extremes. Tornadoes and severe hailstorms are capable of severely damaging any but the strongest structures. Tropical and middle latitude cyclones are capable of causing swathes of wind damage to housing and urban structures, flooding of low-lying areas and coastal inundation from storm-surges. Prolonged rainfall deficiency leads to agricultural and pastoral loss, water shortages, and increased wildfires. Associated with these hazards are increased risks of death, injury or sickness.

A major indicator of a community's stage of development is its ability to withstand weather and climate extremes. Subsistence and itinerant communities are often caught unprepared and exposed to the full force of extremes; they suffer deaths, injury and disease during and following an event. A characteristic of more developed communities are early warning systems such that people can take shelter, either in their own or public facilities; public assistance for the injured and restoration of damage to community infrastructure following an event; and financial services to fund repair of private property and public infrastructures. In more developed communities there is a tendency for fewer lives being lost but greater property damage being suffered during a hazardous event. Nevertheless, regardless of their preparedness, people generally fear the approach of a hazardous event.

It is therefore intellectually dishonest for Al Gore to use recent weather and climate extremes that are fresh in the community psyche and claim, without evidence, that these are an outcome of human-caused climate change and examples of worse to come. Weather systems represent classes of the atmospheric circulation that are largely governed by broadscale thermodynamics. Season and location determine the occurrence of systems but their variability is regulated by the juxtaposition of larger-scale processes. Climate extremes are the extended biasing of larger-scale processes to temporarily increase the frequency or prolong the absence of expected weather systems.

BOX 10



Blocking circulation over Europe during the heat wave of August 2003
(Source: NOAA http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl)

A 'blocking' situation became established over Europe during August 2003 as the normally mobile weather systems became near stationary. The airflow across Southern and Western Europe was more from the south and east, bringing warmer air across these regions. The circulation over the area was strongly anticyclonic with clear skies and subsiding dry air.

At the same time the airflow over Central Europe was biased towards northerly winds, bringing cooler temperatures than normal.

Blocking situations are a regular phenomenon and the duration, location and intensity of each event determine their impact. The heat wave over Western Europe during the summer of 2003 was particularly intense because of the prolonged period and location of the anticyclonic anomaly that resulted in persisting advection of warm air, and the clear skies caused daytime temperatures to be very warm.

Heat waves

Al Gore makes much of the summer heat wave over Western Europe in 2003 for which estimates of the death toll are as high as 35,000 people. Various statistics have been produced suggesting that the episode was sufficiently outside the expected bounds of natural variability that, by implication, it could only have been caused by climate change. Moreover, the climate change must have been related to human-caused global warming. Al Gore claims that the 2003 heatwave is the sort of event that will become more common if global warming is not addressed by reducing carbon dioxide emissions.

In reality, the statistics overlook the thermodynamics of the event. The heat wave was caused by a prolonged blocking situation, a phenomenon that is not itself unusual (see Box 10). The reasons that this event produced such high daytime temperatures over Western Europe were the intensity and location of the anticyclonic circulation anomaly that caused generally subsiding and clear skies to maximise solar heating of the surface. At the same time, warm air was drawn from the south and east. Apart from the strength and duration the anomaly was not unusual.

The highest daytime temperatures from three cities of southeastern Australia with long records underscore that heat waves are extreme weather events. The region had been suffering drought during 1938 and by January 1939 the countryside was parched. On 12 January the maximum temperature at Adelaide (records since 1887) reached 46.1°C and on the 13th reached 44.2°C. These continue to be the hottest and equal second hottest days ever recorded for Adelaide. On 13 January Melbourne (records since 1856) recorded 45.6°C, its highest ever. On 14 January Sydney (records since 1859) recorded 45.3°C, also its highest daytime temperature ever. The intense heatwave persisted for more than a week and in addition to the record temperatures there were many wildfires that caused deaths and widespread destruction. Nobody has attributed the January 1939 heat wave over southeastern Australia to human-caused global warming even though it came at the end of a 3-decade long trend of rising global temperatures.

It should be noted that alarmists focus on the heatwave and deaths associated with the 2003 heatwave event. They fail to discuss the cooler conditions that were part of the blocking circulation and prevailed over Central and Eastern Europe as a consequence of the persisting cooler airflow from the northwest. It is also presumed that heatwaves will always produce deaths, particularly to the elderly and frail. What is overlooked is that heatstroke can be avoided by appropriate care.

Hurricanes and tropical cyclones

Al Gore links an apparent recent increase in the number and frequency of tropical cyclones, including hurricanes and typhoons to human-caused carbon dioxide emissions and global warming. He highlights the terrible loss of life and destruction associated with hurricane Katrina and cites the record number of hurricanes, especially the number of strong hurricanes, in the Atlantic during the summer of 2005. This, according to Gore is a taste of the future as carbon dioxide emissions increase and Earth gets warmer to produce more frequent and more intense hurricanes. The evidence does not support these alarmist predictions.

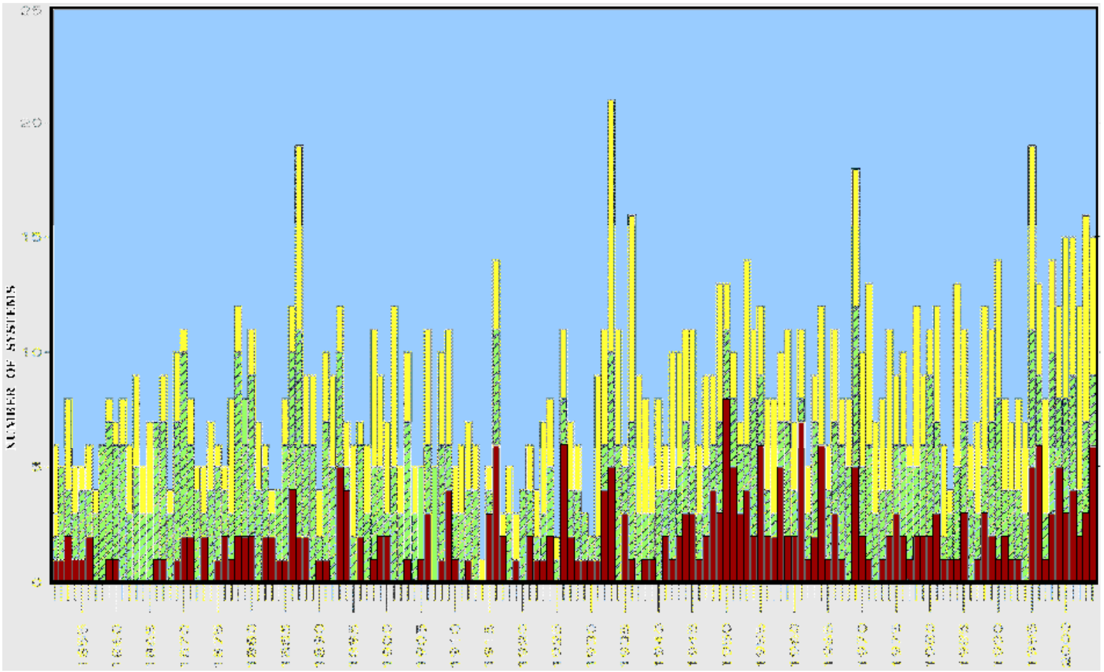
The 2005 hurricane season that laid a path of death and destruction through the Caribbean, the Gulf of Mexico and onto mainland USA received wide media coverage. There is no question that 2005 was an extremely active hurricane season for the region. What is in question is whether the nature of the season had anything to do with global warming trends and carbon dioxide emissions.

Al Gore highlights the death toll and damages caused by Katrina, a severe but not record intensity hurricane. A full review of Hurricane Katrina has not been completed. Without attributing responsibility, it is apparent that much of the loss of life and damage were due to a combination of lack of timely preparation leading up to the storm's onset, failure of vital infrastructure, and slow response in the aftermath following the storm's passage. There are lessons from Katrina for planning, preparation and emergency responses, as there are after any major disaster. However a strategy of cutting back on carbon dioxide emissions to prevent future hurricane loss of life and destruction lacks credibility.

The first things to note about the summer of 2005 is that the broadscale tropical circulation characteristics of the atmosphere were unusually favourable for hurricane development. There were 31 named tropical storms of which 15 reached hurricane strength. These numbers are three times the climatological numbers of 10 named storms and 6 of hurricane strength each year for the region. In sharp contrast to 2005, the summer of 1997, which preceded the warmest year in the instrumental record, had only 9 named storms and 3 hurricanes. This underscores that while warm ocean surface temperatures are essential to initiate tropical cyclone formation it is the broader scale characteristics of the atmospheric circulation that regulate the actual occurrence and intensity of the systems.

The climatological record does not suggest that there has been a trend towards greater numbers and more intense storms. The histogram of annual numbers (see Box 11) would suggest that there is a high degree of year to year variability. High numbers of category 3

BOX 11



Climatology of Atlantic tropical storms

(Source: NOAA National Hurricane Center)

Histogram of number of named tropical storms in the Atlantic. The numbers include all named storms (open yellow), hurricane strength (hatched green), and greater than category 3 (solid red).

The numbers and strength of systems prior to satellite surveillance are less certain because of reliance on ship reports for those storms not making landfall.

There is no clear trend in the annual number of systems. Numbers of hurricane and category 3 strength systems were high during the 1950s and again over the recent decade but fewer during the 1970s and 1980s.

The annual average number of named storms is 10 with 6 reaching hurricane strength. During the summer of 2005 there were 31 named storms of which 15 reached hurricane strength.

hurricanes also occurred in the 1950s and early 1960s with numbers only returning to those earlier values over the past decade.

It is of particular interest that the 6th International Workshop on Tropical Cyclones, sponsored by the World Meteorological Organization and attended by 125 tropical cyclone researchers and forecasters in Costa Rica, issued a Statement in November 2006 that included:

- No conclusion can be drawn on whether there is a detectable anthropogenic signal in the tropical cyclone climate record.
- No individual cyclone can be directly attributable to climate change.
- The recent increase in societal impact is caused by rising concentrations of population and infrastructure in coastal regions.
- There is an observed multi-decadal variability of tropical cyclones in some regions whose cause is unknown and which masks any potential trends.

- It is likely that some increase in tropical cyclone peak wind speed and rainfall will occur if the climate continues to warm.
- There is low confidence in computer projections of tropical cyclone numbers.

These authoritative comments are clearly at odds with the alarmist statements made by Al Gore. The fact that in 2006 the number of storms and hurricanes returned to the long-term average just reinforces the dependence of annual numbers and intensity of storms on factors other than ocean surface temperature.

The experts are clearly concerned about the mounting annual damage bill and point to how the risk is escalating as a consequence of settlements expanding and becoming established in hazardous locations. This is again at odds with Al Gore's attempt to link death and destruction from hurricanes to carbon dioxide emissions. Improved forecasting techniques and community preparedness have seen a clear downward trend in the number of lives lost from hurricane and related disasters. In contrast, the annual damage bill is escalating rapidly for the reasons given by the expert group, especially the poorly formulated construction codes and the willingness of authorities to allow development in hurricane prone coastal regions.

Initiatives to reduce carbon dioxide emissions will have no effect on future hurricane-related loss of life and destruction of property. Hurricanes are a naturally occurring phenomenon of the climate system and are a serious and ongoing hazard. Mitigation of loss of life and destruction is most effectively addressed through relevant research, planning, preparation, early warning and emergency response.

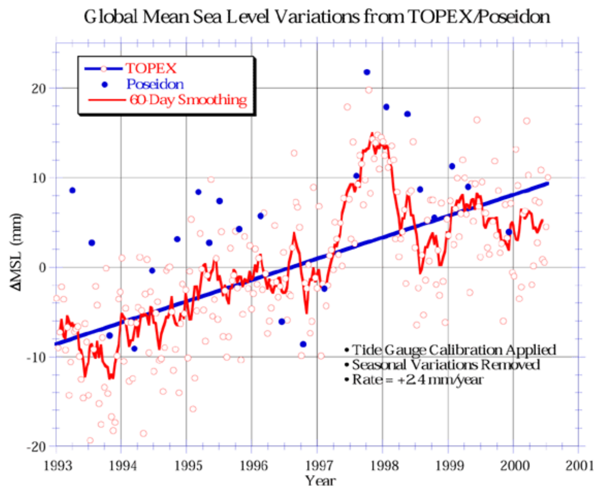
Coastal inundation

The spectre of coastal inundation is raised by Al Gore as a dramatic outcome of global warming ("We will have to re-draw the maps"). Coastal inundation is particularly fearful because of the number of people worldwide who live in close proximity to the sea on low lying coastal margins or islands. Unless early warning is given, there is often significant loss of life when storms raise local sea level to surge ashore. Surges associated with tropical storms are very destructive at the time of landfall but there are also many middle latitude locations where storms produce prolonged winds over long distances that cause a pile up of water and inundation along low lying coastal margins.

There is no doubt that a raising of sea level will increase the severity of the hazard associated with storm surges. However, it is the magnitude and frequency of the storms that primarily determines the extent of the hazard because the observed rate of rise of sea level is small and is generally not significant in the context of natural variations and land movements. Sea level rise will change the severity of the hazard with time but this aspect must be considered in the context of the projected rate of sea level rise.

Estimates of past sea level change have conventionally been made using tide-gauge measurements. These provide an estimate of the rate of sea level rise during the 20^{th} century of about 2 mm/yr. Two issues confound the accurate estimate of sea level change from tide-gauges. Firstly, there are relatively few tide gauges and their geographical distribution provides very poor sampling. Secondly, tide-gauges measure sea level relative to the land; vertical crustal motions may be of the same order of magnitude as the sea level variation.

BOX 12



Satellite Derived MSL Trend

Source: Nerem et al (1999)

Variations in global mean sea level from the TOPEX and Poseidon altimeters observed over the first 8 years of data after calibrating the measurements with the tide gauges. The dots show the 10-day sea level estimates, and the line is the same after smoothing with a 60-day filter.

The 15-20 mm rise and subsequent fall of sea level during the 1997-98 El Niño event underscores the relationship between sea level height and ocean surface temperature. The significant short-term variation highlights the need for a longer observing record in order to reliably estimate trend.

The satellite derived global mean sea level trend for the period was 2.4 mm/yr.

In some regions the vertical crustal motion is at significant rates. The apparent rise or fall of many atoll-capped volcanoes associated with mid-ocean spreading of the seabed is often confused with sea level rise. For many islands changes of land surface elevation are often associated with consolidation of cooling volcanic material. The issue of safety of the island and coastal inhabitants is no less important but the cause for the hazard must be correctly identified if appropriate responses are to be made. There is no evidence for a wave of ‘climate change refugees’ although many low-lying communities are threatened by an apparent sea level rise associated with tectonic and other local land movements.

Measurement of sea level variation using satellite observations has become possible with the development of special instruments but records only date back to 1993. The satellite data identify spatially varying patterns of variation associated with changing ocean surface heat content and ocean currents. The instruments are calibrated against the global tide-gauge network and are not entirely independent of the surface instruments. The satellite data are claimed to have a precision of 4 mm in resolving 10-day global mean sea level variations. They are capable of resolving the 15-20 mm global mean sea level rise and fall associated with the 1997-98 El Niño event[29] (see Box 12) but the temporal variability means that long records will be necessary before an accurate long term trend can be isolated. Nevertheless, the 2.4 mm/yr rate of change of sea level obtained from satellite data is similar to that from conventional tide gauge observations spanning the 20th century. The observed rate of sea level rise is not alarming..

The relatively small rate of change of sea level that is observed cannot be linked to human-caused global warming. Within the range of observational precision, there has been no discernible trend over the 20th century. A range of natural processes affects sea level, including changes in temperature and salinity, melting or accumulation of land ice, and discharge/extraction from land aquifers. There is also a suggestion that out-gassing of water from the Earth’s mantle is continuing and contributing to ocean mass, although the magnitude can only be conjecture.

Natural sea level change is a factor that must be considered in developing and maintaining coastal protection but there is no indication that sea level is rising at a dangerous rate.

Droughts and desertification

It is claimed by Al Gore that global warming will lead to increased numbers and severity of droughts, thus leading to an expansion of deserts. The claim is made on the basis that warmer temperatures will increase surface evaporation and reduce the amount of rainfall available for storage in the soil and runoff to streams. This seemingly plausible logic is backed by the outputs from computer models. Many computer models predict less frequent but more intense rain episodes with increased soil drying during the warmer and more prolonged periods between rain events.

The key to desertification is not temperature but the frequency and intensity of precipitation. As was identified by Priestley[30] in 1966, in hot climates the temperature of air near the ground is regulated by evapotranspiration from the surface. Priestley found from worldwide climate data that there is a sharply defined upper limit of about 33.5^{o}C for temperature above a well-watered surface of sufficient extent. The characteristics of desertification, including soil moisture and daytime temperatures, are regulated by precipitation and high temperatures follow increasing aridity.

There is no clear evidence of recent expansion of deserts, except by poor land management practices. Shifting dunes are natural. The examples given by Al Gore to support his claim are either a result of poor land management practices or the shifting of dunes in a region already characterised by extensive dunes.

The rainfall of semi-arid regions often has centennial or longer period cycles. Anthropologic evidence from settlements over parts of North, Central and South America covering the last two millennia suggest that individual settlements had waxed and waned. There is no clear coherence between the individual sites and the reasons for the population fluctuations are not resolved. One continuing theme, however, is changing climate and in particular changing rainfall patterns.

There is evidence that North Africa and the Middle East have been drying from a savanna-type climate that was more typical 5,000 years ago. Rock carvings and cave drawings that are more than 3,500 years old, from areas that are now desert and semi-desert, often depict large grassland and riverain animals. The archaeological evidence suggests that summer monsoon rains extended further north than they do now. This is not unreasonable because 10,000 years ago the precession of the Earth's axis meant that Earth was closest to the Sun at the time of the northern summer solstice. The northern hemisphere would have intercepted more summer radiation than now.

The relationships between temperature, rainfall, soil moisture and surface water are complex. The summer monsoon circulations that bring rainfall to many tropical and subtropical regions are related to both surface temperature patterns and circulation thermodynamics. It is completely wrong to make the blanket inference that higher surface temperatures will result in more droughts. An expansion of summer monsoon rains into subtropical regions is likely to lower temperatures through increased evapotranspiration.

Rainfall is a very difficult meteorological element to forecast over the coming few days and there is no demonstrable skill in seasonal rainfall prediction. There is no reason to expect that computer models have more skill when it comes to forecasting long term trends.

COLLISION OF EARTH AND HUMANITY

There is no doubt that the activities of humans have affected and continue to shape many local and regional ecosystems. Human settlements are at the expense of pre-existing ecosystems. Broad-acre farming covering agriculture and grazing are outcomes from clearing of forests and woodlands. Even the use of fire by nomadic peoples, such as the aboriginals of Australia before European settlement, is an example of humans shaping the landscape to meet specific needs.

Biosphere response

Al Gore claims that "*many species around the world are now threatened by climate change, and some are becoming extinct….*" He then qualifies this "*in part because of the climate crisis and in part because of the encroachment into the places where they once thrived*". It is important to recognise these two separate causes because they really are separate issues requiring their own policy response. Unfortunately, Al Gore proceeds as if all the biosphere calamities, from tree clearing in Haiti to algal blooms in the Baltic Sea, are due to human-caused global warming.

The collision of Earth and humanity is a real issue but there is no evidence that burning fossil fuels and the increasing concentrations of atmospheric carbon dioxide will lead to dire environmental consequences. The basis for Al Gore's alarmist predictions of species and ecosystem destruction is a perverse interpretation of the well-known observation that populations wax and wane with varying climate. His interpretation of recent changes in climate as being human-caused and extrapolating those trends to project doomsday scenarios cannot be justified. On the unsubstantiated assumption that burning of fossil fuel is the cause of recent climate anomalies, and that further carbon dioxide emissions will cause dangerous global warming, Al Gore predicts widespread species loss, from the polar bears of the Arctic to the coral reefs of the tropical oceans. Such a claim does not stand close scrutiny.

It is appropriate that every attempt is made to maintain the rich bio-diversity of the biosphere. In those local ecosystems that contain remnant species of flora or fauna from an earlier time, when more favourable climate or lack of predators were conducive to species evolution, the population dynamics are fragile. However species emergence and disappearance is a natural part of evolution. Species extinction is natural and it would be wrong to suggest that remnant populations will not die out in the absence of human encroachment.

Human encroachment into what were previously unmanaged (or natural) ecosystems will have an impact, whether it is land clearing or wetland drainage. In many countries, environmental impact is already part of the assessment before authorities allow expansion of settlements and land-use into previously unmanaged tracts, and this practise is strongly supported. Where such impact assessment is not part of a national requirement then governments should be encouraged to enact appropriate legislation.

As Earth emerged from the last major ice age the great North American and Northern European ice sheets melted and allowed rich ecosystems to evolve over the previously frozen wastelands. Certainly the raising of sea level by 130 m submerged wide expanses of coastal lowland but overall the warmer and wetter climate has allowed a wide range of species to expand in numbers and spatial extent. There is no evidence that human activities have contributed to this climate change. The evidence is that a warmer climate is preferable to the colder alternative, which is the direction that climate is inexorably moving.

Coral reefs

It is quite wrong to say that tropical corals are threatened by global warming. What are now pristine coral reefs with diverse marine ecosystems and fish populations were, 20 thousand years ago, high limestone cliff faces. The marine life associated with coral reefs is relatively robust and is able to adjust to large rises and falls of sea level over relatively short intervals. Much of the alarm about coral reefs is the occasional episodes of bleaching, mostly associated with El Niño events. Such ‘warming’ events are heralded by alarmists as symptomatic of destruction that will accompany global warming.

Coral reefs of the Pacific Ocean survive significant rise or fall of local sea level during El Niño events. In December 1997, during the mature phase of the 1997-89 event, local sea level was 24.6 cm below normal at Pohnpei in the Federated States of Micronesia and was 39.3 cm above normal at Santa Cruz, Ecuador as warm surface water flowed eastward[31]. Local sea level falls of the magnitude that occurred across the Western Pacific Ocean either uncovered reefs or reduced the depth of the layer of overlying water so that very warm temperatures occur. The rise in sea level over the Eastern Pacific Ocean was accompanied by the arrival of water that was 2-3 degrees C warmer than the local climatological value. It is quite understandable that local corals became stressed because of the sudden changes.

Tropical rainfall patterns are significantly disrupted during an El Niño event and this also impacts on coral ecosystems. Over some locations, such as the arid coastal regions of Ecuador and Northern Peru, rainfall is up to ten times normal seasonal values and the runoff of silt and detritus changes the salinity, turbidity and nutrient levels in the environs of coastal corals. Elsewhere, where rainfall declines significantly, the salinity of coastal waters increases.

Coral reefs recover from the physical changes that accompany El Niño, much as forests recover from serious wildfires; they are not as they were before the event but they do recover as rich ecosystems. The corals and their dependent ecosystems do not show signs that there has been permanent damage from the very small sea level rise and ocean temperature increase experienced during the 20th century. Just as coral colonies recover from episodes of bleaching so to they are expected to be sufficiently robust to withstand the range of future climate variation. Not only have colonies moved with the rise and fall of sea level accompanying the major ice age cycles but also they have survived sea levels that were several metres higher during the previous interglacial. Corals are more robust and adaptable than the alarmists give credit.

Expansion of tropical disease

The scariest projection given by Al Gore is that of expansion of disease vectors to middle and high latitudes as Earth gets warmer. Algae, mosquitoes, ticks and other germ-carrying life forms are projected to turn up in new places and cover a wider range than at present. To quote Al Gore:

> ".. mosquitoes are profoundly affected by global warming. There are cities that were originally located just above the mosquito line, which used to mark the altitude above which mosquitoes would not venture. Nairobi, Kenya and Harare, Zimbabwe, are two such cities. Now, with global warming, mosquitoes are climbing (sic) to higher altitudes".

In truth we do not know how mosquitoes and other potential disease vectors are affected by global warming. What we do know is that the populations of many of the vectors, if unmanaged, fluctuate with climate variability. This signal is derived from mortality and sickness statistics associated with interannual climate variability associated with El Niño events. It is seemingly plausible, but wrong, to project climate relationships and future patterns of intensity and extent with an expected warmer world.

The frailty of the Al Gore logic is that, although malaria epidemiology is related in part to climate conditions, the actual extent of the disease is dependent on the presence or otherwise of an active program of disease control. Malaria was endemic over the southeastern USA until an eradication program rendered the problem insignificant. Until the second half of the 20th century, malaria was endemic and widespread in many temperate regions, with major epidemics as far north as the Arctic Circle. From 1564 to the 1730s — the coldest period of the Little Ice Age — malaria was an important cause of illness and death in several parts of England. Transmission began to decline only in the 19th century, when the present warming trend was well under way. The history of the disease underscores the role of factors other than temperature in malaria transmission[32].

In a review of the links between global warming and the spread of infectious disease Roland Zell of the Institute of Virology and Antiviral Therapy, Jena, Germany concluded that the factors responsible for the emergence/re-emergence of vector-borne diseases are complex. He noted that insecticide and drug resistance, deforestation, irrigation systems and dams, changes in public health policy, demographic changes and societal changes affect the incidence and spread of parasites and arboviruses[33]. This conclusion underscores an earlier study of the changing patterns of clinical malaria since 1965 in the tea estate population located in the Kenyan highlands[34]. Malaria was previously endemic in the Kenyan highlands and the recent emergence is attributed to disease resistance to the drug chloroquine and is not related to climate.

Polar bears and emperor penguins

Polar bears and emperor penguins are cited by Al Gore as species particularly sensitive to global warming. These photogenic and iconic species live in harsh isolatedpolar environments at the top of the food chain. Each species is large and dependent on marine life for its existence. As a consequence, total numbers of each species is relatively small. The Canadian Wildlife Service estimates that there are about 25,000 polar bears around the shores of the

Arctic Ocean; Australia's Antarctic Division estimates there are about 195,000 breeding pairs of emperor penguins in rookeries of the Weddell and Ross Seas of Antarctica.

Although the population numbers are relatively small and each species is uniquely adapted, they have evolved in what is the most variable climate on Earth. Not only is the annual cycle of temperature greatest over the polar regions but these regions also go through the greatest temperature range during ice age cycles. The species have survived both the glacial maximum 20,000 years ago and the interglacial of 125,000 years ago that was apparently warmer then now. Even the Holocene Optimum between 5 and 10 thousand years ago was apparently warmer than now.

The polar bear population is widely dispersed. However the animals are mobile and can swim more than 80 km in search of food and mates. Polar bears are carnivores and their main diet is seals caught from ice floes. The hunting period is during the winter and spring months and the animals go for long periods, extending from summer to autumn, without food. Warming, with a reduction in the amount and duration of sea ice cover, is seen as a particular threat to the species because it will reduce the hunting and feeding season and extend the fasting period.

Polar bears are recognised as an endangered species. The USA, Canada, Denmark, Norway and Russia have signed an agreement designed to protect habitat components, such as denning and migration patterns. Nevertheless, USA, Greenland and Russia allow hunting of polar bears by indigenous peoples and Canada also makes available limited hunting licences.

At the other end of the world, emperor penguin males fast during the very cold months of the Antarctic winter as they huddle in rookeries. The male and females are reunited after the coastal sea ice breaks up and the emperor penguins gain access to the marine life that constitutes their diet.

Contrary to Al Gore's claim, the emperor penguin population is stable and the species is not classed as endangered. There is no evidence that the area or duration of Antarctic sea ice is declining. There is no basis to the emotive claim that the rookeries might "break apart and drift out to sea, taking the penguins eggs and chicks with it".

For both polar bears and emperor penguins their biggest threat to survival is from human encroachment. Hunting of polar bears, as with hunting of any large species with low population numbers and extensive habitat, will eventually lead to extinction. Emperor penguins, in contrast, congregate in a few large rookeries whose isolation from human interference is their security. Increasing human contact, whether for scientific assessment or tourism, increases the risk of biological or chemical contamination that could seriously disrupt the delicate balance of the emperor penguin lifecycle. Both species are well adapted to their harsh climates, both have withstood major climate changes of the past, and both have survived global warming episodes of the past.

Direct human impacts

One of the truisms of life is that new technologies bring new problems and this has been abundantly clear since the beginnings of industrialisation. Direct burning of coal in early foundries and steam engines was a source of smoke and noxious pollutants. Widespread availability of coal for home heating and cooking led to high levels of pollution over western cities and towns during the first half of the 20th century. Early motor vehicles were accompanied by noxious tailpipe emissions that contributed to urban smog.

In many places there is extreme environmental degradation that is causing deterioration in the natural resource base on which communities depend for their food and shelter. However it would be unjust to suggest that the situation is a result of lack of care by local communities. Mostly the cause is poverty, social dysfunction, and the lack of community organisation to motivate and implement the building of better private and public infrastructures.

It is also generally true that in the past, as democratic communities identified the causes of local pollution, they have implemented measures to improve their environment and amenity. The raft of clean air, clean water and environmental protection legislation attests to this. Mindless exploitation is not a characteristic of western development nor was it a characteristic of early agriculture based societies. The identification, development and implementation of environmental standards are hallmarks of modern development. People, by choice, prefer not to live surrounded by unhealthy and unsightly rubbish and breathing a smog of noxious air. The analogy of a frog failing to jump out of a pot when the heat is turned up is not valid. With resources and appropriate infrastructure, and if not deterred by totalitarian edicts or social dysfunction, people willingly work to improve and maintain their environment and amenity.

Many of the examples of environmental degradation that Al Gore attributes as early signs of the impacts of global warming are nothing of the sort. Land clearing is human encroachment, often to provide a resource base for the necessities of life. Such clearing that is going on in many parts of the developing world is no different to that which preceded farming and grazing of Europe and East Asia over millennia, and more recently North America and Australia. Such clearing will impact on and destroy local ecosystems if no thought is given to conservation and the environment. However there are many lessons to be learned from nature reserves, connecting habitat corridors and on-farm landcare measures that are being adopted as an holistic approach to the managed environment.

Species extinction, land degradation, waste accumulation and noxious smog are not consistent with modern development in democratic countries. Community planning that balances the productivity of land and water resources with a sustainable resource base is what epitomises and is the real hallmark of western development. Al Gore waxes lyrically about the romance of the wilderness, and wilderness and nature conservation have their place. But wilderness is essentially unproductive. Recent promotions of eco-tourism as an economic use suggests that wilderness should be conserved as the playground of the rich who can afford expensive high-tech adventure and survival gear. A balance has to be defined between the needs of nature conservation and the most productive use and amenity of managed lands for community benefit.

As the human population numbers increase it will continue to put pressure on the Earth's resources. There is ongoing pressure to expand settlements and agricultural lands into presently designated conservation and wilderness areas. However this issue, while important, is not directly related to carbon dioxide emissions or their impact on climate change. Carbon dioxide is not a pollutant but an essential component of the biosphere. There is no evidence that increased concentrations of carbon dioxide in the atmosphere will lead to dangerous climate change that threatens the biosphere.

CONCLUSION

Al Gore's book and film, *An Inconvenient Truth*, have assumed the vanguard position in a global movement for decarbonising societies infrastructure. Burning of fossil fuels, the essential energy source of modern societies, produces carbon dioxide emissions to the atmosphere and it is claimed that unconstrained usage will lead to dangerous global climate change. The predicted apocalyptic impacts include melting of polar ice sheets and raising sea level by several metres; more droughts and heatwaves; more storms and floods; poleward spread of tropical diseases; and impacts on the biosphere including widespread loss of species.

The alarmist claims about dangerous human-caused global warming are based on a number of fundamental misconceptions. These include:

- The belief that the climate system was essentially unchanging prior to industrialisation and the observed warming of the 20th century is therefore unusual and directly attributable to carbon dioxide emissions.
- The misinterpretation of measured linear trends of a number of geophysical and biophysical indicators over recent decades as fixed linear trends that will continue indefinitely; these changes are not seen as part of natural multi-decadal or centennial scale variability.
- The misinterpretation of observed changes in climatic, geophysical and biological characteristics of recent decades, including where they have their origins in the emergence of Earth from the Little Ice Age of between 1600 and 1800, as being directly attributable to human activities.
- The acceptance of the more extreme computer model projections of global surface temperature increase as being realistic, and the extrapolation of these to catastrophic outcomes, including destruction of much of the existing polar ice, sea level rise of several metres, and widespread species loss in a warmer world.

Al Gore and his fellow doomsayers fail to acknowledge the natural variability of the climate system that has produced major change in the past, especially the expansion and contraction of polar ice sheets and mountain glaciers, and they place too much credence on what are still rudimentary computer models.

There has been a change in the climate over the 20th century but the changes are within the bounds of the cyclic fluctuations recorded in ice layers and ocean floor sediments that span more than a million years of the recent past. Indeed, temperatures are not as warm as they were during the early Holocene (10,000 to 5,000 years ago) or during the peak warmth of the previous interglacial (about 125,000 years ago) when a significant area of the Greenland's ice mass melted and sea level was several metres above present levels.

The reasons for the fluctuations of Earth's climate over past few million years are not well understood but it is generally believed that they relate to a combination of factors, including:

- the Earth's changing orbital characteristics that vary the seasonal and spatial distribution of solar energy;
- variability of the Sun's irradiance, cosmic ray intensity and magnetic output; and

- internal variability of the interacting ocean and atmospheric circulations as they constantly transport energy from the tropics to polar regions.

The issues about carbon dioxide are whether or not recent global warming and other apparent climate trends since industrialisation have been caused by the increasing concentration of carbon dioxide in the atmosphere, and whether global expansion of industrialisation will cause further and dangerous global warming. One of the fundamental problems preventing resolution of these issues is that there is no clear understanding of what the greenhouse effect actually is. There is a range of confused simplistic metaphors for the greenhouse effect in the public domain but these do not explain how it comes about. There is then a leap of faith to the outputs of computer models. This allows alarmist rhetoric to be propagated through the media to an uncritical public and policy makers.

The greenhouse effect is the combination of processes in the climate system that maintain the Earth's surface at a warmer temperature (about 14^{o}C) then the temperature required (-19^{o}C) for radiation equilibrium with the Sun. Several different simple metaphors are used for describing the greenhouse effect. These metaphors focus primarily on the absorption of infrared radiation. Some suggest that it is the absorption of infrared radiation by the atmosphere that keeps the Earth warm; others, including Al Gore, regard the absorption of back infrared radiation from the atmosphere as the process that keeps the Earth warm. Such explanations are deficient because net infrared radiation loss causes both the atmosphere and Earth's surface to cool. The explanations ignore other important processes of the climate system energetics, especially the Earth-atmosphere energy exchange by conduction and evaporation and the role of deep tropical convection that distributes heat through the atmosphere from the surface. These inadequate explanations lead to false logic when it comes to quantifying the impact of increasing carbon dioxide concentration.

A complete explanation of the greenhouse effect requires an holistic model that recognises the latitudinal imbalance of the Earth's radiation, with excess solar energy input over the tropics and excess infrared radiation to space over middle and high latitudes. The explanation must also recognise that solar radiation is absorbed and tends to accumulate at the Earth's surface (of which seventy percent is ocean) and there is net infrared radiation loss from the atmosphere that tends to cool the atmosphere. The energy disconnect between the surface and the atmosphere and between the tropics and polar regions means that there are additional processes that are important for explaining the temperature distribution of the climate system. The additional processes include the surface-atmosphere energy exchange by conduction and evaporation; convective overturning of the atmosphere; and transport of excess energy from the tropics to high latitudes by the atmospheric and ocean circulations. A simple radiation model cannot explain the Earth's greenhouse effect.

The holistic model of the climate system recognises that:

- the surface temperature, especially over the warmest tropical oceans, is constrained by evaporation as energy is transferred from the surface to the boundary layer,
- the temperature decrease with height in the atmosphere is constrained to the moist adiabatic lapse rate because of the need for convective overturning that is essential for the distributing heat and latent energy through the troposphere from the boundary layer, and

- temperatures over middle and high latitudes are regulated by the rate of transport of excess energy from the tropics by the atmospheric and ocean circulations.

In assessing the future impact of industrialisation it must also be recognised that carbon dioxide concentration has only limited additional impact on the greenhouse effect. Most of the greenhouse effect of carbon dioxide is due to the first 50 ppm of the gas in the atmosphere. The reduction in the Earth's infrared radiation to space from a doubling of carbon dioxide concentration (the radiation forcing) will be less than 4 W/m^2. The temperature increase in the middle and high troposphere necessary to restore radiation balance (ie, to restore the effective emission temperature) is less than 1 degree C. Through the convective adjustment process, such a temperature increase in the middle and high troposphere translates to a requirement to raise the surface temperature by between 0.3 and 0.5 degrees C. Even with water vapour feedback that amplifies the direct forcing of carbon dioxide, a rise in surface temperature of less than 1degree C is the most warming that should be anticipated from the expected doubling of carbon dioxide concentration late in the 21st century.

Computer models, which alarmists rely on for their doomsday scenarios, project a much greater range of global warming by the end of the 21st century – between 1.4^{o}C and 5.8^{o}C. Modellers suggest that the sensitivity of the models is real and due to positive feedbacks through the interaction of clouds and water vapour. Water vapour feedback is positive but likely only relatively small in magnitude because the increased water vapour concentration of a warmer troposphere is constrained to the lower layers and will not contribute significantly to raising the height of the effective emission level (and the greenhouse effect). The theoretical grounds for cloud amplification of the direct global warming from increasing carbon dioxide concentration are controversial. The relatively small changes to the global pattern of cloud structure and height over recent decades are equivocal as to their potential impact on global temperature.

The range of global warming projections from the different computer models underscores the uncertainties associated with climate model construction. It is likely that the exaggerated sensitivities of computer models are due to biases and inaccuracies in the specification of relationships in the physics of small-scale processes, especially those relating to clouds but also those relating to surface-atmosphere exchange of energy. These biases and inaccuracies propagate through the non-linear climate system and amplify with time. It is not possible to distinguish between a real anthropogenic global warming signal and the sensitivities of the simulation to internal approximations and simplifications.

It is on the basis of extreme computer model projections that Al Gore bases his claim that the Greenland and West Antarctic ice sheets will disintegrate and melt, raising sea level up to 6 m higher than now causing coastal and low-lying small island inundation. The computer projections are also the basis for claims that the intensity and frequency of drought, floods, hurricanes and other extreme weather events will increase.

There is no observational evidence to support Al Gore's claims of dangerous climate change. Melting of the Greenland and West Antarctic ice sheets cannot be detected apart from the lower coastal margins of Greenland and from the Antarctic Peninsula region. The observed changes are not unusual and not sufficient to have a detectable effect on sea level. The analysed sea level rise of approximately 2 mm/year has been nearly constant through the 20th century and cannot be considered dangerous.

Al Gore's concern for coral reefs, polar bears and emperor penguins, as victims of human caused climate change, is misplaced. These, and many other species, are potentially endangered by human encroachment on habitats and from chemical and biological pollutants contained in urban and agricultural storm water runoff into the marine environment. The species have generally survived the relatively large swings of climate in the past and will survive future fluctuations as well.

Human activities since industrialisation have caused concentrations of carbon dioxide in the atmosphere to increase. It is likely that concentrations are higher now than at any time in the past few million years but they are significantly less than during the evolution of much of Earth's flora and fauna over hundreds of millions of years. Carbon dioxide is not a pollutant and the growth of many flora species responds favourably to higher carbon dioxide concentrations. Elevated levels of carbon dioxide are used in many glasshouses to enhance the growth of horticultural crops.

The scare-mongering that climate change, any climate change, will lead to widespread species loss is a denial of the innate robustness of most species, even those in relatively small numbers or confined to small regional domains. Over the past hundreds of millions of years, as species have evolved, the Earth has been both warmer and wetter and colder and drier. The robustness of species is underscored by survival through the glacial-interglacial cycles of the past million years as land ice has expanded and contracted and ocean surface temperatures have cooled and warmed. Just as the boreal forests advanced poleward following the retreat of the ice sheets so too the biosphere flourished. Our perspective of these areas is as if through tinted glasses because we are in a time of near maximum retreat of the ice sheets.

The evidence is that the expected near doubling of atmospheric carbon dioxide concentration over the 21st century will have inconsequential impact on climate. The real issues are the need to develop alternative energy sources as the gaseous, liquid and solid fossil fuel resources become depleted, and the direct impact of humans on the biosphere through encroachment and discharge of chemical and biological pollutants. Al Gore's rhetoric and hyperbole deflect our attention and his claimed 'solutions' do nothing to reduce the impacts of weather and climate extremes or promote vital future energy security. END

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AUTHOR BIO

William Kininmonth is an independent climatologist with a Bachelor of Science from the University of Western Australia, Master of Science from Colorado State University and Master of Administration from Monash University. He was an employee of the Australian Bureau of Meteorology for 38 years and for 12 years was head of its National Climate Centre. He was Australian delegate to the World Meteorological Organization's Commission for Climatology (1982-1998) and served two periods on its Advisory Working Group (1985-89 and 1993-97). He participated in Expert Working Groups of the Commission and carried out regional training activities in relation to climate data management and climate monitoring. William Kininmonth was a member of Australia's delegations to the preparatory meetings for the Ministerial Declaration of the Second World Climate Conference (1990) and to the United Nations Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (1991-92). William Kininmonth is author of the book, *Climate Change: A Natural Hazard* (Multi-Science Publishing Co, UK – 2004)

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