IS CARBON DIOXIDE DANGEROUS?

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INTRODUCTION

The hypothesis that global warming and climate change are being caused by industrial emissions of carbon dioxide (CO2) is propagated within sections of the climate science community and promulgated widely in the media. The hypothesis suggests that increasing concentrations of CO2, a so-called greenhouse gas, are trapping heat within the climate system and continuing to warm the Earth. It is even claimed that if humanity does not restrict emissions of CO2 then runaway global warming will make Earth uninhabitable. The view is so pervasive that governments, through the United Nations, have negotiated a Climate Change Convention through which countries have agreed that action should be taken to reduce emissions of CO2 and so prevent dangerous climate change.

What constitutes 'dangerous climate change' has not been defined. However the Kyoto Protocol is an international regime designed to reduce energy production from fossil fuels in developed countries, including Australia. The stated objective is to restrict the build-up of CO2 in the atmosphere.

Australia, with the US, has not ratified the Kyoto Protocol although it has set in place a number of actions designed to limit our CO2 emissions within the target specified by the Kyoto Protocol. Most industrialised countries are having difficulties meeting their initial CO2 reduction targets. Beyond 2012 targets are being proposed that will require cuts of up to 80 percent below the 1990 emission levels. Such targets will be exceedingly difficult to achieve while maintaining current technological efficiency and standards of living.

It should be noted that developing countries, including the industrialising countries of Asia and Latin America, do not have CO2 containment requirements under the current 2012 targets. Much of the continuing intergovernmental negotiations relate to the future responsibilities of developing countries for participating in emission reduction schemes.

The alleged threat from greenhouse gases

For more than two decades there have been media reports alleging that our climate is deteriorating, earth has warmed to unprecedented levels, the environment is degrading, we are facing catastrophic and possibly irreversible climate change, and that human activities are to blame. The Chief Scientist in the UK, Sir David King, claims that global warming is a greater threat than terrorism and that by the end of the 21st century the only habitable continent will be Antarctica. Such a claim is extraordinary given that Antarctica is now an icy wasteland with winter temperatures colder than –80^{o}C.

Australian of the Year Tim Flannery, in his book *"The Weather Makers"*, promotes human caused climate change as a scientific fact. He elaborates on dangerous impacts that he predicts

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the continuing burning of fossil fuels and climate change will have on the environment and on humankind.

Sir Nicholas Stern, as Head of the UK Government Economics Service, has addressed the economic arguments associated with meeting the challenges of the alleged global warming threat. The principal finding of the Stern Review is that it would be better to act early to reduce society's greenhouse gas emissions and the projected global impacts, even though there is no actual evidence for dangerous climate change at this time.

Former US Vice-President Al Gore launched his academy award winning documentary film "*An Inconvenient Truth*" to an adoring and largely uncritical media reception. Gore's prophecies of melting ice caps, rising sea levels, more hurricanes and the widespread loss of species, including iconic polar bears and emperor penguins, received wide publicity and has helped to sway public opinion on the need for drastic action to address climate change.

We read that, because of rising CO2 concentrations:

- The earth is warming rapidly and about to pass a 'tipping point' leading to runaway global warming.
- The polar ice sheets are melting at an alarming rate and sea level will rise by tens of metres as first the Greenland ice cap then the Western Antarctic ice cap melts.
- Australia will have more droughts and floods and there will be more tropical cyclones that are of greater intensity.
- Tropical diseases such as malaria will spread into middle and high latitudes as the earth warms up.

And the list goes on.

Two essential claims underpin these stories:

1. Climate was unvarying prior to industrialisation and consequently recent global warming is abnormal and unprecedented. That is, climate was stable and equable before man-made emissions of CO2 to the atmosphere began to increase.

2. The hypothesis linking atmospheric carbon dioxide concentrations with global temperature levels is soundly based, such that as human-caused CO2 concentration increases so too global temperatures will escalate.

The claims are incorporated in assessments of the United Nation's Intergovernmental Panel on Climate Change (IPCC). The IPCC assessments are reputed to have broad consensus based on the number of experts making input to the reports. The assessments have also been accepted by all governments that are party to the IPCC process.

In February the IPCC released its Fourth Assessment. The IPCC concluded, on the basis of computer simulations, that it is very likely that most of the global warming of the last half of the 20th century was caused by human activities. Moreover, the report endorsed computer-based predictions that earth will warm between 1.4^{o}C and 5.8^{o}C (average 3^{o}C) during the 21st century and sea level will rise up to a half a metre.

From the well-orchestrated media hype associated with the release of the IPCC report the public would be excused for concluding that industrialisation and modern technologies are driving the world to an apocalyptic future.

The media hype neglects to mention that the cleanest air, the purest drinking water, the most productive lands, the most pristine nature reserves, and the societies most resilient to natural hazards are those of developed countries, such as Australia, utilising the methods and technologies of industrialisation.

So, it is a fair questions to ask, is the prospect of human-caused dangerous climate change a reality? Or is the danger being oversold? Three indisputable facts point to the latter:

1. Recent climate characteristics have been neither unusual nor unprecedented.

2. Increasing CO2 concentration in the atmosphere will have little additional impact on the Earth's radiation characteristics (the so-called radiative forcing of climate).

3. There are fundamental deficiencies in how computer models represent the climate system and these exaggerate the temperature predictions.

CLIMATE IS HIGHLY VARIABLE

Evidence of past climates comes from a variety of sources. As climate has changed there are telltale signs left in many places.

Over polar regions the annual accumulation of snow has compacted into layers that build up with time. Each layer embeds physical and chemical characteristics of the prevailing climate. Over Greenland and Antarctica the compacted annual layers of snowfall now reach to depths of several kilometres. Deep cores drilled from the ice and analysed provide information that records variations of climate over the past several hundred thousand years.

On the ocean floor the physical, chemical and organic structure of sediment layers also reflect changing climate. Cores drilled from the ocean floor provide information of changing climate back through millions of years.

Deep ice cores from Antarctica and Greenland confirm that Earth has mostly been in glacial conditions for at least the past 500,000 years. Earth has emerged from the icy conditions for relatively brief warmer periods, such as the current interglacial, approximately every 100,000 years.

Only 20,000 years ago Earth was in the grip of glacial conditions.

- Great ice sheets covered North America and northern Europe, much as Greenland and Antarctica are still covered in ice today.
- The southern boundary of the North America ice sheet extended from Vancouver through St Louis to New York. Chicago was under more than a kilometre of ice.
- London was at the southern extent of the European ice sheet.

The extensive ice sheets of the last glacial epoch caused sea level to be about 130 metres lower than it now is. Tasmania and New Guinea were connected to Australia by land bridges and the separation from Asia was a waterway only about 100 km wide.

The now pristine coral atolls making up the Great Barrier Reef were, at that time, high limestone cliffs.

Australia's climate was colder than now and very dry. Permanent ice formed over the higher elevations of Southeastern Australia and Tasmania. Inland was arid and wind-blown sand formed extensive dunes that still characterise the Central Australian landscape.

There is evidence of sudden and significant climate fluctuations during the last glacial epoch that began about 100,000 years ago and abruptly ceased about 19,000 years ago. The Greenland ice cores indicate regional temperature rises exceeding 10^{o}C within a century that lasted a thousand years and more. There are indications of more than a dozen of these Dansgard-Oeschger events.

Ocean sediment cores from the North Atlantic Ocean identify sudden increases in the rate of iceberg formation during the last glacial epoch. These Heinrich events are characterised by sediment layers with an increase in granular soil material, or ice rafting debris, in the structure. The granular material comes from melting of icebergs whose origins can be traced to the land bounding the Hudson Strait and from eastern Greenland.

During the glacial periods climate was very different to now but even then there were frequent periods when the climate changed very quickly, and for reasons that we do not understand.

The Current Interglacial Period

A great global warming event commenced about 19,000 years ago and this caused much of the North American and European ice sheets to melt and be replaced by forests. Sea level rose about 130 metres over the next 8,000 years to reach near present elevations. Tasmania and New Guinea were isolated from the Australian mainland and coral growth followed sea level rise.

During much of the last 10,000 years, a period known as the Holocene, temperatures were generally slightly warmer than now and tropical lands were wetter. The now semi-arid and desert lands of North Africa, the Middle East and Central Australia were, until relatively recently, grassy savanna. This is the period that human civilisation evolved.

The advocates of human-caused global warming claim that the Earth's climate has been continually mild and equable over the past 10,000 years before the onset of industrialisation. The widespread evidence for variability of climate even during this period challenges their proposition.

In 1966, before human-caused global warming was a matter of public debate, the English historian Kenneth Clark wrote:

> *"There have been times in the history of man when the earth seems suddenly to have grown warmer or more radioactive….. I don't put that forward as a scientific proposition, but the fact remains that three or four times in history man has made a leap forward that would have been unthinkable under ordinary evolutionary conditions. One such time was about the year 3,000 BC, when quite suddenly civilisation appeared, not only in Egypt and Mesopotamia but in the Indus Valley; another was in the late 6th century BC, when not only was there the miracle of Iona and Greece – philosophy, science, art, poetry, all reaching a point that wasn't reached again for 2,000 years – but also in India in a spiritual enlightenment that has*

perhaps never been equalled. Another was about the year 1100. It seems to have affected the whole world; but its strongest and most dramatic effect was in Western Europe ……. In every branch of life – action, philosophy, organisation, technology – there was an extraordinary outpouring of energy, an intensification of existence."

Each of these periods of apparent human cultural development can be linked to periods of climatic warmth. They were times of plenty with ample food production to sustain the populations and support trade.

The Greco-Roman civilisations declined during the cooling of the early centuries of the first millennium of the Common Era. There is strong evidence of advancing glaciers over the Rocky Mountains of North America and the European Alps. In England, Saxon settlements continued to decline for more than a century after the withdrawal of the Romans in the early 5th century.

The Norse settled Iceland and coastal parts of Greenland during the warmer Medieval Period that extended from about 800 to 1200. At the peak there were more than 3,000 individual settlements. This was also a period of generally increased food supplies across Europe that enabled major construction activities, including the many cathedrals that survive from the period.

Current climate is neither unusual nor unprecedented.

A summertime view of the Alps behind Chamonix, France shows how glaciers have retreated up the valleys. There are historical accounts of how the glaciers extended to the valley floor during the Little Ice Age of the 16th and 17th centuries. Archaeological evidence supports the view that the glaciers have advanced and retreated many times over the past several millennia. ***Any suggestion that current climate is either unusual or unprecedented is unfounded.***

The onset of cooler conditions commenced in the late 1200s. There is evidence that many European settlements were in decline in the half-century before the onset of the Black Death plague that killed up to a third of the population in 1348. The last Greenland settlement perished about 1550.

It was not constant cold during the centuries of the Little Ice Age. Cold was at its worst in the 17th century. The duration of glacier advance in the French Alps during the 15th century and their persistence from the 16th to the 18th century is well documented by the French historian Emmanuel Ladurie.

Winter Frost Fairs were common as many rivers of Europe periodically froze during the Little Ice Age. The London diarist John Evelyn records that in 1683-84 the Thames River froze from late December to early February. He wrote:

Conditions were terrible with men and cattle perishing and the seas locked with ice such that no vessels could stir out or come in. The fowls fish and birds and exotic plants and greens were universally perishing. Food and fuel were exceptionally dear and coal smoke hung so thickly that one could scarcely see across the street and one could scarcely breathe.

This is not the description of some Arcadian climate that we are led to believe existed in pre-industrial times. It is certainly not a climate state that we should voluntarily attempt to achieve by way of CO2 reduction.

Recent Warming

There is no convincing evidence that the climate of the late 20th century is unusual or unprecedented. Global mean temperature since the late 1800s, as measured by instruments, suggests a rise of about 0.6°C. The warming was mainly over two periods, 1910-1940 and 1975-1998, with declining temperatures between. Unfortunately the historical temperature records tend to be sparse prior to 1950 and averages may not be globally representative. For example, the temperature records from Upsalla and Stockholm that are continuous from the middle 1700s identify the 1780s, the 1930s and the recent decade as equally warm periods. In the US, where records go back to the middle 1800s, the 1930s were as warm as the recent decade.

For Adelaide, Melbourne and Sydney, where temperature records also began in the middle 1800s, the extreme daily maximum temperatures were recorded during a prolonged heat wave in January 1939.

Many of the Medieval Norse settlements of Greenland remain icebound. This suggests that in that region temperatures were generally warmer during the Medieval Period than they are today.

Some high mountain passes of the European Alps have recently become accessible as permanent snow and ice have melted. Archaeological studies, based on the dating of items discarded by travellers, suggest that these passes have previously been used as transport routes. The passes have opened and closed in the past as temperature and precipitation have varied.

The evidence does not support the proposition that the current warmth of the Earth is unprecedented. Nor does it support the view that climate over the past 10,000 years was steady. Rather, the evidence is that the current interglacial was at it warmest between 8,000 and 5,000 years ago and that temperatures have been slowly declining since in a series of irregular fluctuations.

The concept of a stable climate prior to human industrialisation is one that has little relationship to historical and proxy climate records. Also, from the evidence, a warmer climate would seem to be preferable to a colder one – if we had the choice.

The Melting of the Greenland Ice Cap and Sea Level Rise

One of the scare scenarios promulgated by Al Gore and his fellow advocates is that human-caused global warming is likely to melt Greenland and Antarctic ice caps. Such melting will lead to dangerous sea level rise and the drowning of low-lying islands and coastal margins. It is claimed that only the reduction in fossil fuel burning will prevent such calamity. However:

- 120,000 years ago during the previous interglacial, unrelated to industrialisation and burning of fossil fuel, the world was slightly warmer than it is today. A large part of the Greenland ice cap did melt and sea level was several metres higher than now.

We have to be prepared for such an event recurring irrespective of CO2 concentration, although the evidence suggests that Earth is now in a gradual temperature decline.

- Today the Greenland ice cap is melting around the periphery and coastal regions are again being settled, just as during the Medieval Warm Period. However, many of the locations of settlements from the Medieval Period remain icebound.
- There is no evidence that the Greenland and Antarctic ice masses are contracting. Ice continues to accumulate inland over the high cold plateaux.

Satellite derived data suggest that recent rate of sea level rise has been about 2 mm/yr and is no more than the average for the 20th century as estimated from long tide gauge records.

THE SCIENCE OF CLIMATE CHANGE

The climate system is very complex and explanations of human caused global warming have been simplified for public discussion according to two different approaches.

The first approach suggests that greenhouse gases warm the atmosphere. Tim Flannery uses this explanation in his book, The Weather Makers (p28).

"CO2 acts as a trigger for the 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 planets temperature to ever-higher levels."

It is this suggestion of a positive feedback that leads to the illusion of runaway global warming, but it is nonsense. In the atmosphere, greenhouse gases emit more radiation than they absorb. Overall, the direct effect of greenhouse gases on the earth's radiation is to cool the atmosphere, not to warm it.

The energy flow from the Sun follows a well-understood pathway through the climate system.

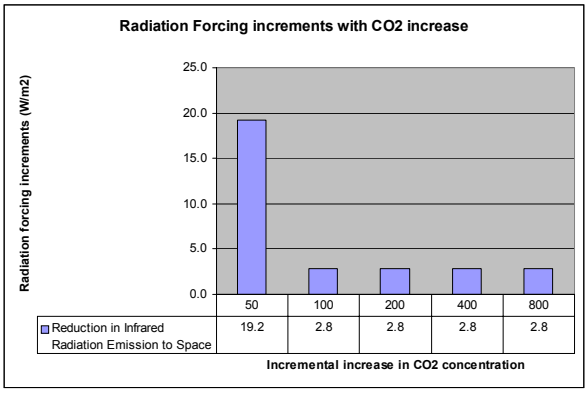
- Over the tropics, and elsewhere during summer, solar radiation is absorbed by and heats the earth's surface.
- Conduction and evaporation are the dominant processes for transfer of energy from the earth's surface to the atmosphere. It is convection and air currents that distribute the heat through the atmosphere and offset net radiation loss.
- The greenhouse gases (that is, water vapour and CO2) and clouds radiate energy to space.

The primary role of the greenhouse gases is to dissipate the Earth's energy by cooling the atmosphere. ***Greenhouse gases do not directly warm the atmosphere.***

The second approach, as used in the IPCC assessment reports, is based on the proposition that increasing CO2 concentration reduces radiation to space. This proposition, and the assumption that earth was in radiation balance (or constant climate) prior to industrialisation, underpin the IPCC hypothesis for anthropogenic global warming. The theory is that, as atmospheric CO2 concentration increases, the radiation to space emanates from a higher colder altitude in the atmosphere. As a consequence, there is less radiation to space, heat is retained in the earth system, and warming takes place. IPCC claims, based on computer model

simulations, that there is a linear relationship between the reduction in radiation to space and global surface temperature increase.

At current concentrations, an increase in CO2 will only marginally reduce infrared radiation to space.



CO2 has lost potency as an agent for climate change.

The radiative forcing of CO2 is dominated by the first 50 ppm of concentration. The incremental addition to radiative forcing for each doubling of concentration is small. ***Any additional CO2 in the atmosphere above the current concentration of nearly 400 ppm will have little forcing effect on climate.***

It is the first 50 ppm* of CO2 in the atmosphere that is the most important for climate. The first 50 ppm reduced the infrared radiation to space by nearly 20 W/m^{2+} (ie, a radiation forcing of 20 W/m^2). Doubling the CO2 concentration to 100 ppm provided an incremental increase to the radiative forcing of only 3 W/m^2. A further doubling to 200 ppm (the concentration 20,000 years ago at the time of the Last Glacial Maximum) added a further 3 W/m^2 of forcing. Again doubling the concentration of CO2 to 400 ppm (about the present concentration) only added another 3 W/m^2 of forcing. If we continue to burn fossil fuel and achieve another doubling of CO2 concentration to 800 ppm we will only add another 3 W/m^2 of forcing.

At pre-industrial levels the radiative forcing of CO2 was about 26 W/m^2. Over the 20th century the burning of fossil fuels and other industrial activities have increased the CO2 concentration from 280 to 370 ppm with little more than 1 W/m^2 increase in radiative forcing. This increase in CO2 has had little impact on climate. ***As a potential agent for climate change, as concentration increases above current levels, CO2 is rapidly decreasing in potency.***

Interactions of the oceans and atmosphere

The IPCC global warming hypothesis is based on a one-dimensional construct of the climate system. It ignores the fact that most solar radiation is absorbed over the tropics; that over middle and high latitudes there is net loss of radiation energy to space. In order to achieve a global radiation balance it is necessary to constantly transport energy from the tropics to the polar regions by the atmospheric and ocean circulations.

The atmosphere and the oceans, however, are dynamic and interacting fluids.

- The oceans are the inertial and thermal flywheels of the climate system. The total energy of the atmosphere is contained within the top 3 metres of the ocean and it is the oceans and the patterns of surface temperature that regulate climate variations.
- Surface winds drive the ocean currents and induce regions of upwelling and downwelling that vary the ocean surface temperature patterns.

* ppm: parts of CO2 per million parts of air by volume
+ W/m2: Watts per square metre heat transfer

- Changing sea surface temperature patterns, such as associated with El Niño events, have profound impact on climate.

The interactions between the atmosphere and oceans lead to climatic variations with interannual, decadal and longer timescales. Only the shorter period events, the El Niño that often are associated with intense drought over Australia, have been studied in any detail. ***There is a range of climate cycles with decadal to centennial timescales that are poorly understood.***

There is much more research to be done to understand the ocean circulations and their variations before we can be confident of being able to predict the natural cycles of climate variability. The observation programs to produce the necessary ocean data were only commenced in the last decade. These programs will take many more decades to reach fruition.

LIMITATIONS OF COMPUTER MODELS

The predictions of future global temperatures are based on computer models that are claimed to simulate the climate system. The computer models are forced by increasing concentrations of atmospheric CO2 and simulate an expected rise in Earth's temperature. ***However, the simulated temperature response of computer models is exaggerated.***

The computer models are rudimentary in their construction and in the representation of important physical processes.

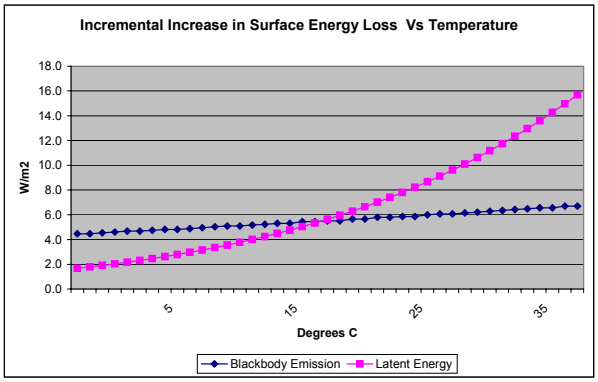
- The computer models do not adequately represent a range of energy exchange processes, including those associated with clouds, with transfer of heat and moisture between the Earth's surface and atmosphere, and with the growth and decay of ice sheets.
- There are only limited observations of sub-surface ocean circulations and their variability. Understanding the ocean circulations is crucial to modelling the natural variability of the climate system.

In essence, computer models represent a highly constrained version of the complex non-linear and chaotic climate system. Computer models cannot predict major and important short-term climate events, such as El Niño; they are certainly not able to predict the next Little Ice Age.

Without a forcing mechanism the global temperature of computer models remains essentially constant – the stable climate scenario. However, a stable and unvarying climate is not what we observe.

In an example of convoluted logic the IPCC claims that, because computer models only have limited internal variability, then the climate system must also have only limited natural internal variability! There is no acceptance that perhaps it is the constraints of the computer models that prevent them from reproducing the observed variability of the climate system.

The computer model predictions of global warming are the basis for quantifying the Earth's temperature response to increasing man-made CO2 concentration in the atmosphere. The direction of the response is predetermined and it is only the magnitude of response that can vary, depending on assumptions and formulations of physical processes specified in each model.



Evaporation damps CO2 forcing.

The direct effect of radiation forcing from increasing CO2 concentration is to warm the surface and atmosphere. The warmer atmospheric temperature and corresponding higher water vapour concentration from CO2 increase will cause an increase in back radiation to the surface. The increased back radiation tends to further raise the surface temperature, thus again raising the atmospheric temperature and water vapour and amplifying the initial CO2 forcing.

However, as surface temperature increases, the surface energy losses from IR emission and evaporation (latent heat loss) also increase rapidly. These quickly offset the increased back radiation and strongly constrain further surface temperature rise. Most computer models grossly underestimate the rate of increase of latent energy exchange with temperature increase and thus have an exaggerated temperature response to CO2 forcing. ***The concept of runaway global warming is implausible.***

Evaporation is a natural constraint to surface temperature increase because evaporation and the exchange of latent energy between the Earth's surface and the atmosphere follow the Clausius-Clapeyron relationship. The rates of increase of evaporation and exchange of latent heat increase nearly exponentially as temperature increases. Evaporation is a powerful constraining factor because the oceans cover about 70 percent of the Earth's surface. Proxy records indicate that a natural upper limit to the surface temperature of tropical oceans is about 30^{o}C, as is currently observed.

Recent analyses of the computer models used by the IPCC in its 2007 assessment, as published in peer-reviewed journals, identify that the rate of increase of evaporation (and latent energy exchange) with temperature increase is grossly underestimated. On average, the rate of increase of evaporation in the models is only about one-third of the observed value.

The primary reason for the exaggerated sensitivity of the model temperature response to CO2 forcing is the under-specification of the rate of increase of evaporation and latent energy exchange with surface temperature increase. The exaggerated sensitivity is not real and is a consequence of errors in the specification of evaporation processes.

A simple mathematical analysis of the role of evaporation suggests that underestimation of evaporation in some computer models is so severe that those models border on instability. This potential for instability is misinterpreted as runaway global warming. ***Runaway global warming is an implausible concept because a more realistic representation of evaporation would strongly constrain surface temperature response to CO2 forcing.***

SUMMARY

In the past, Earth's climate has undergone constant change. There have been cyclic glacial periods when large parts of the high latitude Northern Hemisphere lands have been covered in deep layers of ice. We are presently enjoying one of the brief interludes of warmth and are near the upper limit of the feasible global temperature range. However, even during the past 10,000 years there have been regular fluctuations between slightly warmer and significantly colder conditions.

There are neither sound theoretical grounds nor observational evidence to support the argument that changing concentrations of atmospheric CO2 will have any significant impact on future climate or global temperatures. In particular, there is no reason to believe that there

is a mystical tipping point beyond which runaway global warming will lead to dangerous climate change. To the contrary, because of the damping effect of evaporation, the Earth's temperature is bounded at a value not too much warmer than current values.

There is, therefore, no reason that levels of CO2 in the atmosphere should influence either international protocols or national policies. The paramount consideration should be that fossil fuels are a non-renewable resource and are to be used judiciously.

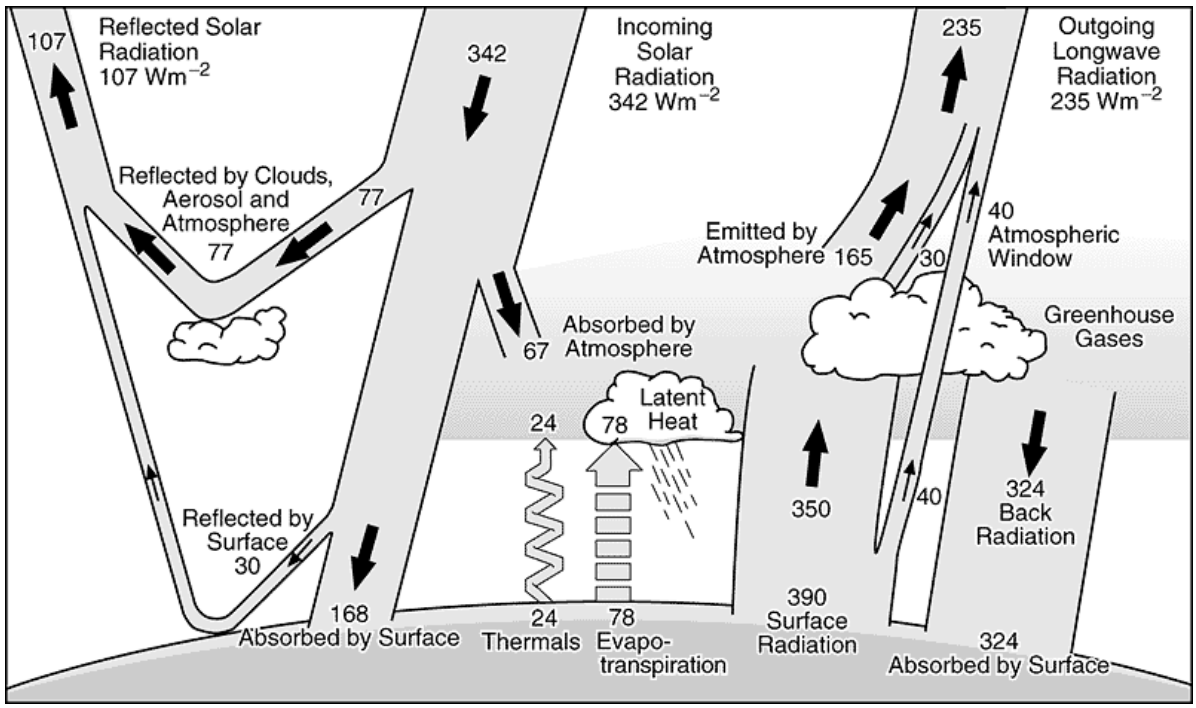
Environmental propagandists, such as Al Gore and Tim Flannery, insist that laws should be passed to regulate our behaviour and limit fossil fuel usage to ensure climate returns to what it was in pre-industrial times. Just like in Camelot, where King Arthur mandates:

> *"Its true! Its true! The crown has made it clear!*
> *The climate must be perfect all the year."* (Lerner and Lowe)

We do not live in Camelot. We can neither control nor predict future climate and we certainly do not want to intentionally return to a pre-industrial climate as characterised by The Little Ice Age.

In closing, it should be noted that the magnitude of energy flowing through the climate system has the potential to meet all future needs, if it can be economically harnessed. This should be a guiding principle as non-renewable fuels that are now widely in use are steadily depleted.

October 2007



THE GLOBAL ENERGY BUDGET Source: Kiehl and Trenberth, 1997

THE GREENHOUSE EFFECT

The greenhouse effect is the raising of surface temperature above that required for radiation balance between the incoming solar radiation and the outgoing infrared (IR) emissions. The processes that contribute to the greenhouse effect are:

- The absorption of solar energy at the Earth's surface,
- The transfer of energy from the Earth's surface to the atmospheric boundary layer by conduction and evaporation.
- The distribution of energy through the atmosphere by convection and wind circulation.
- Emission of IR to space by the greenhouse gases (water vapour, CO_2, etc), clouds and aerosols.

1. The greenhouse gases, clouds and aerosols elevate the altitude from which IR emanates to space from the surface to a layer within the atmosphere (about 5 km). However the effective emission temperature for radiation balance (about –19^{o}C) is not changed [IPCC TAR 1.2.1 p90].
2. Greenhouse gases, clouds and aerosols emit more radiation energy (to space and back to Earth) than they absorb (102 W/m^2) and act to cool the atmosphere.
3. At the surface, more solar radiation is absorbed than is lost by net emission of IR (a net gain of 102 W/m^2) and this excess solar energy tends to warm the surface.
4. Overall, radiation processes tend to warm the surface and cool the atmosphere. Conduction and evaporation transfer excess energy from the surface to the atmospheric boundary layer.
5. Convective overturning is necessary to distribute heat and latent energy through the atmosphere from the atmospheric boundary layer of the tropics, and thus offset the net radiation loss from greenhouse gases, clouds and aerosols (Riehl and Malkus, 1958).
6. Convective overturning requires buoyant saturated ascent in the updraughts of deep convection clouds. Surface temperature and rate of temperature decrease with altitude in the buoyant convective updraughts (about 6.5^{o}C per km in the lower atmosphere) control the temperature of the atmosphere.
7. The greenhouse effect is regulated by the height of the effective emission layer in the atmosphere (5.1 km) and the temperature change with height generated by convective overturning (6.5 ^{o}C/km). It is 33 ^{o}C above the effective emission temperature (-19 ^{o}C) and elevates the Earth's average surface temperature to 14 ^{o}C.