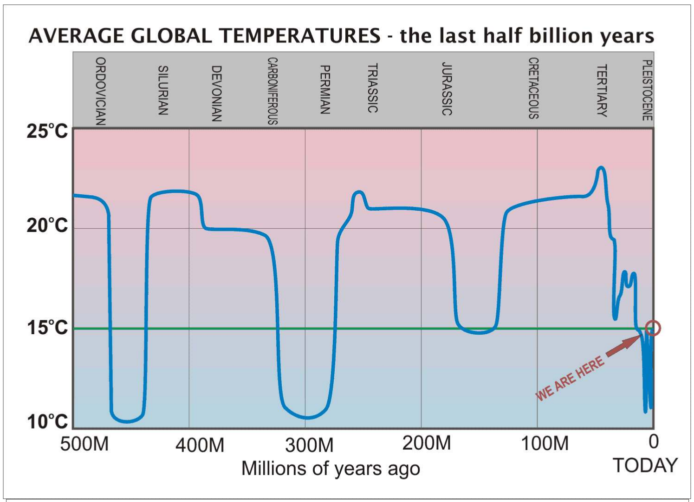
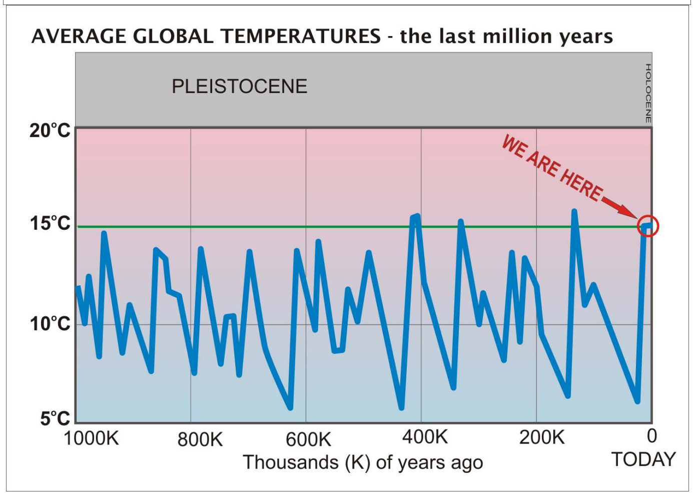
Climate Science – an Introduction





In the last few hundred million years the Earth has swung between a global hothouse with no ice at all and a frozen ‘snow-ball’ with snow and ice covering much of the globe. In the hothouse periods the average global temperatures were around 22°C, compared to 15°C today, and sea levels were one or two hundred metres higher than today’s. The ‘snowball Earth’ average temperature was below 10°C with sea levels about one hundred metres lower than today.

Believe it or not, we are actually now in an ice-age which has lasted for the last couple of million years. However, during this ice-age there have been hundred thousand year swings between ‘glacial’ periods and ‘interglacial’ periods, as shown in the second graph – which expands the last one million years of the first graph. In the glacials ice covered much of the northern and southern latitudes and glaciers were widespread. Temperatures were over five degrees colder and sea levels about 100 metres lower.

It is probably no accident that human civilization has developed rapidly in the last ‘interglacial’ – the last 11,000 years shown in the circle of the second graph. Temperatures have been more moderate and stable in this period than in most previous interglacials. Consequently plant and animal life has become more abundant and diverse.

Left to itself, the Earth would probably linger in this comfortable interglacial period for a few thousand more years before gradually heading back to a cold glacial. Characteristically it has spent considerably longer in glacials (around 100,000 years) and only around 12,000 years in interglacials.

However, the Earth is not being left to itself. The problem is that we humans are upsetting the delicate balance between the incoming solar energy and the outgoing long wavelength heat radiation that keeps the temperature reasonably stable.

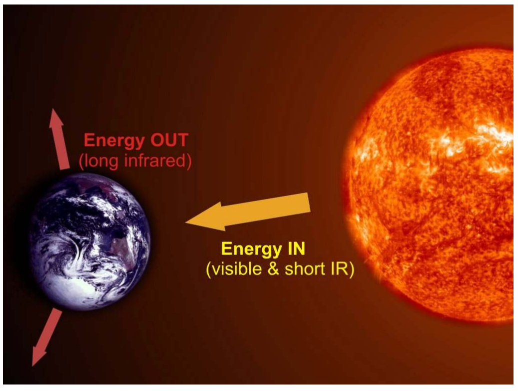
There is a chance that, if we do nothing to restore the balance, the Earth could jump right out of the glacial-interglacial cycle of the last two million years and back into the hothouse conditions in which it has spent the bulk of last few hundred million years. If not to the complete hothouse, certainly it could go to a warmer state such as that it was in the Miocene (around 20 million years ago) when temperatures were several degrees higher and sea levels 10 to 20 metres higher than today. As far as life on Earth generally is concerned this could be a good thing. There would probably be more fertile land and certainly less frozen wastes. The only problem is that it would take a few thousand years for the new pattern to become established and in the meantime virtually all coastal cities would be drowned and huge areas would become unfertile wastelands. Millions of species would die out, but new ones would eventually evolve adapted to the new conditions. Human life would probably survive in some form, but whether civilization would is another question altogether.

But is this an accurate picture? How sure can we be of the science that is warning us of dire consequences of our interference with the Earth’s climate?

The Big Picture

Our Earth sits in space between Venus and Mars. Venus is a hothouse hell and Mars is a frozen wasteland. This is partly due to the fact that Venus is closer to, and Mars further from, the Sun. But only partly. In fact, Venus is a 'greenhouse' gone mad. It has a thick atmosphere of carbon dioxide which keeps its temperature at over 460°C. That's enough to melt lead! Mars, on the other hand has an almost negligible atmosphere and no oceans and hence its temperature swings wildly between –140°C and +20°C.

The Earth is indeed the Goldilocks planet – with a just right temperature and only moderate variations from the average. That is because the Earth has developed some very nice mechanisms to keep the temperature at a comfortable average of +15°C. One of the most important is what we call the 'greenhouse effect'. If it wasn't for the greenhouse effect the Earth would be a frozen ball of ice at around –18°C and we certainly would not be here discussing our effect on it! But before discussing the greenhouse effect we need to understand some simple physics.



Some simple science

The Earth stays at a fairly constant temperature because the amount of energy coming in from the Sun is balanced pretty much by the amount escaping.

The energy coming in is obvious – we can feel it whenever we sunbake. It is largely composed of visible light and what physicists refer to as short wavelength infrared (IR) – which is just the invisible 'light' beyond the red end of the 'rainbow' spectrum.

The energy escaping is not quite so obvious. Think of a black car sitting in the Sun. It is black because it absorbs visible light energy. But it doesn't just sit there absorbing energy, it also radiates the energy away – as we can feel if we put our hand near it. This radiated energy is actually long wavelength IR 'light'. Eventually the temperature of the car stabilises when the incoming visible energy is balanced by the outgoing IR energy.

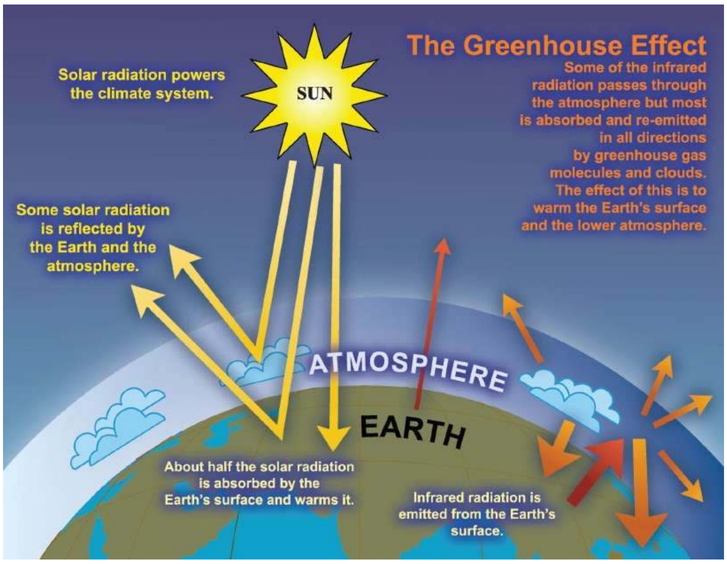
Clearly, the hotter the object, the greater the total amount of heat energy radiated away. If the car is absorbing more heat than it is radiating, the temperature increases. Eventually the temperature increases to the point at which the heat radiated is equal to the heat absorbed.

As well as the increase in total energy radiated there is another change that occurs as the temperature increases. The hotter the object radiating heat the *shorter the wavelength* of this IR light. The filament in an old fashioned light bulb (remember them?) is so hot that most of the energy radiated is short wavelength IR and some (but only about 5%) is actually visible light.

These two facts (hotter produces *more* IR and hotter produces *shorter wavelength* IR) are well known laws of physics called, respectively, the Stefan-Boltzmann law and Wien's law. Physicists can use them to calculate all sorts of things about the way hot objects, including the Earth, radiate energy.

The Earth is like a big radiator sitting in space. It's not very hot, so the IR being radiated is long wavelength, but the total amount being radiated is pretty much the same as that coming in from the Sun. In fact, if the amount being radiated away is less than that absorbed from the Sun there is an imbalance and heat will build up – the Earth warms. But the physics tells us that it will only warm until the increased amount of radiation again equals that coming in.

So what are we doing to interfere with all this? To put it in a nutshell, we are trapping more of the escaping energy than normal and so the Earth needs to warm a little to radiate more of it back into space. We need to return to the greenhouse effect in order to see why this is the case.



The Greenhouse Effect

Most of our atmosphere consists of nitrogen and oxygen. Fortunately for us, both these gases are transparent to visible light and most infrared (IR) light. *[Our blue sky results from the fact that the atmosphere is actually not quite as transparent to blue light as it is for red – a tiny bit of the blue is 'scattered'. It's that scattered blue light we see in the sky.]*
It's a different story for the other two most common gases in our atmosphere – water vapour and carbon dioxide. Although they are transparent to visible light, both of them absorb some IR light. In particular, they absorb some of the long wavelength IR radiated away from the Earth as part of the energy balance we spoke of earlier.

The water vapour (H_2O) and carbon dioxide (CO_2) molecules in the atmosphere don't just hang on to the IR energy they absorb, they re-radiate it. This re-radiated IR goes off in random directions. Some will go up (on out into space) – and some will head back down to where it came from. Some will also be converted to heat in the atmosphere. So instead of escaping out into space some of the IR radiated by the Earth ends up being trapped back on Earth.

Just as a glass 'greenhouse' traps some of the heat of the sunlight that comes in, so the 'greenhouse gases' H_2O and CO_2 trap some of that outgoing IR radiation. The mechanism is a little different, but the effect is similar and so the expression 'greenhouse effect' has become well established as shorthand for this process by which H_2O and CO_2 molecules keep us warm. In fact, they trap heat to the extent that the Earth stays 33 degrees warmer than it would without them. The Earth would be at that frozen –18°C if it weren't for the H_2O and CO_2 in the atmosphere!

So the greenhouse effect is actually essential to life on Earth. The problem, however, is that by releasing huge amounts of carbon dioxide (from the burning of fossil fuels) into the atmosphere, we humans are increasing the amount of greenhouse gas in the atmosphere. In fact we have increased the amount of CO_2 in the atmosphere from around 600 gigatonnes to almost 800 gigatonnes in the last century. The big question of course is: what effect will this have on the total greenhouse effect?

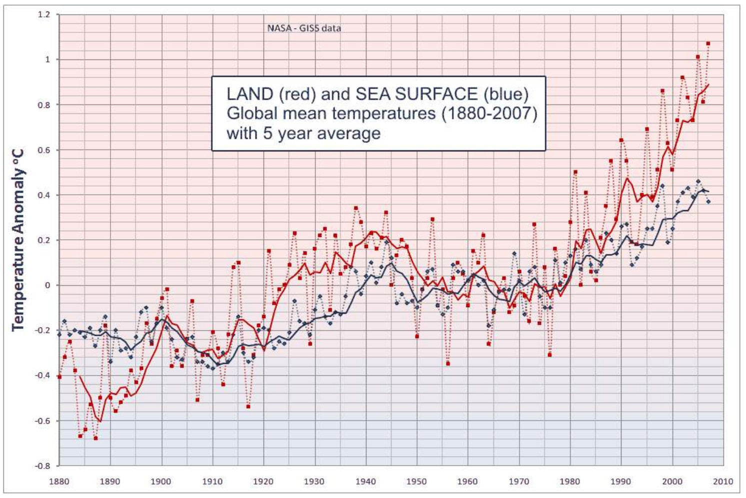
All the basic chemistry and physics of the interactions of the greenhouse gases with the atmosphere have been studied in great detail. We know very well how the gases interact with the IR radiation from the Earth and we know the thermodynamics of the Earth's energy balance. Laboratory experiments and observations of both the Earth and other planets confirm the basic science. Furthermore, we are running the biggest science experiment in human history by pouring massive amounts of carbon dioxide into the atmosphere and waiting to see what happens! Unfortunately, however, we can't wait to run the real experiment to the end because that will a) take many centuries to run its course, and b) most likely result in catastrophic and irreversible changes (for us) to the climate.

Climate Models

There are many complex interactions between the components of the atmosphere, including clouds, water vapour, snow and ice as well as the ways in which heat is distributed by winds and ocean currents. These are difficult to study experimentally but scientists have developed very sophisticated computer models which take as many of these factors as possible into account and then apply the basic laws of physics and chemistry.

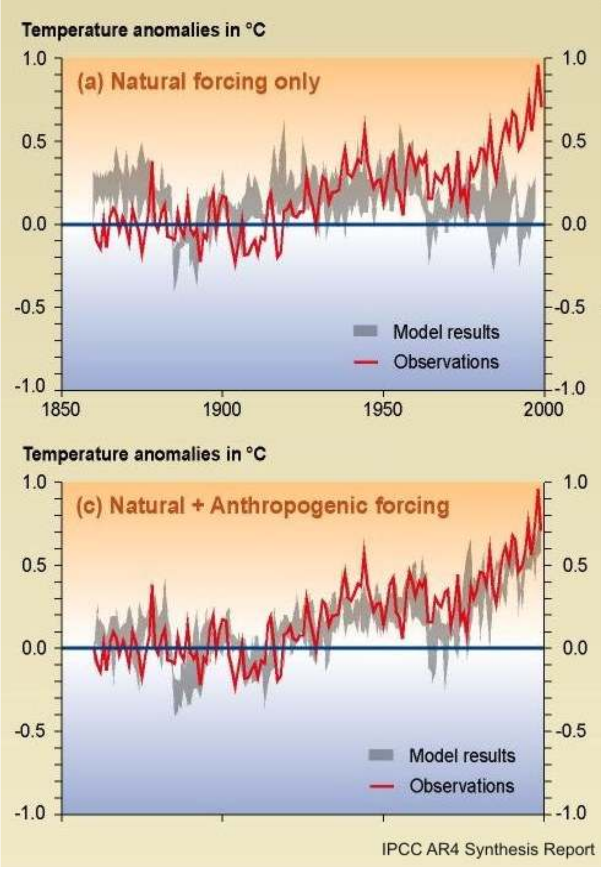
Basically, the models divide the atmosphere, and the oceans, into 'cells' about 100 km square and a few km high. The physics of heat transfer, Newton's laws of motion, and the principles of conservation of mass and energy are used to determine how mass (wind or ocean currents) and energy (heat) will flow between the cells. Factors such as the energy input from the Sun, the position of the Earth in its orbit and the output in the form of infrared radiation, and much more, are all taken into account.

The models can be tested against past real climate events and by 'forecasting' previous climates. Modern global climate models are proving very effective at this 'past-casting' and while they have their limitations they represent our best attempts to understand the Earth's climate. As we know, virtually all of these models suggest that our added carbon dioxide will warm the planet significantly. The ultimate test of the models, however, is whether we can see the predicted global warming in the real climate data.



As we well know, day-to-day weather, and even year-to-year weather, is very variable. There are all sorts of factors that make it hard to see the relatively small effects of global warming we expect so far. Natural variability of the climate results from factors such as small changes in the strength of the Sun's radiation or volcanic eruptions. Natural cycles in the ocean-atmosphere system – such as the well known El Niño - La Niña Southern Oscillation (ENSO) switch between warm and cool phases rather erratically every few years.

It is important not to take short term trends as indicative of climate change – or the lack of it. A few hot (or cool) years could well be the result of combinations of ENSO and other cycles, some of which we probably don't even understand fully. The 11 year sunspot cycle can also help to disguise longer term trends as the Sun's power varies slightly with sunspot activity. The relatively cooler year 2008, for example, occurred at a low in the solar cycle as well as in a strong La Niña – although it was a hotter year than any in the 20th century except for 1998, which was at a high in the solar cycle and with a strong El Niño. (This graph did not include 2008, but it was just a little lower than 2007.)



So in amongst all this variability are there signs of human induced global warming? Collecting data on global temperatures is not easy. All sorts of spurious effects have to be screened out from temperature records from thousands of sites around the world. For example, as the size of cities increases the 'heat island effect' increases. (Increases in pavement and number of buildings traps heat and artificially increases the temperature.) Much painstaking work has been done to sort out the real data from the 'noise'. The results from different research teams are quite consistent however. A slow warming in the 1920's, 30's and 40's with a drop until the 60's when the rise resumed and has continued to the present.

Climate models can be made to start from a previous date and forward predict the climate – which can then be compared to what actually happened. The graphs at left (from IPCC AR4) show the results of model runs assuming only natural conditions and then including human produced (anthropogenic) greenhouse gases from burning fossil fuels. When the models are run **without** considering the extra carbon dioxide we have added they invariably predict a reasonably steady temperature (grey shading, upper graph). Only when the greenhouse effect of the extra CO_2 is taken into account do they predict temperatures close to those that have actually occurred (grey shading, lower graph).

So the only reasonable explanation for the generally increasing temperature, particularly since the 1960's, is the carbon dioxide we are putting into the air. Why then are there people who apparently do not believe that human produced carbon dioxide is a problem?

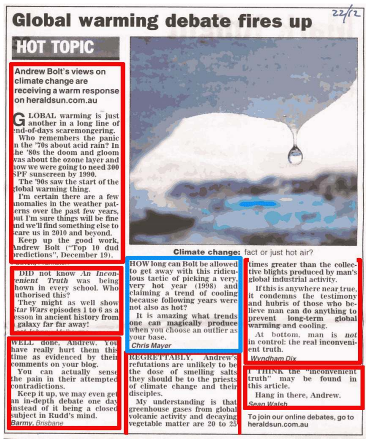
Could the sceptics be right?

Firstly, we must distinguish between the few genuine scientific sceptics and the very much larger number of ‘deniers’ who use arguments that may sound ‘scientific’ but which are usually well and truly outdated or just misrepresentations of the real science.

Science progresses because scientists question each other’s ideas. It is not surprising then that some scientists have questioned the conclusions of the vast bulk of climate scientists who are agreed that climate change is real and mostly caused by our greenhouse gases emissions. These sceptical scientists help to test out the science and find any faults in the reasoning and conclusions. They normally publish their work in the peer reviewed scientific literature and discuss it with their colleagues.

Unfortunately, there are those in the community who, for a variety of reasons, including vested interests in industries that might be adversely affected by moves to cut greenhouse gases emissions, are willing to grab any small piece of science that seems to question some of the mainstream conclusions and focus on it out of all proportion to its real significance in the scientific literature.

There are a small number of high profile journalists who like to take this so-called sceptical position and continue to create confusion in the public mind by publishing opinion pieces which suggest the problem is not as real as the huge bulk of climate scientists say it is. Because these journalists have a high readership they have a totally disproportionate influence in the community. They are in fact being totally irresponsible in their actions as the effect of their work is to delay the urgent action needed to mitigate the emission of greenhouse gases. Future generations, if not our own, may well have cause to curse them.



Global warming debate fires up — 22/12

HOT TOPIC

Andrew Bolt’s views on climate change are receiving a warm response on heraldsun.com.au

GLOBAL warming is just another in a long line of end-of-days scaremongering.
Who remembers the panic in the ’70s about acid rain? In the ’80s the doom and gloom was about the ozone layer and how we were going to need 300 SPF sunscreen by 1990.
The ’90s saw the start of the global warming thing.
I’m certain there are a few anomalies in the weather patterns over the past few years, but I’m sure things will be fine and we’ll find something else to scare us in 2010 and beyond.
Keep up the good work, Andrew Bolt (“Top 10 dud predictions”, December 19).

DID not know *An Inconvenient Truth* was being shown in every school. Who authorised this?
They might as well show *Star Wars* episodes 1 to 6 as a lesson in ancient history from a galaxy far far away!

WELL done, Andrew. You have really hurt them this time as evidenced by their comments on your blog.
You can actually sense the pain in their attempted contradictions.
Keep it up, we may even get an in-depth debate one day instead of it being a closed subject in Rudd’s mind.
Barmy, Brisbane

Climate change: fact or just hot air?

HOW long can Bolt be allowed to get away with this ridiculous tactic of picking a very, very hot year (1998) and claiming a trend of cooling because following years were not also as hot?
It is amazing what trends one can magically produce when you choose an outlier as your base.
Chris Mayer

REGRETTABLY, Andrew’s refutations are unlikely to be the dose of smelling salts they should be to the priests of climate change and their disciples.
My understanding is that greenhouse gases from global volcanic activity and decaying vegetable matter are 20 to 25 times greater than the collective blights produced by man’s global industrial activity.
If this is anywhere near true, it condemns the testimony and hubris of those who believe man can do anything to prevent long-term global warming and cooling.
At bottom, man is *not* in control: the real inconvenient truth.
Wyndham Dix

I THINK the “inconvenient truth” may be found in this article.
Hang in there, Andrew.
Sean Walsh

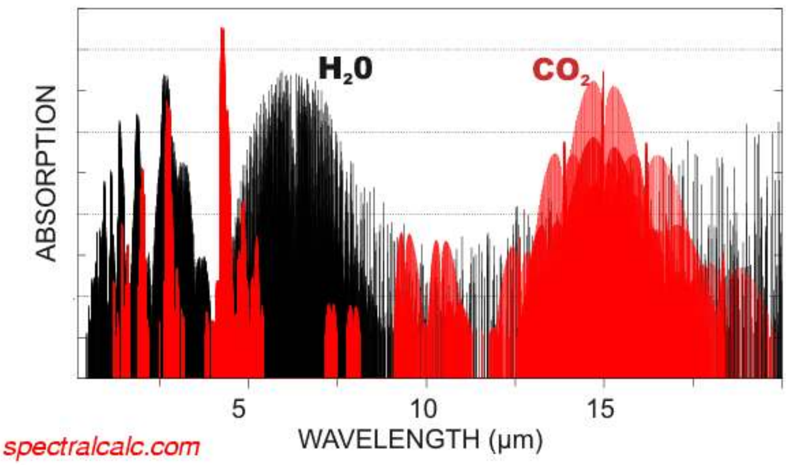
To join our online debates, go to heraldsun.com.au

The illustration at right is a section from the letters page of the Herald-Sun (22/12/08) with 5 (red) out of 6 letters supporting an opinion piece that suggested that various predictions of climate ‘alarmists’ were wrong – mainly based on the fact that 2008 was a little cooler than the few previous years. As pointed out earlier, it is simply nonsense to take any one year as indicative of climate trends. In fact none of the five (red) letters said anything meaningful. Only the single opposing letter (blue) made the sensible point that the journalist should not have used the single hottest year on record (1998) to claim a cooling trend in the following years. This, unfortunately seems to be typical of the irresponsible approach taken by some sections of our media.

Unfortunately the general public is not really aware of the fact that something like 95% or more of scientists working in the field are agreed on the general conclusions. Of the few who are not sure, most agree that in any case the risk of inaction is too great to ignore. Virtually all of the key scientific bodies in the world have issued statements to the effect that climate change is real and dangerous and it is crucial to cut greenhouse gas emissions. However, because of the presence of a small number of very vocal deniers in the media many of the public are under the misapprehension that there is still some sort of debate among the scientists. It could well be said that the actions of these people in delaying effective action on reducing emissions may in future be seen as the cause of a massive human tragedy.

Is there really enough CO_2 in the atmosphere to matter?

We don’t have space here to answer all the denier arguments, but perhaps an illustration of the falsity of a common one will suffice. It is often said that carbon dioxide is not as important a greenhouse gas as water vapour, and in any case CO_2 only comprises about 0.03% so it can’t have much effect. This is true in that most of the IR radiation emitted by the Earth is captured by water vapour. However, there are several other factors which must be taken into account. Firstly, H_2O molecules and CO_2 molecules absorb different parts of the IR spectrum. While there is some overlap, H_2O absorbs mostly at around 5 to 10 micrometers while CO_2 absorbs mostly at around 15 micrometers which is the peak wavelength of the Earth’s



infrared radiation. So it doesn't matter how much water vapour is in the atmosphere, CO_2 will always absorb radiation that H_2O can't absorb. Unfortunately, the other main greenhouse gas we are putting into the atmosphere, methane, absorbs strongly at around 8 micrometers – an area which neither water nor carbon dioxide absorb significantly.

While 0.03% may sound like a very small amount, this does not mean CO_2 only absorbs a small amount of IR radiation. Remember that oxygen and nitrogen don't absorb IR at all – it is only the water vapour and other greenhouse gases that are absorbing the radiation.

Consider a glass of water. It is completely transparent. All those water molecules have virtually no effect on the amount of light passing through the glass. But put about 3 drops (roughly 0.03%) of ink or other strong dye in the glass. That relatively tiny amount of ink will absorb much of the light and the glass of water becomes quite dark (middle glass). The point is that the water molecules in the glass, and most of the air molecules in the atmosphere, simply don't absorb anything – it is only the ink, or the CO_2, which is doing the absorbing. The percentage fraction is simply meaningless, but changes in that fraction are crucial. In the third glass the fraction has doubled to 0.06%. (Note that 0.03% is equivalent to 300 ppm, parts per million. So far we have raised the atmospheric CO_2 level from the pre-industrial 280 ppm to about 380 ppm, or 450 ppm equivalent if methane and other greenhouse gases are taken into account.)

There is a another very important difference between the water and carbon dioxide molecules in the atmosphere. The average water molecule might stay in the air for a few days or weeks. When the humidity becomes too high it simply rains out. The average carbon dioxide molecule, once in the atmosphere will stay there for around a century. For this reason carbon dioxide is referred to as a forcing greenhouse gas while water vapour is a feedback gas. Small increases in CO_2 will result in a small increase in temperature, but this will result in more evaporation of water which in turn will add to the greenhouse effect. This is one of the many positive feedback effects in the climate system which make it hard to model, but which may well be responsible for the abrupt climate changes that we know have occurred in the distant past.

By adding more and more carbon dioxide to the atmosphere we risk getting to a point where these various positive feedback effects – changes which reinforce themselves and become greater and greater – take us into a new (for humans, not the Earth) and warmer state of the climate. There are two very obvious possible feedback effects which could bring us to the point where there is nothing we can do to prevent the Earth warming catastrophically.

The first is the 'ice-albedo' effect. When ice at the poles (or in glaciers) melts, darker land is exposed which absorbs the solar radiation much more effectively – and thus warms, melting the remaining ice still faster.

The second example of a possibly dangerous feedback is the melting of the permafrost in Arctic regions which could release huge amounts of methane, a greenhouse gas with 20 times the power (per molecule) of carbon dioxide. The more methane released the warmer it gets – and the more methane released.

There are of course negative feedback effects as well – other wise we would have had runaway climate change a long time ago! With increased evaporation the reflectivity of clouds increases as well as the greenhouse capture for example. Remember, however, that the total greenhouse effect is responsible for about 33 degrees of warming. Relatively small changes in the system could easily make a few degrees difference. A few degrees of warming would be catastrophic for human civilization. We have already increased the amount of carbon dioxide in the atmosphere by over 30%.

Keith Burrows Feb 2009