Greenhouse Gases and Climate Sensitivity

Heat moves from hotter to cooler places in three ways - by conduction, convection and radiation. In a garden greenhouse, sun light passes through the glass (or plastic) roof and walls heating the ground by radiation. The air layer in contact with the soil warms by conduction and then starts moving upwards by convection. It is also true that some of the energy coming off the heated surface is electromagnetic radiation in the infrared part of the spectrum. The physical barrier of glass (or plastic) which stops the warm air escaping by convection is the main reason that a greenhouse works. Any retention of heat by limiting the escape of infrared radiation from the ground is very much a secondary effect.

The third and fourth hypotheses I listed previously (scroll down blogs) as forming the overall Anthropogenic Global Warming (AGW) Hypothesis directly concern the two main so-called greenhouse gases in the Earth's atmosphere. Just to remind you I listed these two hypotheses as:

(iii) As a greenhouse gas CO2 absorbs upwelling infrared radiation from the Earth and re-emits in all directions effectively causing warming.

(iv) The increase in heat (caused by the CO2 warming) evaporates more of the primary greenhouse gas, water vapour, this multiplying the effect of CO2 increase by a factor of about three.

As you can probably appreciate, the Greenhouse Gas (GHG) effect that one hears about in the context of global warming involves rather different mechanisms than what goes on in actual greenhouses. The central idea, but not the only one, is that some types of molecule absorb certain frequencies of upwelling electromagnetic infrared radiation from the warmed surface of the Earth (water, soil etc). Such molecules then re-emit infrared radiation in all directions, including back to the ground. For reasons to do with the laws of physics and thermodynamics in particular, I prefer to describe the effect as one which changes the rate of loss of heat to space which results in a slightly different temperature than if the absorbing gases had not been present. The main infrared absorbing gases present in the Earth's atmosphere are water vapour (highest absorber by far) followed by our old friend carbon dioxide (CO_2) as a poor second. Others include methane, nitrous oxide and ozone.

The idea that some part of the Earth's atmosphere effectively keeps us warmer than could otherwise be expected is attributed to the brilliant French mathematician and physicist Joseph Fourier (1768-1830). John Tyndall (1820-1893) identified water vapour and carbon dioxide as the "heat –trapping" components of the atmosphere. Svante Arrhenius (1879-1927) reasoned that because water vapour fluctuated continually cycling in and out of the atmosphere carbon dioxide is the key component. He argued that increasing atmospheric carbon dioxide would cause warming and this would cause increased evaporation of water. As you can therefore see, the basic idea is far from new.

Water is a remarkable compound. According to its position in the Periodic Table of Elements, oxygen hydride (chemical formula H_2O) should be a gas at room temperature. Indeed the hydrides of the next three elements in the same series, sulphur, selenium and tellurium are all gases at room temperature. Only the hydride of polonium, the next element in the series, is a liquid at room temperature. Water is in fact rather like a polymer with the formula n (H_2O) with a small amount of ionised component giving it a pH value of seven. In fact, I suspect that the anomalous behaviour of water features in disagreement s between scientists on the sign and extent of the GHG effect.

The changes of state of water, from ice to liquid water, from liquid water-to-water vapour and vice versa, involve large changes in energy, referred to as latent heat. The amount of sunlight reflected from the Earth's surface, called its albedo, depends crucially on the surface type and if H_2O its form being high when the form is snow and ice. All these factors play important roles in the Green House Gas (GHG) Effect. However as mentioned there is considerable argument about the overall effect of GHG on the Earth's energy balance. The majority opinion favours a reduced rate of loss of heat as GHG increase although both effective warming and cooling take place. There is a minority view suggesting a slight overall cooling effect. Unlike politics consensus means nothing in science and so it is possible that the minority are correct. However, for the purpose of the discussion below I shall assume increased GHG have an overall warming effect.

Scientifically the big issues are climate sensitivity to changes in radiative forcing and the nature and extent of positive and negative feedbacks in the climate system. The term "sensitivity" is often used specifically for estimates of the increase in equilibrium atmospheric temperature, when the amount of atmospheric CO_2 is doubled. The range of estimates for sensitivity is very wide from typically 0.6 ^{0}C to 4.5 ^{0}C and perhaps confusingly in computer models it includes for the compounding effect of increased water vapour expected for the increase in temperature caused by the increase of CO_2 by itself. Interestingly, although one would expect an increase in the Earth's atmospheric water vapour content for increasing temperature (for whatever reason), this has not been observed as far as I am aware although it is generally agreed that the Earth has warmed up by almost one degree Centigrade in the last 200 years.

There is a great deal of science hidden in the above remarks and I plan for the moment at least to make just a few comments which I may elaborate on in future. Firstly, when the quantity of any particular infrared absorbing gas increases in the atmosphere each new molecule has less effect than the one before it. The relationship is logarithmic. Secondly, unlike a real greenhouse there is no physical barrier to radiation finding its way to space it just takes a little longer than if there were no GHG present. Thirdly, in recent years despite continuing increases in atmospheric CO_2 there has been no significant change in the Earth's temperature. It had been thought that the effect was being hidden by aerosols, which have a shielding effect on sunlight. However, although real, this effect has been shown to be far less important than previously assumed. In fact, the only place where there is catastrophic global warming (CAGW) is in computer climate models which have been departing considerably from measured values for many years.

Until I have discussed the final two AGW hypotheses I will hold off on two important topics – alternative mechanisms for climate change and appropriate policies for dealing with the consequences of climate change. However, before leaving the CO_2 water vapour issue I will relate a short story, which you may find interesting, frustrating or shocking depending on your understanding and point of view.

In late February 2010, I attended a two-day discussion meeting at the Royal Society in London. The title of the meeting was "Greenhouse gases in the Earth system: setting the agenda to 2030". Before attending, I had not seen the list of papers.

However, I expected that since water vapour is largely responsible to the so-called greenhouse effect on Earth there would be a number of papers on the subject. I was looking forward to those addressing water vapour variability especially since increased water vapour levels are linked to increased CO2 levels and an enhanced greenhouse effect. I was disappointed that there was not one single paper on water vapour, its variability or indeed any on the multiplying effects inherent in one of the main AGW hypotheses. Consequently, at the first opportunity, I asked why there were no such papers. The only answer that I received was that climate models fully account for water vapour. Sadly you will not be able to check exactly what I asked or indeed the response I received because these days the “Philosophical Transactions of the Royal Society do not actually include a record of the question, answer and discussion sessions although for the progress of science these are often the most important parts of a meeting.

In the coffee break immediately following my water vapour question, I got into conversation with David MacKay (then Chief Scientific Advisor of the Department of Energy and Climate Change) in connection with one of my learned society roles. After dealing with that matter and another related topic about which we disagreed, David commented about my question to the meeting – “Very rude” he said.