CO_2 The Miracle Molecule

The capabilities of the CO_2 molecule are truly wonderous. It is of course known by everyone that it is a dangerous greenhouse gas and is the root cause of the climate emergency that we are facing. It is not only warming the earth in ways never before experienced, it is responsible for both record high global temperatures and record low temperatures. It is causing record snowfalls that are currently crippling skiing resorts while at the same time causing catastrophic melting of polar icecaps and the loss of mountain glaciers. It is the cause of sea level rise and the wholesale displacement of impoverished people because of climate change. Hundreds if not thousands of animal species are on the brink of extinction because of climate change. We have very little time to save the planet.

We must respond to this crisis by reducing the levels of CO_2 in the atmosphere, by banning the use of fossil fuels, the combustion of which is producing ever increasing levels of CO_2. We must also eat less red meat to minimise the emissions of methane by cattle. We must even go so far as to actually sequester or capture CO_2 and store it underground in order to prevent runaway temperatures

And yet CO_2, possibly above all other molecules, is responsible for supporting all life on earth. It is the feedstock upon which all plant life depends, in order to produce the complex organic molecules necessary for growth, by means of photosynthesis. Without atmospheric CO_2 there could be no plant life and consequently no animal life either. Planet Earth would be dead!

The Greenhouse Effect

Without atmosphere the world be a very cold inhospitable place. The heat from the sun absorbed by the earth would be reradiated into space at a rate dependent solely on the earth's temperature.

If Io is the radiated energy from the sun measured in W/m2 the amount of energy captured by the earth will be

$$\text{Energy received} = Io \times \pi r^2 \quad \text{where r is the radius of the earth.}$$

The energy R reradiated by the earth is given by Stefan's law

$$R = \sigma T^4 \times 4\pi r^2$$

since the earth radiates outwards over the whole of its spherical surface. T is the equilibrium earth temperature measured in Kelvin; σ is Stefans constant.

So that at thermal equilibrium, energy in = energy out

$$\text{and} \quad I_0 . \pi r^2 = \sigma T^4 \times 4\pi r^2$$

$$\text{Thus, temperature } T = (I_0/4\sigma)^{1/4}$$

This is often referred to as the effective temperature of the earth and is generally calculated to be 255Kelvin or -18deg Celsius from a knowledge of the sun's irradiance Io and the absolute value of Stefan's constant.

Fortunately for us the earth does have a very effective atmosphere whose composition is typically

Nitrogen	77%
Oxygen	21%
Water Vapour	0.5 to 3%
Argon	1%
Carbon Dioxide	0.04% (400ppm)

The main variable here is water vapour whose concentration in the atmosphere is very dependent on temperature. The higher the temperature the higher the water vapour concentration. We shall return to the implications of this variation later.

Carbon dioxide or CO2 is very much the junior partner in this grouping. This very often raises the question, how could a concentration of CO2 molecules, represented by 4 molecules in every 10,000, be such a driver of climate catastrophe. The answer is because it is a "greenhouse gas".

Only two of the five major atmospheric constituents are classified as greenhouse gases, H2O and CO2. These gases have the ability to absorb the outgoing infra-red radiation from the earth, and act to reduce the amount of reradiation into space, thus increasing the earth's temperature. The other gases, nitrogen, oxygen and argon are totally transparent to this radiation and have no impact upon temperature.

The Impact of Greenhouse Gases

Incoming radiation from the sun is predominantly short wavelength visible and near infra-red radiation. This passes through the atmosphere without significant absorption. The reradiation from the earth however is purely a function of its temperature and is readily calculated from a formula derived by Planck at the start of the 20^{th} century. Figure 1a shows the spectral range and intensity of radiation from a body at a temperature of 288K, the average temperature of the earth's surface. The radiation extends over a wide range of wavelengths from 2 to 100 microns (10^{-6} m)

In order to assess the impact of these greenhouse gases it is necessary to be able to calculate exactly what fraction of the reradiated energy is absorbed by differing concentrations of CO2 and H2O throughout this radiation spectrum. In this we are indebted to a web database known as HITRAN (www.hitran.iao.ru) jointly maintained and developed at the Harvard-Smithsonian Center for Astrophysics, USA and the Institute of Atmospheric Optics, Tomsk, Russia. This database enables detailed accurate calculation of absorptivity of a wide range of gases, including CO2 and H2O over the wavelength range 1 to 100 micron as a function of temperature and gas concentration.

The Simple Model

The atmosphere, while a very thin layer of gas compared to the diameter of the earth, is extremely complex and chaotic. In analysing such a system, it is often wise to start with a very simple descriptive model and see where it leads. The simplest possible model for the atmosphere is to consider it to be a single infra-red absorbing thin layer wrapped around the earth.

In order to assess the absorption effects of CO2 and H2O it is necessary to know both the concentration of the gases and the thickness of the atmosphere through which the radiation has to pass. This is complicated by the fact that atmospheric pressure and hence density of the atmosphere reduces with altitude. A useful rule of thumb for CO2 is that an altitude of 10,000m would be sufficient to contain all the atmospheric CO2 at a pressure of one atmosphere. So that we may represent the concentration x thickness product for CO2 as 400ppm x 10,000m or 4m.atmospheres.

For H2O this is a little more complicated since the atmospheric temperature also reduces with altitude, further reducing the H2O concentration. An effective atmospheric thickness of 3000m has been chosen as a fair representation for water vapour, so that an average 1% H2O concentration over 3000m gives a concentration/thickness product of 0.01 x 3000 m atmospheres (30 m.atmospheres).

Using the HITRAN database we can compute the absorptive effects of both H2O and CO2 on the reradiation spectrum of the earth.

Figure 1b shows the impact of a concentration of 400ppm CO2 on the outgoing radiation spectrum. CO2 takes a huge bite out of the transmitted energy. We should not be fooled by the meagre 4 molecules/10,000 concentration of CO2. It is a very powerful IR absorber.

Figure 1c shows the equivalent effect of a 1% concentration of H2O. This just doesn’t take a bite out of the IR spectrum. It makes a whole meal of it, dwarfing the effects of CO2.

The effect of combining the two gases is shown in figure 1c. Qualitatively you can see that some 80% of the reradiated energy has been absorbed, which leaves one to wonder how effective an increase in CO2 beyond 400ppm would be.

This question is answered in figure 1d where the CO2 concentration has been doubled to 800ppm. Qualitatively there doesn’t appear to be much change.

To determine the total energy (W/m^2) reradiated and transmitted through the atmospheric gases we need to sum the areas under the curves in Figure 1. This will provide us with the total energy transmitted through the atmosphere for each condition of CO2 and H2O concentrations and using the spectral curve in Figure 1a as a 100% transmission we can calculate the transmissivity and hence absorptivity (Absorptivity = 1 – Transmissivity) for those conditions.

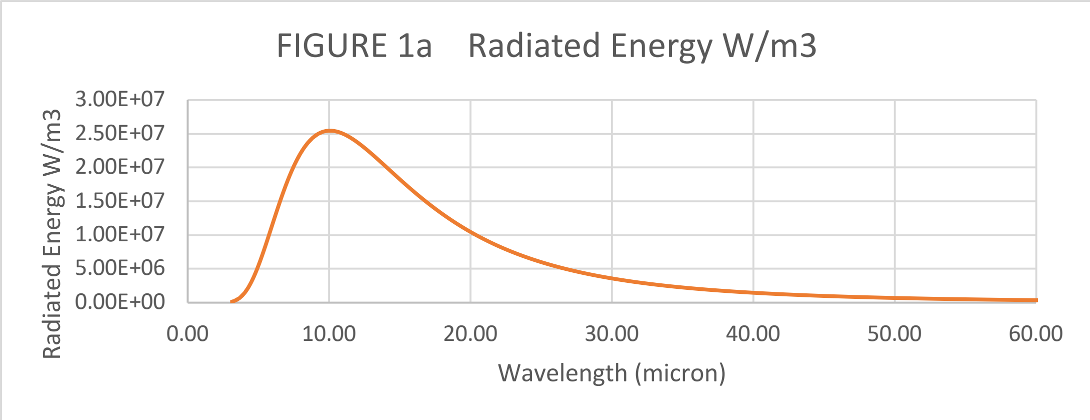


FIGURE 1a Radiated Energy W/m3
Radiated Energy W/m3
3.00E+07
2.50E+07
2.00E+07
1.50E+07
1.00E+07
5.00E+06
0.00E+00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Wavelength (micron)

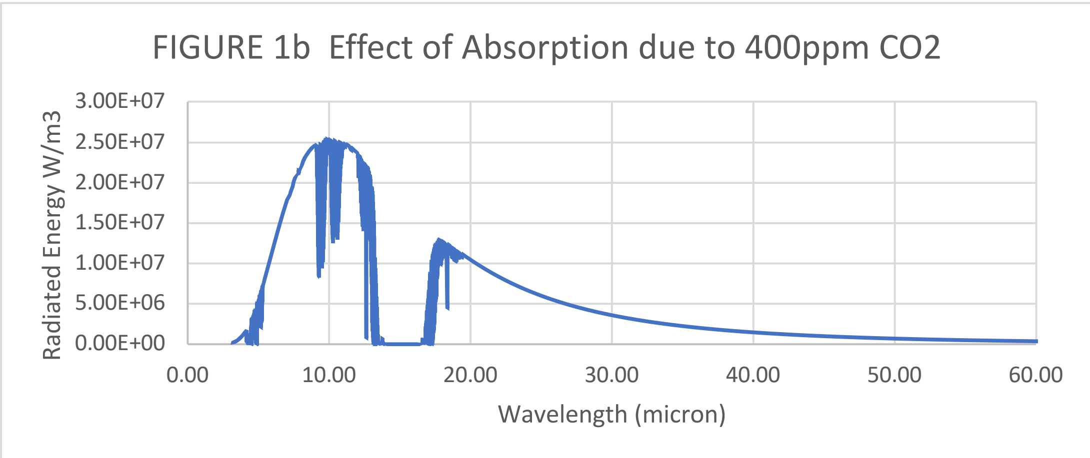


FIGURE 1b Effect of Absorption due to 400ppm CO2
Radiated Energy W/m3
3.00E+07
2.50E+07
2.00E+07
1.50E+07
1.00E+07
5.00E+06
0.00E+00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Wavelength (micron)

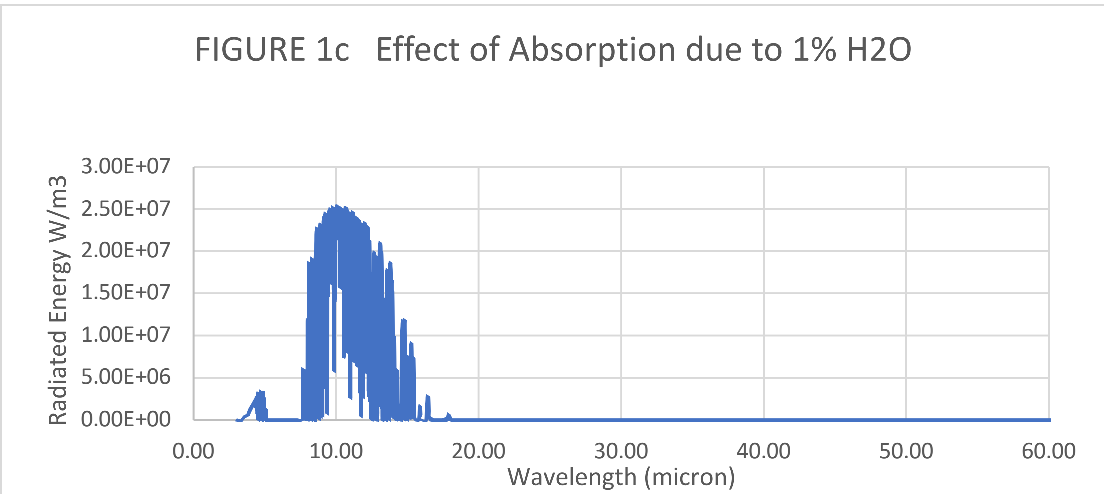


FIGURE 1c Effect of Absorption due to 1% H2O
Radiated Energy W/m3
3.00E+07
2.50E+07
2.00E+07
1.50E+07
1.00E+07
5.00E+06
0.00E+00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Wavelength (micron)

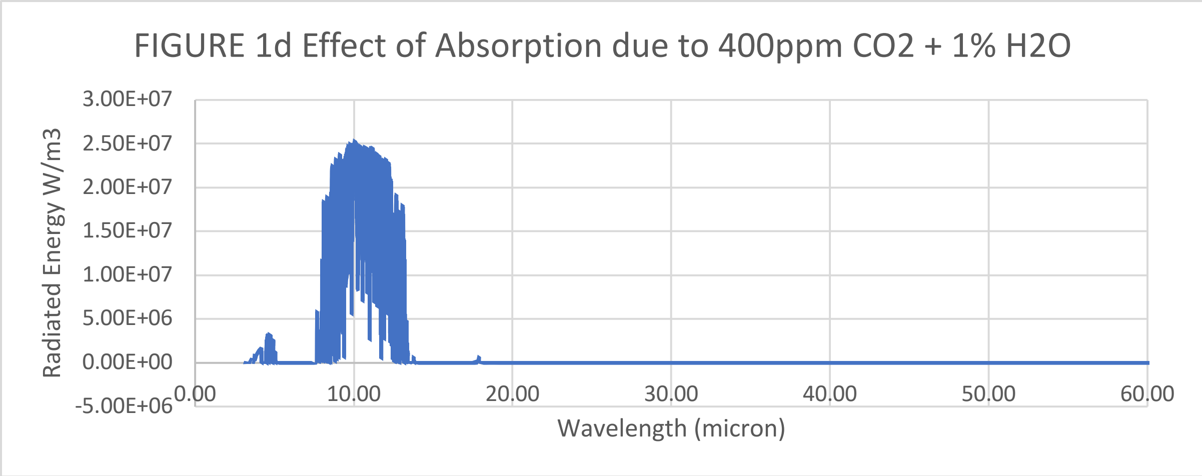


FIGURE 1d Effect of Absorption due to 400ppm CO2 + 1% H2O
Radiated Energy W/m3
3.00E+07
2.50E+07
2.00E+07
1.50E+07
1.00E+07
5.00E+06
0.00E+00
-5.00E+06
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Wavelength (micron)

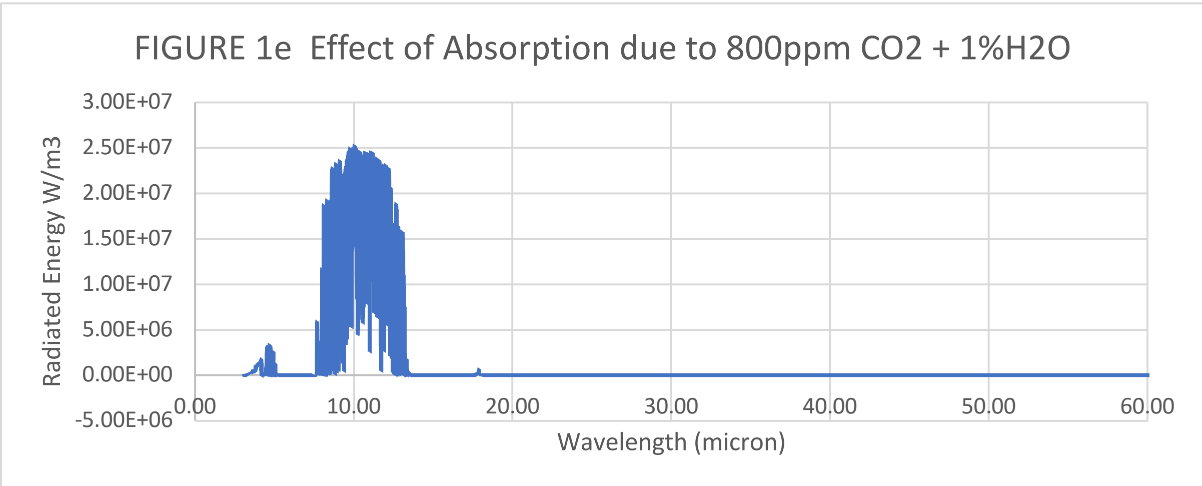


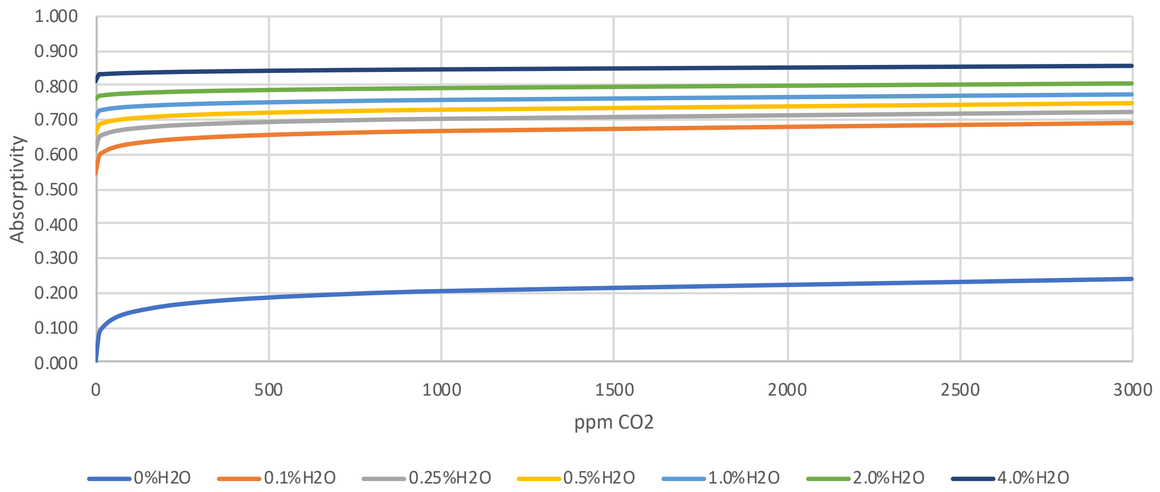
FIGURE 1e Effect of Absorption due to 800ppm CO2 + 1%H2O
Radiated Energy W/m3
3.00E+07
2.50E+07
2.00E+07
1.50E+07
1.00E+07
5.00E+06
0.00E+00
-5.00E+06
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Wavelength (micron)

The following table(1) gives the results of those calculations for CO_2 levels varying up to 3000ppm and H_2O up to 4%. This data is graphed in figure 2.

Table 1

%H2O	0.0	0.1	0.25	0.5	1.0	2.0	4.0
ppm CO2	Absorption						
0	0.000	0.544	0.613	0.662	0.711	0.761	0.810
10	0.082	0.595	0.649	0.688	0.727	0.769	0.832
20	0.101	0.605	0.656	0.693	0.730	0.771	0.833
50	0.126	0.619	0.666	0.700	0.735	0.774	0.834
100	0.144	0.631	0.674	0.706	0.740	0.777	0.836
200	0.163	0.642	0.683	0.713	0.745	0.781	0.839
300	0.174	0.649	0.688	0.717	0.748	0.784	0.841
400	0.182	0.653	0.692	0.720	0.751	0.786	0.842
500	0.188	0.657	0.695	0.723	0.753	0.787	0.843
600	0.192	0.660	0.697	0.725	0.755	0.789	0.844
1000	0.206	0.668	0.705	0.731	0.760	0.793	0.848
3000	0.241	0.692	0.725	0.749	0.776	0.807	0.859

FIGURE 2 Atmospheric IR Absorptivity



At this point we have made no assumptions about the dynamic nature of the atmosphere. We have simply calculated what fraction of the outgoing energy radiated by the earth will be absorbed by the atmosphere, using the HITRAN database. What is immediately obvious from

this data is that the bulk of the IR absorption is due to H_2O, CO_2 providing less than 25% of the total absorption. It is also clear from Figure 2 that most of the IR absorption occurs at very low concentrations of both CO_2 and H_2O. At the concentrations currently enjoyed on earth, further increases in either CO_2 or H_2O will have little further effect on the IR absorptivity of the atmosphere. How does this impact on global temperature?

If we represent the absorptivity of the atmosphere by "a" we can represent the intensity of the outgoing transmitted energy I from the earth as

$$I = R.(1 - a)$$

Where R is the total reradiated energy from earth $= \sigma T^4$

T being the actual temperature of the earth.

We must also determine what happens to the radiation absorbed by the atmosphere, equal to R x a. When a body absorbs energy, it becomes hotter and will itself reradiate energy. At equilibrium this reradiated energy will be equal to the absorbed energy "R x a". The atmosphere however will reradiate this energy in all directions, with the effect that half the energy will be directed back towards the earth, thereby warming it further, while the other half will be radiated outwards into space.

In order to calculate the earth temperature at the equilibrium condition we must determine the energy balance at the very top of the atmosphere. As before

Energy received from the sun $= Io \times \pi r^2$

Energy transmitted through the atmosphere $= R.(1 - a) \times 4\pi r^2$

Energy radiated outwards by the atmosphere $= (R.a)/2 \times 4\pi r^2$

Thus, at equilibrium $Io \times \pi r^2 = [R(1 - a) + R.a/2] \times 4\pi r^2$

$$= R(1 + a/2) \times 4\pi r^2$$

Thus $Io = 4R(1 + a/2)$

$$= 4\sigma T^4. (1 + a/2)$$

And thus, the equilibrium temperature of the earth $T = (Io/4\sigma)^{1/4}/(1 + a)^{1/4}$

But we already know that the term $(Io/4\sigma)^{1/4}$ represents the effective earth temperature, without any protective atmosphere and is equal to 255K.

Thus, the equilibrium earth temperature $T = 255/(1 + a/2)^{1/4}$

We now have a simple relationship between the infra-red absorptivity of the atmosphere and the equilibrium earth temperature.

When assessing the effectiveness of a theory or model it is essential to compare specific calculated values with actual data. In this case the obvious comparison to make is to see how the predicted equilibrium earth temperature compares with the generally accepted value for the mean global temperature of 288K or 15°C.

Using the calculated absorptivity data from table 1 we can readily calculate mean global temperatures for each of the combinations of H2O and CO2 concentrations. The results are shown in Table 2. Highlighted in this table is the predicted mean temperature for a CO2 atmospheric concentration of 400ppm and H2O concentration of 1%. This value is 286.8K. This is not an unreasonable level of agreement considering the assumptions made when estimating atmospheric H2O concentration and atmospheric thickness.

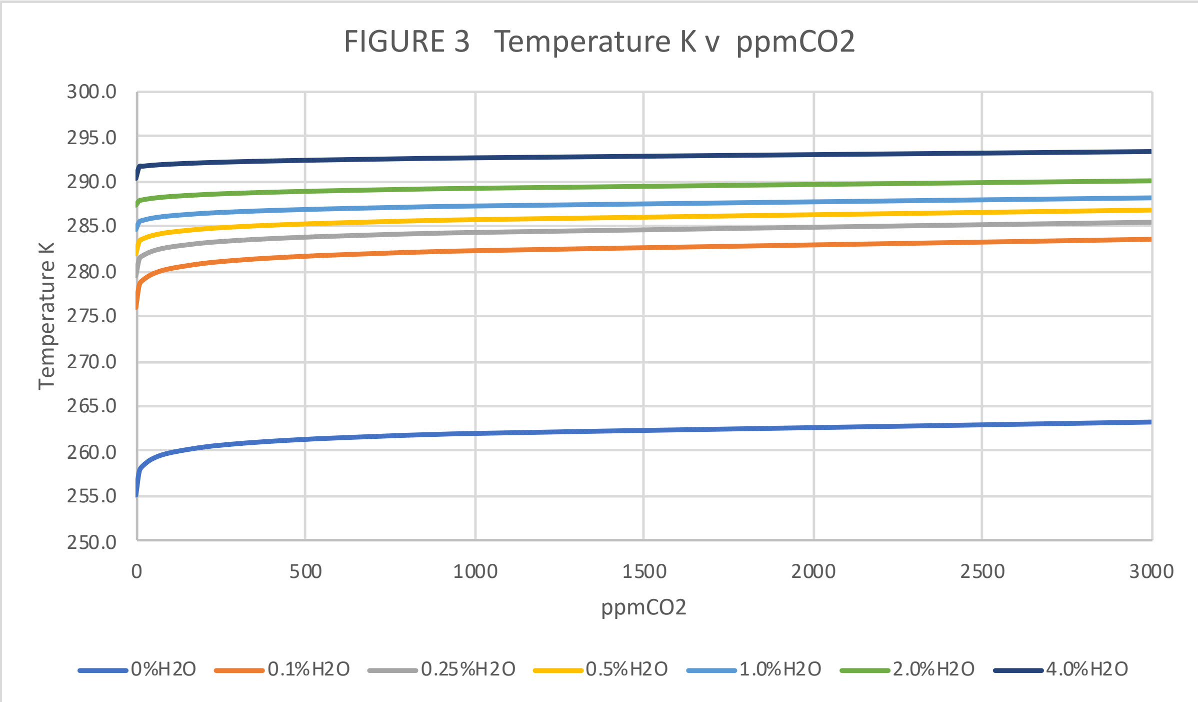
Table 2

%H2O	0.0	0.1	0.25	0.5	1.0	2.0	4.0
ppm CO2	Absorption						
0	255.0	276.1	279.4	282.0	284.6	287.4	290.4
10	257.7	278.5	281.3	283.3	285.5	287.9	291.7
20	258.3	279.0	281.7	283.6	285.7	288.0	291.7
50	259.2	279.8	282.2	284.0	286.0	288.2	291.8
100	259.8	280.3	282.6	284.3	286.2	288.4	292.0
200	260.5	280.9	283.1	284.7	286.5	288.6	292.1
300	260.9	281.3	283.4	284.9	286.7	288.8	292.2
400	261.1	281.5	283.6	285.1	286.8	288.9	292.3
500	261.4	281.7	283.7	285.2	287.0	289.0	292.4
600	261.5	281.8	283.8	285.4	287.1	289.1	292.5
1000	262.0	282.3	284.2	285.7	287.4	289.3	292.7
3000	263.3	283.6	285.4	286.8	288.3	290.2	293.4

Also highlighted are the temperature values calculated for variations in CO2 from 300 to 500ppm and H2O from 0.5% to 2%. Equilibrium earth temperatures all fall within the band 285 to 289K.

Analysis of Results

Figure 3 shows in graphical form how the variation of both CO2 and H2O will impact upon the global equilibrium temperature.



The first thing to notice is that without the impact of H2O, CO2 is incapable of increasing mean global temperatures by more then 10K. Even at a concentration of 3000ppm the increase in temperature is only 8.3K.

Adding as little as 0.1% H2O sees this temperature rocket upwards by 25K demonstrating that H2O is the key driver of global temperatures. However increasing H2O concentrations further has a much-reduced impact on temperatures. By far the most significant effects of CO2 occur at concentrations below 100ppm. Above this the impact on temperature reduces rapidly. This follows precisely because of the strength of the absorption spectra of CO2 and H2O. Relatively low concentrations bring about a saturation within the main absorption bands where IR transmissivity has reduced to zero. Increasing the concentration has relatively little further effect.

Climate Sensitivity

Climate sensitivity is a term introduced to characterise the impact on global temperatures of a doubling of atmospheric CO2 levels. Various complex atmospheric models have indicated climate sensitivity values varying between 1.5 and 5degC (from the Intergovernmental Panel for Climate Change IPCC). The assumption that a doubling of CO2 levels will produce a linear temperature response suggests a logarithmic function between CO2 concentration and temperature change. Let us first see if the values calculated here show such a response.

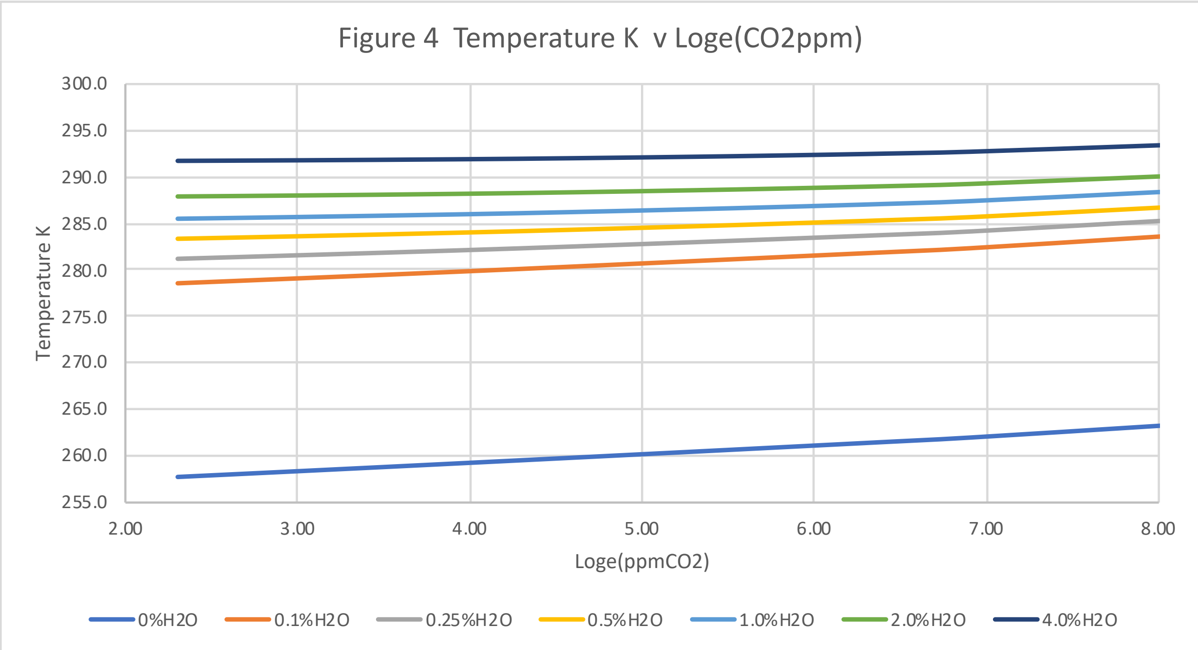
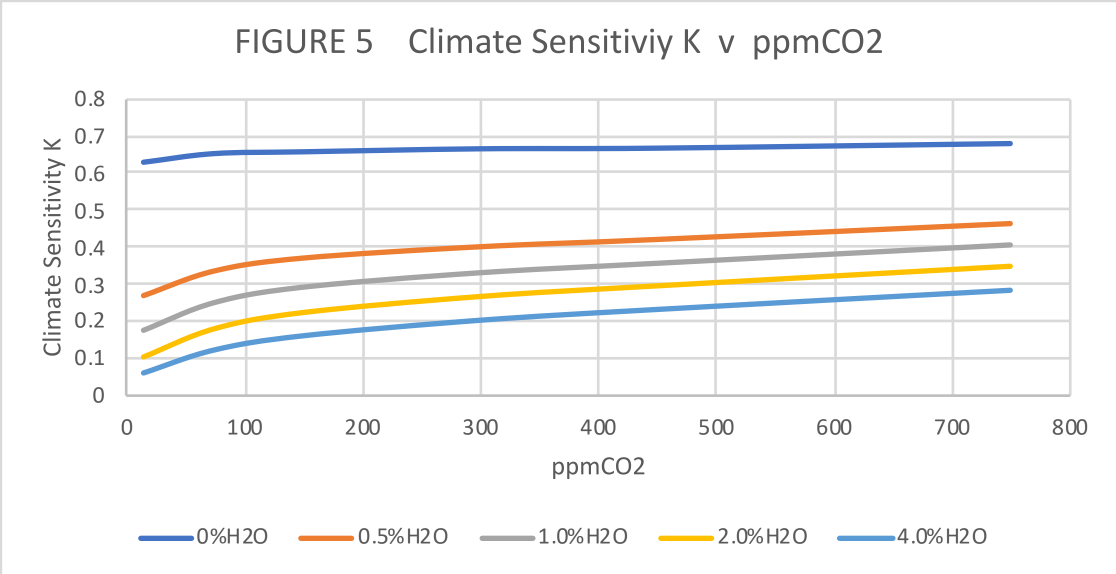


Figure 4 shows a graph of calculated temperatures against $\log_e$(CO2ppm). This does confirm an almost logarithmic relationship. The graph shows the temperature response at H2O levels varying up to 4%. The surprise here is that the climate sensitivity to CO2 actually decreases with increasing H2O levels. H2O desensitises the temperature response to CO2. The following table 3 and Figure 4 show how the climate sensitivity varies with H2O and CO2 concentrations. It is clearly not a constant.

Table 3

Climate Sensitivity					
%H2O	0.0	0.5	1.0	2.0	4.0
CO2 doubling ppm	Temperature Increase K				
10 to 20	0.63	0.27	0.18	0.11	0.06
50 to 100	0.65	0.34	0.25	0.18	0.12
100 to 200	0.66	0.37	0.29	0.22	0.16
200 to 400	0.67	0.40	0.33	0.27	0.20
300 to 600	0.67	0.42	0.36	0.29	0.23
500 to 1000	0.68	0.47	0.41	0.35	0.28



The big issue of course is that the calculated values of climate sensitivity are an order of magnitude lower than those evolving from the various climate models and the IPCC, varying between 0.2 and 0.5degC. This result derives directly from the known absorption characteristics of CO_2 and H_2O.

A further point to make is that these calculations, without any adjustment factors predict a current global equilibrium temperature of 286.8K in close agreement with current temperature assessments. This is achieved with a climate sensitivity of less than 0.5degC. Why should the climate sensitivity suddenly jump to a value between 1.5 and 5degC for future increases in CO_2 levels?

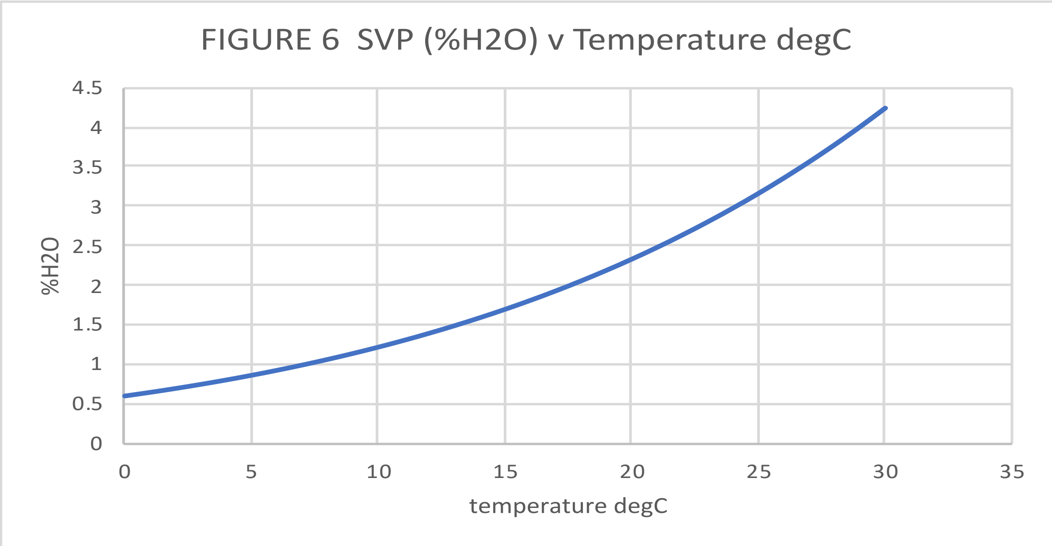
The Impact of H_2O

Of course, the result of these calculations will be criticised because of their simplicity in describing an inherently complex system such as the earth's atmosphere and in particular for not taking into account the effects of feedbacks, which it is claimed, increase the climate sensitivity. The principle effective feedback is attributed to water vapour.

H_2O is unique among the atmospheric constituents in that its concentration is temperature dependent. 70% of the earth's surface is covered by water and there is an overall equilibrium between gaseous H_2O and the oceans determined by the H_2O saturated vapour pressure (SVP) which determines how much gaseous H_2O can be held in the atmosphere before condensing out as cloud and rain. The SVP and its relationship with temperature has been accurately determined experimentally and can be represented by an exponential relationship to temperature.

This is illustrated in figure 5 showing the equilibrium H_2O concentration v temperature. The picture is further complicated by the reduction in atmospheric temperature with altitude, the atmospheric adiabatic lapse rate, induced by gravitational effects. Basically, this determines that temperature will reduce by 6.5degC per 1000m. (from the International Civil Aviation

Organisation). Thus, the ability of the atmosphere to hold gaseous H2O will reduce rapidly with altitude.



The question is how an inherently low climate sensitivity of the order of 0.5degC can impact upon the concentration of H2O and its further effect on temperature. From the graph in figure5 a 0.5K increase in global average temperature will increase the SVP of water vapour by 0.05% and have a negligible further impact upon temperatures. While from Table 2 a doubling of water vapour concentration from 1 to 2% would only increase average temperatures by 1.5degC, but it would take an increase in temperature of 10degC to produce such an increase in SVP.

It is a far stretch to imagine how a water vapour feedback mechanism might increase climate sensitivity by an order of magnitude to match the figures detailed by the IPCC.

Effects of Methane and Nitrous Oxide

An additional claim is that positive feedbacks are generated by the presence of additional greenhouse gases such as methane (CH4) and nitrous oxide(N2O). These gases are present in the atmosphere at sub ppm levels. Using the same HITRAN data base we can calculate the additional impact of 1ppmCH4 and 0.33ppmN2O(current atmospheric level) on the atmosphere of 400ppm CO2 and 1% H2O.

The result is given in the following table showing immediately that the warming potential of both CH4 and N2O are small for the simple reason that much of their absorption bands are overlapped by CO2 and H2O, leaving very little IR energy for them to absorb. Typical atmospheric concentrations for CH4 at 1ppm and N2O at 0.33ppm produce a total increase in warming of 0.2K. Increasing these concentrations 10-fold only increases the warming to 0.7K.

Effect of CH4 & N2O		255	
Atmosphere Content	Absportion	Temp K	increase K
400ppmCO2 + 1%H2O	0.7508	286.8	0
+ 1ppm CH4	0.7522	286.9	0.1
+0.33ppm N2O	0.7530	287.0	0.2
+1ppmCH4+0.33ppm N2O	0.7540	287.0	0.2
+10ppm CH4	0.7556	287.1	0.3
+3.3ppm N2O	0.7603	287.4	0.6
+10ppmCH4+3.3ppmN2O	0.7627	287.5	0.7

FIGURE 7a Absorption due to 400ppmCO2 + 1%H2O

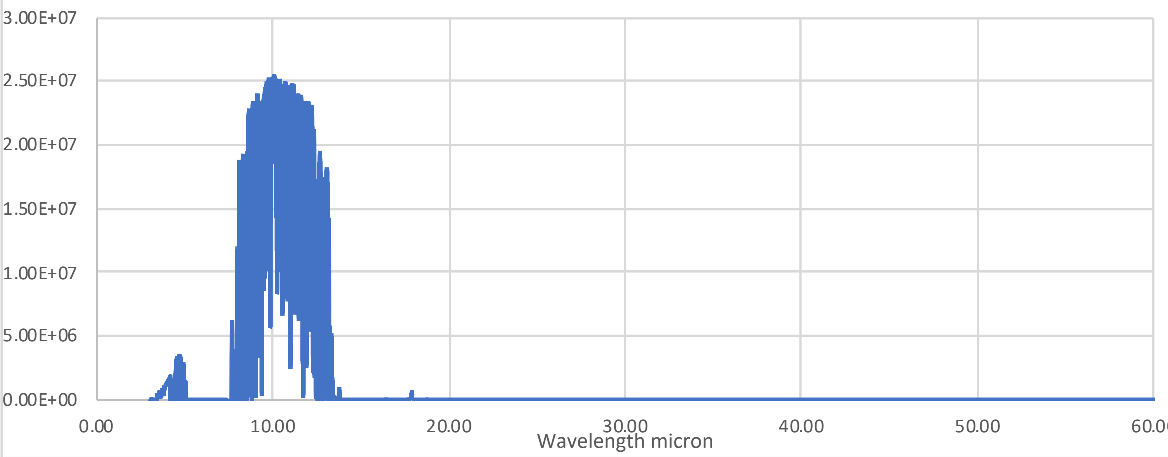
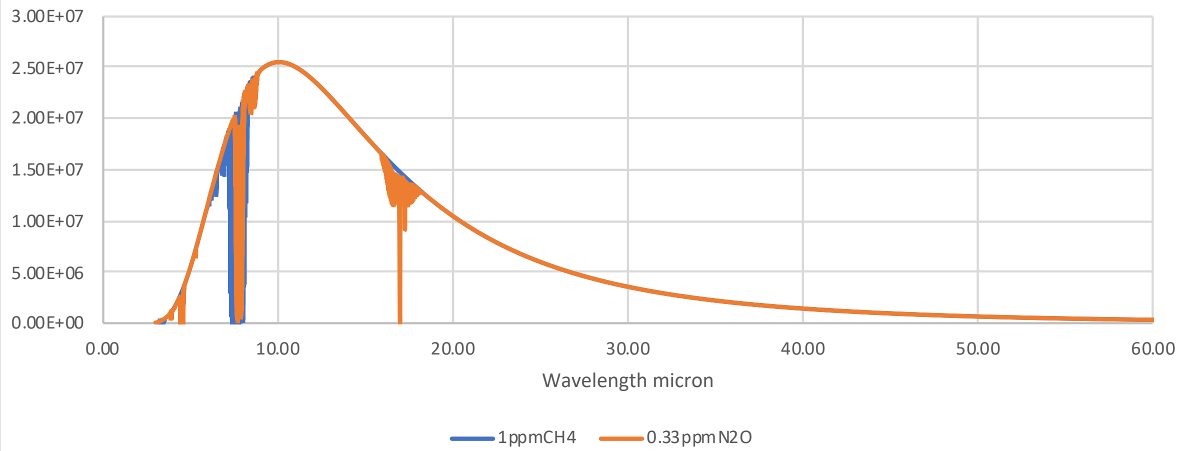


FIGURE 7b Absorption due to 1ppmCH4 and 0.33ppmN2O



Hopefully we can cancel any plans for the wholesale culling of the world's dairy and beef herds. Their flatulence is clearly only a problem for those with a nervous disposition.

We see repeatedly the effects of the strong broad absorption bands of CO_2 and particularly H_2O making impotent the effects of the introduction of more greenhouse gases. Once the energy in those bands has been depleted there can be little or no further increase in absorptivity and temperature.

The Impact of Clouds

These calculations have specifically assumed a clear sky condition free from clouds. What impact will cloud formation have on these calculations? The structure of clouds is diverse and complex. It is close to impossible to derive a set of equations to describe the formation, structure and impact of clouds on the radiative balance of the earth. Perhaps the best that can be achieved simply is to consider the impact at the limits of cloud extent, the first limit being the zero-cloud condition already covered.

The opposite limit is one of total cloud cover. Clouds can occur at almost all altitudes in the atmosphere, but for this exercise let us assume that the cloud cover is between 1000 and 3000m altitude. At these altitudes the cloud will consist of liquid water droplets which will totally absorb the outgoing IR radiation. The result is that no radiation from the planet earth will escape to space. It will all be absorbed by the cloud. The band between the cloud base and the earth surface will effectively become a black body at a uniform temperature. Radiation into space, required for thermal equilibrium will be emitted by the upper surface of the cloud base, instead of the earth surface. The temperature of the cloud, and therefore the temperature of the earth, will be determined by the heat balance equation.

The crucial difference however is that there will now be less molecules of H_2O and CO_2 above the cloud, resulting in lower values of radiative absorption, which in turn will result in a lower earth surface temperature. From Table 2 we can immediately see that if the effective concentration of both H_2O and CO_2 reduces by say 50% to 0.5%H_2O and 200ppmCO_2 the temperature will reduce from 286.8K to 284.7K a reduction of 2.1K.

This is a relatively small reduction for such a dramatic change in atmospheric condition. The significant outcome is that cloud will reduce earth surface temperatures, assuming no change in the solar incoming energy Io. Clouds, it appears, provide a negative feedback.

I have to declare that I know of no evidential data to either support or reject this supposition.

Summary

Using well documented data on the infra-red absorption spectra of atmospheric gases it is a straight-forward process to infer the overall atmospheric IR absorption and from that the effective global average temperature. The simplest of atmospheric models has been used: the atmosphere is considered to be a uniform thin absorbing layer of gas. The results demonstrate clearly that the warming effect of the atmosphere is almost entirely due to the spectral absorption characteristics of CO_2 and H_2O. They are both exceptionally strong absorbers of

infra-red radiation. It is however this strength which determines the characteristics of the earth's temperature, and in particular its stability.

70% of the energy radiated from the earth is removed by a mixture of 0.1% H_2O and 200ppm of CO_2. This alone is sufficient to raise global temperatures from the chilly 255K of the estimated zero atmosphere condition to 284.3K, less than 4deg below current average temperatures. An estimation of the current atmospheric mixture of gases is calculated to deliver a global mean temperature of 286.8K close to the best estimate of 288K for that temperature. Further increases in both H_2O and CO_2 have relatively small impacts on temperatures. This is due simply to the fact that at current concentrations the spectra of both H_2O and CO_2 have effectively extracted most of the energy at wavebands corresponding to their molecular absorption spectra. There is little further energy to be extracted by adding more H_2O and CO_2. This results in climate sensitivity values of less than 0.5degC, in comparison to the 1.5 to 5 degC range quoted by the IPCC.

CO_2 levels of 3000ppm will only raise temperatures by a further 1.5K. These temperature increases are in fact well within natural variations seen in the past, including the medieval warm period and the little ice age of some 300 years ago.

The possibility of positive feedback from water vapour is discounted by the simple fact that the H_2O spectrum is incapable of absorbing significant further amounts of radiated energy and the modest increase in temperature due to increasing CO_2 levels is unable to deliver any significant increase in H_2O concentration due to the specific relationship of H_2O saturation vapour pressure and temperature. It would take an increase in temperature of 10degC to double the mean H_2O atmospheric concentration, and that doubling would only result in a temperature increase of 2degC.

The impact of other known "greenhouse' gases, CH_4 and N_2O are also calculated from known IR spectra data. Their absorption spectra are swamped by H_2O and CO_2. The combined warming caused by current atmospheric concentrations will elevate temperature by only 0.2K and increasing concentrations by a factor of 10 will only result in a further temperature increase of 0.5K.

The "greenhouse effect" is dominated by the absorption spectrum of H_2O with a little help from CO_2. At current concentrations of both gases it is inconceivable that further increases in concentrations will lead to any significant warming. Increasing CO_2 concentration to 3000ppm and doubling the mean H_2O level to 2% would result in a global temperature increase of 3.4K.

In short, there is no climate emergency, at least due to "greenhouse gases".