Man made global warming explained - closing the blinds

T. Sloan.
(Dept of Physics, University of Lancaster)
A.W. Wolfendale,
(Dept. of Physics, University of Durham)

Abstract

One of the big problems of the age concerns 'Global Warming', and whether it is 'man-made' or 'natural'. Most climatologists believe that it is very likely to be the former but some scientists (mostly non-climatologists) subscribe to the latter. Unsurprisingly, the population at large is often confused and is not convinced either way. Here we try to explain the principles of man-made global warming in a simple way. Our purpose is to try to understand the story which the climatologists are telling us through their rather complicated general circulation models. By limiting our attention to latitudes in the Southern Hemisphere we minimise the effects of industrial and land-generated aerosols. Here we only consider carbon dioxide and methane and their effect on water vapour. The simple model comprising mainly the direct heating from the absorption of infrared radiation, illustrates the main principles of the science involved. The predicted temperature increase due to the increase of greenhouse gases in the atmosphere over the last century follows roughly the observed temperature increase.

1 The simple model

The climate is very complex with many simultaneously changing phenomena. This complexity serves to confuse both scientist and layman alike. To illustrate the physics behind the global warming caused by greenhouse gases, we describe a simple calculation in which the complexity is neglected. Nothing that we say is new, but by concentrating on fundamentals we hope to bring out the basic physics. The calculation assumes that the Earth is warmed by the sun, reaching an equilibrium temperature, $T$, at which the energy re-radiated into space is balanced by the energy absorbed. We assume that the atmosphere equalises the temperature so that the absolute temperature in degrees Kelvin is roughly uniform over the globe. Under these conditions the energy radiated, $E$ watts per m$^2$, from the Earth system follows Stefan’s Law

$$E = kT^4$$

where $k$ is a constant number. Here the 'Earth system’ means the Earth and its atmosphere. If the total energy absorbed by the Earth system changes by an amount $\Delta E$, it follows from equation\[1\] that the change in temperature to re-reach equilibrium will be given by

$$\frac{\Delta T}{T} = \frac{1}{4} \frac{\Delta E}{E}.$$
At the temperature of the Earth the re-radiated energy is in the infrared region of the spectrum. In this region there is much absorption of energy by the so called greenhouse gases: water vapour, carbon dioxide (CO\textsubscript{2}), methane (CH\textsubscript{4}), ozone (O\textsubscript{3}) and other impurities present in the atmosphere. Note that the main constituents of the atmosphere (oxygen and nitrogen) do not absorb infrared radiation since they are symmetric molecules with zero electric dipole moments. Without the greenhouse gases the average temperature of the Earth (from equation 1) would settle to 255K (-18°C). This is too low for life as we know it to exist since liquid water would be scarce at such temperatures. However, the energy absorbed by the small concentrations of greenhouse gases allows the atmosphere to act as a blanket for the Earth, warming it to a more comfortable average of 14°C. Man-made increases of the greenhouse gases are then thought to produce further warming on top of this i.e. man-made global warming.

In this note we describe calculations using the simple model to derive the increase in temperature due to the increase in the greenhouse gases CO\textsubscript{2} and CH\textsubscript{4} in the atmosphere observed over the last century. The response of water vapour (WV) to the increased temperature is also discussed. The absorption and re-emission of energy radiated from the Earth and its atmosphere, at a fixed temperature, is computed in the program MODTRAN \cite{2}. The program is used to compute the radiated energy from the Earth system for a given set of concentrations of CO\textsubscript{2} or CH\textsubscript{4} allowing for all known absorption and re-emission effects of radiation in the atmosphere. The resulting change in the mean temperature of the Earth can then be derived from the change in energy radiated as the greenhouse gas concentration is changed, using equation 2. The MODTRAN programme, though complex, is straightforward and simulates the absorption, re-emission and scattering of the infra-red radiation in the atmosphere. It should not be confused with the more complicated climatological models which give somewhat disparate results although all show an upward trend of temperature with increased CO\textsubscript{2} and methane. These differences are used by some ‘man-made global warming skeptics’ as reasons for refusing to accept the overall man-made explanation. They have no relevance, here.

Similar calculations to ours were published previously by Bellamy and Barrett \cite{3}.

2 The heating effects of greenhouse gases

Figure 1 \cite{4} illustrates the processes involved. The left hand upper curve (fig. 1a) shows the input radiation from the sun (left hand curve) and the outgoing radiation from the Earth (right hand curve) each plotted against the wavelength of the radiation. The latter is the curve for the Earth as a perfect radiator without the effects of greenhouse gases. Under these conditions its mean temperature would reach an equilibrium value of 255K (-18°C) when the energy re-radiated balances that coming from the sun.

The lower curves (figure 1d) show how the radiation is absorbed by the greenhouse gases in the atmosphere (and fig 1b gives the total absorbance). The graphs show the fraction of the radiation which is absorbed by each gas in the atmosphere plotted against the wavelength of the radiation. With such absorption of heat the atmosphere acts like a blanket allowing the Earth system to reach a new more comfortable average equilibrium temperature of 287K (13.7°C).

The addition of extra CO\textsubscript{2} and CH\textsubscript{4} will cause a further increase in temperature. In the case of CO\textsubscript{2} this is caused by the extra absorption in the wings of the band between wavelengths 13
and 18 microns (see figure 1). This makes the band appear wider so that the transparent gap between wavelengths of 8 to 13 microns becomes narrower i.e. the blinds referred to in the title are being closed. The second and third rows of Table 1 shows the changes in the concentrations of these greenhouse gases since industrialisation started in about 1850 [5]. The fourth row shows the energy absorbed in the increased greenhouse gas concentration, as computed in MODTRAN applying our simple model. The last row shows the necessary increase in the temperature of the Earth system to re-establish equilibrium with the amount of energy re-radiated balancing that falling on the Earth (computed according to equation 2).

Table 1

| Date   | 1850 | 1875 | 1900 | 1925 | 1950 | 1975 | 2000 |
|--------|------|------|------|------|------|------|------|
| CO₂ Concentration (ppm) | 286  | 289  | 297  | 304  | 310  | 331  | 369  |
| CH₄ Concentration (ppm)   | 0.79 | 0.82 | 0.86 | 0.95 | 1.05 | 1.29 | 1.56 |
| Re-radiated energy decrease (W/m²) at fixed Earth system temperature. | 0.0  | 0.09 | 0.25 | 0.41 | 0.60 | 1.04 | 1.70 |
| Temperature increase (°C) needed to maintain equilibrium | 0.0  | 0.03 | 0.08 | 0.12 | 0.18 | 0.31 | 0.51 |

The energy radiated to space from the Earth takes place from layers of the upper troposphere below the stratosphere. Here the atmosphere is thin enough not to absorb much of the energy radiated from below. As the greenhouse gas concentration increases this altitude moves to a higher level where the temperature would normally be lower. However to radiate the extra energy equation 1 shows that the temperature at this level must increase (final row of Table 1) to re-establish the equilibrium. Below this altitude the heat in the Earth’s atmosphere circulates mainly by convection, a process that is understood. The temperature in the atmosphere decreases linearly from that at ground level to roughly -55°C in the stratosphere. This is easily understood from the thermodynamics of the atmosphere [6] which predict that the rate of fall of temperature with altitude (the so called lapse rate) is fixed. Assuming such a fixed lapse rate, the changes in temperature given in the last row of table 1 are transmitted to the Earth’s surface.

Figure 2 shows the measured mean surface temperature of the Earth as a function of time since 1880 in a region chosen where industrial aerosols are almost absent (24-90°S). Some of the variations on these data (at the level of 0.1°C) can be explained in terms of large volcanic eruptions (the major dips, such as that due to Agung in 1963 and Pinatubo in 1991), ozone variations, El Nino events and the ‘Southern Oscillation’ (oceanic changes) [7]. The curves shows the predicted temperature rises using the simple model described above (the solid curve is the last row of table 1).

It can be seen that the calculations, based on these simple physical principles, ignoring all complications, give a reasonable explanation of the measurements to date with values which are not far from those observed.
3 Discussion of the Results

The simple calculation based on infrared absorption roughly reproduces the observations, demonstrating the underlying physical principles of the more complicated climate models. However, the calculations shown in figure 2 seem to increase somewhat more slowly than the measurements. Furthermore, these calculations overestimate the overall warming since some of the energy is absorbed by the oceans rather than radiated away. The temperature rise in the oceans is much slower than in the atmosphere because of their large mass (this will eventually lead to delayed future warming). This shows that the absorption of infra-red radiation by the atmosphere is not the only contributing process. There are also other processes which we have ignored such as the increases due to other greenhouse gases (e.g., NOx, CFCs etc) as well as all other complications. We have also ignored feedback effects. One positive feedback is that the warming increases the amount of water vapour in the atmosphere by evaporation. Water is a good greenhouse gas (see figure 1), so warming causes more infra red radiation to be absorbed which in turn produces further warming, hence the term positive feedback. Such extra absorption is in the wavelength range 6-10 microns (see fig 1) closing the gap from the left (whereas CO$_2$ closes the gap from the right). There are also 'negative' (i.e., cooling) feedbacks such as those from atmospheric aerosols which reflect away sunlight so that their increase by industry causes cooling. In addition there is a negative feedback from clouds.

The Intergovernmental Panel on Climate Change (IPCC), using their more exact models for the whole Globe, produce the predictions shown in figure 3. It can be seen that the warming of the last century (black curve in figure 3) is well reproduced by the models only if the man-made greenhouse gases are included, although it will be noted that the excess in the region of 1940 found in our limited Southern region is also present here as is 'our' deficit near 1910. The 1940 excess could possibly be ascribed to the effect of an El Nino event. The IPCC estimates that doubling the CO$_2$ level in the atmosphere will change the mean surface temperature of the Earth by between 2 and 3.5$^\circ$C. Our model predicts a rise of $\sim$1.3$^\circ$C (see also [3] who ignore all effects except infra red absorption), again illustrating that something extra is needed beyond the simple absorption of the infra-red radiation.

Most climatologists subscribe to the view that the global warming over the last century is man made. Nevertheless, the IPCC are not completely certain and only say that it is “very likely” that the global warming since industrialization is man-made. Why is the IPCC not completely certain? A serious problem is ‘how to deal with clouds?’. These entities are highly variable in space and time and are complex. It is also possible that the climatologists may have made a mistake and one or more of the many other contributing processes, alluded to above, have margins of error which are bigger than currently thought. This leads to the only argument that might be invoked to justify ‘doing nothing’ about man-made emissions; this is to assume that the inevitable warming from anthropogenic gases is nullified by a process such as from man-made aerosols (a not uncommon claim some decades ago). The undoubted warming is then due to unknown natural causes. There are three objections to this scenario:

(a) The ranks of climatologists must have made serious errors. We know of no such errors, although, undoubtedly small changes will result from future measurements and analyses.
(b) Our analysis of the man-made aerosol-poor region in figure 2 (the Southern hemisphere) mitigates against the problem of aerosols.

(c) In our so-far unsuccessful attempt to find a suitable natural cause, none of the following have proved acceptable: meteoric dust, changes in the frequency of volcanoes, oceanic temperature re-distributions, geothermal emission changes. Furthermore, no changes in the obliquity of the Earth’s axis or Earth-sun distance, nor of solar irradiance of sufficient magnitude have occurred in the last Century (unlike in history when major temperature variations followed such changes).

In the face of this it is prudent to do something now if only as an insurance policy. Otherwise we would be relying on an unexpected future cancellation due to a completely unknown mechanism to save us from the possible ravages of climate change induced by ever growing amounts of greenhouse gases in the atmosphere.

References

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[4] “The Physics of Climate”, J.E. Peixoto and A.H. Oort (published by the American Institute of Physics 1992).

[5] The IPCC Fourth Assessment Climate Change Reports 2007, The Synthesis Report available at http://www.ipcc.ch/publications and data/publications and data reports.htm

[6] “Elementary Climate Physics”, F.W. Taylor (Oxford University Press 2005).

[7] “Clouds, solar irradiance and the mean surface temperature over the last century”, A.D. Erlykin, T. Sloan and A.W. Wolfendale J. Atmos. and Solar-Terr. Phys. (2010) in press.

[8] http://data.giss.nasa.gov/gistemp/graphs/
Figure 1: (a) The left hand upper curve shows the intensity of the radiant energy reaching the Earth from the sun which is mainly in the visible part of the spectrum (0.4 to 0.8 microns wavelength). The right hand upper curve shows the intensity of the radiation emitted by the Earth as a perfect radiator with no absorption by greenhouse gases. This is at a much longer wavelength in the infrared part of the spectrum. (b) shows the total absorbance for the entire vertical extent of the atmosphere and (c) for the portion of the atmosphere above an altitude of 11 km. (d) show the fractions of the radiation at each wavelength absorbed in the atmosphere by each major greenhouse gas. Note that most of the energy re-radiated by the Earth is absorbed in the atmosphere except in the gap from 8-13 microns wavelength.
Figure 2: The points joined by the solid lines show the measurements of the average annual mean surface temperature of the Earth from meteorological stations as a function of time since 1880 [8] in the Southern Hemisphere where industrial aerosols are almost absent. The dashed curve shows the change in temperature predicted by the simple model where the CO$_2$ concentration only increases from its 1850 value. The solid curve shows the behaviour when the CO$_2$ and CH$_4$ are changed together since 1850.
Figure 3: a) - Global mean surface temperatures over the 20th century from observations (black) and as obtained from 58 simulations produced by 14 different models driven by both natural and human-caused factors that influence climate (yellow) (red is the mean). b) shows 19 simulations from 5 models with natural forcings only. Temperature anomalies are shown relative to the 1901 to 1950 mean. Vertical grey lines indicate the timing of major volcanic eruptions. This is Figure 9.5 from the IPCC Fourth Assessment Report WG1 report (2007).