The original version of this article was published on the Activist Teacher blog on May 8, 2011, here:
[*http://activistteacher.blogspot.com/2011/05/radiation-physics-constraints-on-global.html*](http://activistteacher.blogspot.com/2011/05/radiation-physics-constraints-on-global.html)

The present is the May 12, 2011, revision following peer criticism. See below for the section on changes made to this Revised version.

This research was opposed by the University of Ottawa:
[*http://uofowatch.blogspot.com/2010/09/court-ordered-released-document-shows.html*](http://uofowatch.blogspot.com/2010/09/court-ordered-released-document-shows.html)

Radiation physics constraints on global warming – Revised

By Denis G. Rancourt

Abstract – I describe the basic physics of planetary radiation balance and surface temperature, in the simplest and most robust terms possible that capture the essential ingredients of planetary greenhouse warming. Our revised simple radiation-balance model uses only (i) the satellite-measured absolute longwave Earth emission, (ii) a present mean global surface temperature of 14^{o}C, (iii) the satellite-measured fraction (~0.26) of longwave absorbance due to CO2, (iv) a satellite-measured global mean surface albedo of 0.30, (v) the season-average solar constant and (vi) known characteristics of the CO2 longwave absorption cross section at the dominant 15 μm absorption band. The model gives: (a) a total longwave emission atmospheric mean transmittance <te> and mean longwave emissivity <ε> product <te><ε> = 0.62, (b) a zero-greenhouse-effect Earth mean surface temperature of To = -18^{o}C, (c) a post-industrial warming due only to CO2 increase of ΔTind = 0.29^{o}C, and (d) a temperature increase from doubling the present CO2 concentration alone (to 780 ppmv CO2; without water vapour feedback) equal to ΔTdbl = 1.0^{o}C. Earth's radiative balance determining its surface temperature is shown to be two orders of magnitude more sensitive to solar irradiance and to planetary albedo and emissivity than to the atmospheric greenhouse effect from CO2. All the model predictions robustly follow from the starting assumptions without any need for elaborate global circulation models. A recent critique of the dominant climate change science narrative is evaluated in the light of our model.

Simplest model with essential features

Let us start by building the simplest possible model of planetary radiation balance, realistic enough to capture the essential global average features.

We take the planet to be a perfect sphere with a smooth and homogeneous surface and to have a thin (compared to the planet radius) and homogeneous atmosphere. The planet is uniformly irradiated by a distant sun.

The incident intensity (in Watts per square-meter, W/m2) of "shortwave" radiation (largely visible light) from the sun at the planet is the so-called solar constant, Is, where for Earth Is = 1366 W/m2 (having a real seasonal variation in magnitude from 1412 to 1321 W/m2, or 6.7% of its average value).

Different parts of the planet's surface receive different intensities of incident shortwave radiation. This is because the surfaces at different latitudes receive the incident rays at different angles and because half of the planet's surface is shielded from all incident rays (only one hemisphere is exposed to the sun at any given time).

Rather than deal with the latter complexity of non-uniform irradiation, instead we take the entire planet's surface to be uniformly irradiated with an intensity equal to the corresponding average solar constant. The correct average solar constant is <Is> = (1/4)Is = 341.5 W/m2, as is well known and easy to calculate.

In our model, therefore, every part of the planet's surface is identical in terms of the radiation balance conditions. Each part of the planet's surface represents what is happening on average, in terms of radiation balance, and of the planet properties which we will take to be the Earth's average properties.

Of all the incident shortwave solar radiation that strikes the planet a fraction is reflected back into outer space without being absorbed by any part of the planet (surface or atmosphere). This fraction (from zero to one) of the incident shortwave solar radiation energy that is reflected out from the planet is called the planet's (Bond) albedo. Put simply: Albedo = Solar-Out/Solar-In.

The reflected outgoing shortwave radiation need not have the same spectral distribution (radiation intensity versus radiation frequency or wavelength) as the incoming incident solar shortwave radiation because the amount of absorption/reflection can be (and generally is) dependent on wavelength. The albedo is the net energy fraction that is reflected.

Modern satellite spectroscopic measurements can quantify the solar constant and the amount of out-reflected shortwave radiation, can resolve these radiations from longwave thermal radiation, and can measure continuously in orbit to obtain planet-wide averages.

Satellite measurements allow us to conclude that the average Earth albedo is <a> = 0.30 [1]. Arguably-more-direct and reliable Earth-based so-called "Earthshine observation" measurements give <a> = 0.297(5) where, using scientific error notation, the latter means

0.297 ± 0.005 [2]. There are daily changes in Earth's albedo (from large scale weather changes) of ~5% and seasonal variations of ~15% (from snow and ice cover, vegetation, and weather and cloud cover) [2].

The source of heat on the planet is taken to be the planet's surface that absorbs shortwave solar radiation. The physical absorption process transforms the electromagnetic energy of the incident solar radiation into heat energy (vibrational energy of the surface's molecules).

Any opaque body at any temperature above 0 K (i.e., having vibrating rather than motionless molecules) in turn emits electromagnetic radiation. The latter so-called "thermal" or "black-body" radiation has characteristics that depend of the body's (emitting) surface temperature. For the temperatures of interest the surface thermal radiation is shortwave (or infra-red) radiation.

The intensity Ie (in W/m2) of the emitted thermal (shortwave) electromagnetic radiation coming from the surface of an opaque body is given by the Stefan–Boltzmann law:

Ie = ε σ T^4   (eq.1)

where T is the temperature of the emitting surface in K, σ is the Stefan–Boltzmann constant σ = 5.6704 10^-8 W/m2K4, and ε is the "emissivity" of the emitting surface. "T^4" means T to the power 4 and "10^-8" means times 10 to the power minus-eight, giving 0.000000056704 W/m2K4.

The emissivity has a dimensionless value between zero and one. It is the fractional energy emission from the surface compared to the surface's emission if it were an ideal black body emitter. ε = 1 for an ideal black body surface and ε = 0 for an ideally reflective surface (i.e., a surface having an albedo of exactly 1).

The global average longwave emissivity, <ε>, of Earth's surface is difficult to evaluate. It can be reasonably estimated or deduced from relevant physical principles.

Let us next describe how the planet's mean surface temperature is established.

If the net radiant energy into the planet is larger than the net radiant energy escaping from the planet then the net received energy will heat the planet and increase its temperature. Likewise, if the net radiant energy out from the planet is larger than the net energy into the planet then the net loss of energy of the planet will cause the planet to loose heat and decrease its temperature.

Therefore, in a "steady state" situation, after a certain planetary response time following any change affecting radiation balance, the temperature of the planet's longwave radiation emitting surface will stabilize at some value corresponding to the rate of energy-in being equal to the rate of energy-out and there will be "radiation balance" at a stable surface temperature.

The net energy-in is the incident solar radiation minus the albedo loss. The net energy-out is the portion of all the shortwave emission energy that manages to escape the planet into outer space. By setting in = out we can solve for the resulting radiation-balancing planet surface temperature.

The corresponding radiation balance equation, therefore, is:

<Is> (1 – <a>) = <te> <ε> σ T^4 (eq.2)

where <te> is the fractional transmittance (having a dimensionless value between zero and one) of the total emitted longwave radiation energy.

In other words, <te> is the planetary average transmission coefficient for escape of the emitted longwave radiation through the atmosphere and into outer space. In the absence of all greenhouse effects <te> = 1. For a completely infrared-opaque atmosphere <te> = 0.

Solving for the planet surface temperature (in K), eq.2 gives:

T = [(1 – <a>)<Is> / <te><ε>σ]^(1/4) . (eq.3)

where "^(1/4)" means "to the power ¼".

Eq.3 is the central result for the steady state surface temperature in our simplest possible radiation balance model.

Evaluating needed parameter <te><ε>

Note that <te>, like <ε>, is difficult to measure. It is usually only estimated using model assumptions (e.g., [1]: Fig.1). Note also, that for infrared-opaque atmospheres, as <te> approaches a value of zero the resulting temperature tends to an infinite value (things get very hot).

On the other hand, the average net outgoing longwave intensity, <te><Ie>, is accurately measured by satellite [1]. It is <te><Ie> = 238.5 W/m2 [1]. Since the global average surface temperature is accepted to be accurately known [3], it is therefore possible to calculate the value of the product quantity <te><ε> for Earth as:

<te><ε> = <te><Ie> / σ T^4 (eq.4)

by using T = 287.15 K, since the reported mean surface temperature is 14.0 ^{o}C [3].

This gives an accurate evaluation of <te><ε> for the current Earth as <te><ε> = 0.62.

[Note that all such products of average physical parameters assume statistical independence of the parameters, or that the inter-parameter correlations do not affect the averaging – that is, we assume <te ε>=<te><ε> and so on.]

As a self-consistency verification, using the latter value of <te><ε> in eq.3 indeed gives a mean surface temperature of 14.0 ^{o}C, as expected since satellite measurements confirm the near equality (1 – <a>)<Is> = <te><Ie> relating energy-in and energy-out [1].

Having determined the Earth value of <te><ε>, one can use the determined value in eq.3 and explore the impact of variations in <a>. This is reported below.

Earth temperature with zero greenhouse effect, To

Next, we calculate the Earth's mean surface temperature in the absence of all greenhouse effects (i.e., when <te> = 1). We take "To" to be the symbol for the latter zero-greenhouse-effect surface temperature. In order to use eq.3 for this purpose it is necessary to know the Earth value of <ε> itself.

Virtually all researchers and authors have used <ε> = 1, usually without providing a justification. That is, they have assumed that the Earth's surface is an ideal black body emitter for longwave radiation.

Using the latter assumption for <ε> and with <te> = 1 eq.3 gives To = 254.8 K or minus (–) 18.3^{o}C. Compared to the accepted actual mean global surface temperature of 14.0^{o}C this would imply a total global greenhouse effect warming on Earth of 32.3^{o}C – corresponding to the repeatedly stated textbook value of 33^{o}C of greenhouse effect warming [4]. I also taught this value in my university physics courses and repeated it in my 2007 critique of global warming [5]. Wikipedia is no exceptions [6]. American Geophysical Union (AGU) press releases typically announce [7]:

> *"Overall, the greenhouse effect warms the planet by about 33 °C, turning it from a frigid ice-covered ball with a global average temperature of about -17 °C, to the climate we have today. Heat-absorbing components contribute directly to that warmth by intercepting and absorbing energy passing through the atmosphere as electromagnetic waves."*

In describing the "physical science basis" the Intergovernmental Panel on Climate Change (IPCC) in its 2007 "Contribution of Working Group I to the Fourth Assessment Report" (incorrectly, see below) put it this way [8]:

> *"The energy that is not refl ected back to space is absorbed by the Earth's surface and atmosphere. This amount is approximately 240 Watts per square metre (W m–2). To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space. The Earth does this by emitting outgoing longwave radiation. Everything on Earth emits longwave radiation*

> *continuously. That is the heat energy one feels radiating out from a fi re; the warmer an object, the more heat energy it radiates. To emit 240 W m–2, a surface would have to have a temperature of around –19°C. This is much colder than the conditions that actually exist at the Earth's surface (the global mean surface temperature is about 14°C). Instead, the necessary –19°C is found at an altitude about 5 km above the surface.*
>
> *The reason the Earth's surface is this warm is the presence of greenhouse gases, which act as a partial blanket for the longwave radiation coming from the surface. This blanketing is known as the natural greenhouse effect."*

The scientists at RealClimate.org also use this 33^{o}C number in their interpretations [9]:

> *"Since we are looking at the whole of the present-day greenhouse effect (around 33 C), it is not surprising that the radiative forcings are very large compared to those calculated for the changes in the forcing. The factor of ~2 greater importance for water vapour compared to CO2 is consistent with the first calculation."*

Virtually all mainstream science and teaching has accepted this idea that the planetary greenhouse effect on Earth causes a warming of approximately 33^{o}C. In addition, research scientists use it ($\langle\varepsilon\rangle = 1$) in their peer-reviewed published calculations about Earth global processes [1].

In all of these sources the assumption $\langle\varepsilon\rangle = 1$ is virtually never explicitly justified. It is important to provide a justification because, at first glance, the assumption appears to violate Kirchoff's Law of radiation physics.

Kirchoff's Law of radiation physics says generally that the larger the reflectivity the smaller the emissivity. More precisely, Kirchoff's Law is expressed for a given wavelength λ as:

$$1 - a(\lambda) = \varepsilon(\lambda). \qquad \text{(eq.5)}$$

It is essential to note that the law holds at each wavelength (and direction) of radiation but that albedo at one wavelength need not be related via eq.5 to emissivity at a different wavelength.

On Earth, the relevant mean (Bond) albedo is for shortwave radiation (solar radiation, largely visible) and has a value $\langle a\rangle = 0.30$ whereas the needed emissivity is for longwave radiation (infra-red or thermal Earth-surface radiation) such that $\langle\varepsilon\rangle$ can have a value significantly different from the 0.70 (incorrectly) predicted by eq.5.

We must therefore appeal to measurements of ε for representative Earth surface materials. A main Earth surface material is water. The longwave emissivity of water is indeed almost 1. This is understandable because water is almost perfectly absorbing in the infrared. Dry rocks and sand also have near-1 values of their longwave emissivities, that is values of ~0.91-0.92. Any vegetation coverage significantly increases the value of the emissivity, given the water content of vegetation. For example, green grass has emissivity in the range ~0.97-0.99 [10].

This is why it is not unreasonable to use <ε> ~ 1 for our ocean, lake and vegetation-covered Earth.

Note that despite the large (~33^{o}C) predicted greenhouse warming on Earth this is for the total planet greenhouse effect whereas CO2 absorption is presently saturated (see below), such that a large CO2 change impact is not implied.

Evaluating longwave atmospheric transmission, <te>

Using <ε> = 1 and <te><ε> = 0.62 (determined above gives <te> = 0.62. The latter value of <te> in turn implies a value of the so-called "longwave radiative forcing" (1 – <te>) of 1 – 0.62 = 0.38 (38%).

As a self-consistency check, one uses <ε> = 1 and the measured mean surface temperature (14.0^{o}C [3]) with eq.1 to obtain a surface emission intensity of <Ie> = 396 W/m2 [1]. By comparison with the satellite-measured outgoing longwave radiation intensity (239 W/m2 [1]) one has <te> = 239/396 = 0.60, in acceptable agreement.

One can measure the longwave scattering transmittance (or cross section) of a greenhouse effect gas (e.g., CO2, H2O) in the laboratory. However, almost all such measurements evaluate the loss of transmitted intensity in the incident beam direction, thereby quantifying the amount of longwave radiation (incident on the gas sample) that is not scattered away from the incident beam direction. The error in using this measured total scattering cross section when reasoning with the atmosphere is that much of the scattered (and multiply scattered) radiation may actually escape to outer space and therefore must be counted as part of the atmosphere's net transmittance <te>.

In other words, one cannot, as has too often been done, calculate atmospheric scattering transmittance from collimated-beam laboratory measurements of scattering cross sections without calculating the escape probabilities for the atmosphere of all the scattered and multiply scattered radiation.

Instead, one must perform the correct calculation of infrared radiative transfer theory, as recently reviewed by Pierrehumbert [11].

Refining the model

We now have a robust model (eq.3) that can be used predicatively. Here <te> directly arises from all contributions from greenhouse effect gases, clouds, etc., and any solar input variations (whether due to solar activity or Earth's orbit) are modelled by <Is>. In particular, this allows robust sensitivity analyses (see below).

The model could be refined to include correlations between surface and atmosphere properties in doing the global time (day, season) and planet surface averages, as mentioned above.

Given the straightforward nature of the model (eq.3) following directly from the most fundamental considerations of radiation physics, those who argue [12][13][14][15] that the more complex circumstances of a real (and thermodynamically active) atmosphere and a real non-uniform and non-smooth surface are such that no net global greenhouse effect warming of the planet surface can result have the burden of the proof in that they must explain in simple physical terms how no warming (whether measurable or not [5][16]) would occur despite the prediction of eq.3.

On the latter point, recognized expert Pierrehumbert [11] had this to say informally to the present author:

> *"Gerlich and Tscheuschner is utter rubbish. The criticisms leveled at G&T are correct, but only scratch the surface of what was wrong with that paper, which was so fundamentally flawed it should never have been published. Further, G&T are flatly in contradiction with satellite and laboratory measurements which completely confirm the greenhouse effect calculations as conventionally carried out (see my Physics Today article, available on my web site for free).*
>
> *It is a complete waste of time to argue about the reality of the basic greenhouse effect. If people want to argue about how well we know the bounds on climate sensitivity, and how the policymakers should deal with that uncertainty, that's a worthwhile discussion. But arguing about the greenhouse effect is in the same category as being an Obama birther."*

I have not examined the physics calculations of "G&T" nor do I have a negative opinion *a priori* of Obama birthers.

Further predictions from the model

Next we consider the model (eq.3) predictions for doubling the present atmospheric CO_2 concentration and for the post-industrial increase in atmospheric CO_2 concentration, without changing anything else. That is, in the absence of any water vapour feedback or any other such positive or negative feedback.

For these calculations we must develop an equation that relates changes in atmospheric CO_2 concentration to corresponding changes in net longwave transmission through the atmosphere, <te>. A given atmospheric CO_2 concentration (in ppmv, parts per million per volume) is denoted C_{co2}.

The present value of <te> (~0.62) is significantly smaller than 1 and CO2 longwave absorption occurs in a limited wavelength range (from ~600 to ~800 wavenumber, 1/cm) predominantly centered on ~15 μm (micro-meter wavelength), such that absorption saturation occurs in this main relevant CO2 absorption band [11].

This implies that the induced change in <te> is not simply (anti-)proportional to the considered change in CO2 concentration (change in Cco2) but instead is highly attenuated. Indeed, the decrease in <te> from an increase in Cco2 arises not from an increased absorption at resonance but instead from increased absorption on the outer edges of the absorption band, thereby increasing the wavenumber-width of the absorption region that corresponds to saturation absorption conditions (e.g., [11]: Fig.2).

Here, we derive the needed relation between <te> and Cco2 as follows.

We take the main relevant CO2 longwave absorption band to be mathematically represented by a Gaussian function having a height and width equal to the height and width of the actual (non-saturated) absorption cross section for the CO2 band centered at the radiation frequency (νo) corresponding to 15 μm wavelength.

This choice is mathematically convenient, is motivated by the fact that a single motion-broadened resonance band in a gas atmosphere has a Gaussian shape, and gives a fair though approximate representation of the actual resonant absorption cross section for CO2 in the atmosphere.

The Gaussian cross section is written:

$$G(\nu) = \sigma m \exp[- (\nu - \nu o)^2 / 2 \omega^2] \quad \text{... (eq.6)}$$

where σm is the (maximum) absorption cross section at resonance (at νo) and ω is the Gaussian width of the cross section function. [Note: I am using total cross section, not specific cross section on a per molecule or per mass of gas basis.] The Gaussian function is such that the half width at half maximum (HWHM) of the cross section function (intrinsic absorption band) is related to ω as:

$$\text{HWHM} = (2 \ln 2)^{(1/2)} \omega \quad \text{... (eq.7)}$$

Next, we find the needed frequency-width of the region of absorption saturation by setting $G(\nu)$ equal to the cross section σe at which the CO2 longwave absorption becomes effectively saturated. That is, we set $G(\nu) = \sigma e$ and we solve for the two absorption band edge positions in frequency ν, on either side of the central resonance frequency νo.

This gives a saturation band full width as:

$$\Delta\nu = 2 \omega [2 \ln(\sigma m/\sigma e)]^{(1/2)} \quad \text{... (eq.8)}$$

Here, σe is a constant property of a CO_2-bearing Earth atmosphere and σm, by definition, is directly proportional to the atmospheric concentration of CO_2. Also $\sigma m/\sigma e \sim 10^4$ for CO_2 at Earth concentrations ([11]: Fig.2, using intrinsic specific not total cross section).

We then examine the variation ($\delta(\Delta\nu)$) of $\Delta\nu$ (eq.8) with σm and obtain:

$$\delta(\Delta\nu) / \Delta\nu = [\, 2 \ln(\sigma m/\sigma e)\,]^{-1}\, \delta(\sigma m)/\sigma m \quad \text{... (eq.9)}$$

where $\delta(\sigma m)$ is the considered variation or change in σm. Next, we note that:

$$\delta(\Delta\nu) / \Delta\nu = -\delta(<te>)/<te> \quad \text{... (eq.10)}$$

since the saturation band width, by definition, negatively and proportionally affects the relevant CO_2 longwave transmission through the atmosphere (nothing at saturation escapes the planet), and

$$\delta(\sigma m)/\sigma m = F_{co2}\, \delta(C_{co2})/C_{co2} \quad \text{... (eq.11)}$$

where F_{co2} is the present fraction (from 0 to 1) of all greenhouse effects that arise from CO_2. Eq.11 follows from the linear proportionality of cross section with greenhouse effect gas concentration for a given gas.

Therefore we need F_{co2}. It can most reliably be obtained from satellite spectral measurements. This was done in [17] where $F_{co2} \sim 0.26$ (for clear sky conditions).

Next, we choose to express changes in $<te>$ or in $<\varepsilon>$ or in $<te><\varepsilon>$ or in $<te\ \varepsilon>$ as fractional (τ) changes relative to 1. For example, a new value of $<te>$ could be $(1+\tau)$ times the old value of $<te>$. That is, the change in $<te>$ would be $\tau<te>$. The resulting new surface temperature $T\tau$ is:

$$T\tau = (1 + \tau)^{-1/4}\, Tp \quad \text{... (eq.12)}$$

where Tp is the present global surface mean surface temperature (14.0°C, [3]) in K, given by eq.3 with present values of all the parameters. Therefore, the change in surface temperature is:

$$\Delta T = T\tau - Tp = [(1 + \tau)^{-1/4} - 1\,]\, Tp \quad \text{... (eq.13)}$$

For $<te>$, $\tau = \delta(<te>)/<te>$; for $<\varepsilon>$, $\tau = \delta(<\varepsilon>)/<\varepsilon>$; and so on.

Using eq.13, eq.11, eq.10, and eq.9, we deduce ΔT for a change from present (390 ppmv) to pre-industrial (280 ppmv) C_{co2} to be $\Delta T_{ind} = -0.29$ K or -0.29°C. Here the value of τ was 0.0040. Since $0.0040 \ll 1$, we used the approximation

$$\Delta T = -(1/4)\, \tau\, Tp \quad \text{... (eq.14)}$$

Therefore, the predicted pre-industrial to present warming from the increase in CO2 alone is approximately 0.29^{o}C.

Similarly, we calculate the effect of doubling the present atmospheric concentration of CO2 (without changing anything else). Here $\delta(C_{co2})/C_{co2}$ = [(780 ppmv – 390 ppmv) / 390 ppmv] = 1. This gives τ = -0.014 and a predicted warming ΔT_{dbl} = 1.0 K (or 1.0^{o}C).

And so on. It is immediate to calculate the warming effect of positive or negative so-called water vapour feedback simply by applying the assumed multiplicative factor to the modelled change in CO2 concentration.

We note that our simple and correct model for global radiation balance gives all the same predictions as the state of the art global circulation models (GCMs). This suggests that the complexities of surface-wise inhomogeneities, altitude-wise atmospheric inhomogeneities, and atmospheric circulation are not relevant to the global mean radiation balance and resulting mean temperatures, as the above simple physics suggests.

Sensitivity analysis of the model

Finally, let us consider the simple-model-calculated sensitivities regarding mean global surface temperature for different model parameters applied to the present Earth.

Using the same methods as described above, ΔT for small changes (fractional changes τ relative to 1) in either the mean solar constant <Is> or the shortwave transmittance+absorbance (i.e., (1 – <a>)) is given by:

$\Delta T = + (1/4)\ \tau\ T_p$ ... (eq.15)

Likewise, ΔT for a small fractional change τ (relative to 1) in shortwave albedo <a>, is given by:

$\Delta T = - (1/4)\ [\langle a\rangle/(1 - \langle a\rangle)]\ \tau\ T_p$ ... (eq.16)

where <a> is the starting value, before the change.

Since the solar constant itself varies by 6.7% of its mean value over the course of the seasons, let 6.7% variations be our standard of variation (τ = 0.067). The results are as follows:

- 6.7% increase in <Is> causes ΔT = +4.8 K
- 6.7% increase in the transmittance+absorbance (1 – <a>) causes ΔT = +4.8 K
- 6.7% increase in <te> or <ε> or <te><ε> causes ΔT = -4.8 K
- 6.7% increase in albedo <a> causes ΔT = -2.1 K
- 6.7% increase in Cco2 causes ΔT = +0.068 K

The radiation balance steady state temperature of Earth's surface is **two orders of magnitude more sensitive** to changes in solar constant, albedo and emissivity than to changes of atmospheric concentration of greenhouse effect CO_2.

This arises because of attenuation of the CO_2 greenhouse effect due to absorption saturation of the dominant CO_2 longwave absorption band centered at 15 μm.

It stands to reason, therefore, if reason matters and if we are concerned about the global mean surface temperature, that more research funding should go into studying solar variations and regional/planetary shortwave albedo and longwave emissivity rather than trying to deduce the relatively subtle effects of changes in "longwave radiative forcing". After all, large scale human land use changes can have dramatic effects on both surface radiative properties and colloidal atmospheric particle pollution concentrations and depositions.

Likewise, land use practices should be subject to much more scrutiny, if radiation warming is our concern, than CO_2 fluxes into and out of the atmosphere.

In addition, the tenuous practice of assuming a positive water vapour feedback in models would need rigorous validation, despite recent overly optimistic opinionating [18].

I have extensively argued from both the social science and climate science perspectives that global warming should not be our concern regarding environmental destruction and social injustice [5][19].

In view of the above model sensitivity calculations and given the physical simplicity of the model based on established physical principles it is clear that many factors will have a larger effect on surface-temperature-determining radiation balance than CO_2 concentration in the atmosphere. For example, such factors as changes in longwave emissivity due to changes in land use (soil humidity, vegetation type), changes in surface temperature response times regarding the diurnal irradiation cycle, changes in albedo from aerial mineral dust variations due to land use changes, changes affecting cloud dynamics, changes affecting dynamic radiation balance response times on a rotating Earth, solar irradiance variations, and many more, are all expected to have larger impacts than CO_2 concentration under present saturation absorption conditions.

Anyone wishing to focuss on CO_2 concentration as a climate driver should have the onus to explain ignoring the above straightforward demonstration of a two order of magnitude irrelevance of CO_2 relative to solar irradiance (of known seasonal variation) and albedo and emissivity (both under-studied and significantly complicated).

The above sensitivity results corroborate these statements in my recent critique [20]:

> "There are three main problems with this amplification hypothesis [positive water vapour feedback]. First, there is no empirical support or experimental verification for it. Global average atmospheric water vapour concentration is impossible to

measure because water constantly changes phase (vapour, liquid, ice) and is distributed inhomogeneously (vapour, rain, snow, clouds, fog, surface condensation/sublimation/vaporisation, etc.).

Second, there are innumerable hypothetical mechanisms whereby any feedback between CO2 and water vapour could be negative rather than positive and no practical way to evaluate most of these possible mechanisms. For example, just to name one, an increase in CO2 could change the plant ecology in such a way as to reduce evaporation from plants. One could sit and invent hundreds of such plausible scenarios (all equally irrelevant with respect to global climate).

Thirdly, it is likely that there are other negative (or positive?) also negligible climate feedbacks with CO2 that do not depend on coupling with water vapour. CO2 can be a growth limiting plant nutrient such that its impact on albedo might produce greater climate leverage than any greenhouse effect gas coupling could ever achieve?

In summary, as I showed in 2007 [2]: "There is of course much more wrong with state-of-the-art global circulation models (climate models) than the assumption and implementation of CO2-H2O feedback. Although these models are among the most elaborate predictive models of complex non-linear phenomena, they are nonetheless sweeping oversimplifications of the global climate system and its mechanistic intricacies."

Overall, therefore, there is no established reason to believe that CO2 could be a climate driver and many reasons to conclude that, although CO2 may often follow or correlate with climate indicators [2], climate drivers are related to solar irradiance and albedo and have nothing to do with CO2."

Original versus Revised versions of this article

The present revised article has benefited from the helpful criticism of Ray Pierrehumbert (author of reference [11]). Pierrehumbert's criticism ("peer review") has been made public here [21].

In the original article [22] Kirchoff's Law was incorrectly applied to the spectral-region-averaged shortwave Bond albedo (<a>) and longwave emissivity (<ε>) whereas Kirchoff's Law (eq.5) is only valid for a given specific wavelength and direction.

This caused an artificially small emissivity <ε> to be used (0.7 instead of ~1) which in turn caused the incorrect conclusion that longwave atmospheric transmission <te> was large (0.9 instead of ~0.6) and far from saturation conditions.

The longwave atmospheric absorption in the CO2 absorption band is saturated in Earth conditions and this is important because it is the physical reality and because it significantly attenuates the climate impact of changing CO2 concentrations. It was necessary to take this saturation effect correctly into account (eq.6 and so on).

My error stems from trusting the conclusions of an expert author regarding Kirchoff's Law rather than examining the physical foundation of the law myself. One must never build on the conclusions of experts without examining every assumption directly.

Radiation process expert Martin Hertzberg has made the same error about Kirchoff's Law in his critical assessments of climate warming mechanisms [23][24]. It is unfortunate that climate scientists do not take the time to transparently communicate with those outside their "clubs" and point out straightforward errors in published reports that are of public interest.

Relevance to the dominant climate science narrative

Recently, I critically reviewed the dominant narrative of climate science on several of its central points [20]: That the post-industrial atmospheric CO2 concentration increase is directly a result of fossil fuel burning production of CO2, that the post-industrial increase in atmospheric CO2 concentration causes a greenhouse warming, that a measurable global mean surface warming has occurred in the post-industrial period, and that anthropogenic global warming radiative forcing drives "climate chaos" and produces extreme weather events.

The considerations of the present model are consistent with the critical review of reference [20].

The global inter-carbon-pool flux dynamics of exchanges with the atmosphere and the factors affecting these inter-compartment fluxes remain the dominant determinants of the resulting atmospheric CO2 concentration value [20] (and references therein).

There remains a vehement debate among atmospheric physicists on the question of whether or not a planetary greenhouse effect can occur on a real planet having a greenhouse effect gas bearing atmosphere [12][13][14][15][20]. However, as mentioned above, the simplicity and robustness of the model developed in the present paper imply that scientists claiming a complete absence of a planetary greenhouse effect mechanism should have the onus to provide a simple physical explanation regarding the strict absence of a planetary greenhouse effect in models of the radiation balance with a realistic atmosphere.

The physical-measurement and mathematical-statistics difficulties in obtaining a mean global surface temperature and in estimating the uncertainty error in this mean global surface temperature remain [5][16][20].

The reality of a post-industrial increase in extreme weather events remains undemonstrated and highly contested by climatologists and the physical mechanism whereby “climate chaos” would result from extra-CO2 “greenhouse radiative forcing” is at the level of a tenuous theoretical fantasy [20].

I hope that the present revised paper will further help to clarify concepts regarding Earth’s planetary radiation balance in relation to global mean surface temperature.

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