Physics Based Climate Modeling

by

George White

The climate system is widely misunderstood due in large part to how climate science is popularized using esoteric concepts like feedback which are accompanied with guilt, fear and misinformation. This essay will clarify the relevant physics so that the fatally flawed feedback heuristics can be superseded with a testable physics based model.

Developing the model starts with quantifying the non controversial steady state behavior of an ideal black body. The Stefan-Boltzmann Law quantifies the power emitted by matter as a consequence of its temperature for both ideal black body radiators and non ideal radiators. It's the only relevant physical relationship between the temperature of matter and W/m^2 and it's the slope of this relationship that's at the core of the climate science controversy. This law plus Conservation of Energy are all that's required to determine the average response of a black body while quantifying its steady state dynamic behavior also requires accounting for its specific heat capacity.

Equation 1) is the Stefan-Boltzmann Law that equates the wavelength independent radiated power flux density in W/m^2 to a temperature in degrees Kelvin.

1) $P = \varepsilon\sigma T^4$

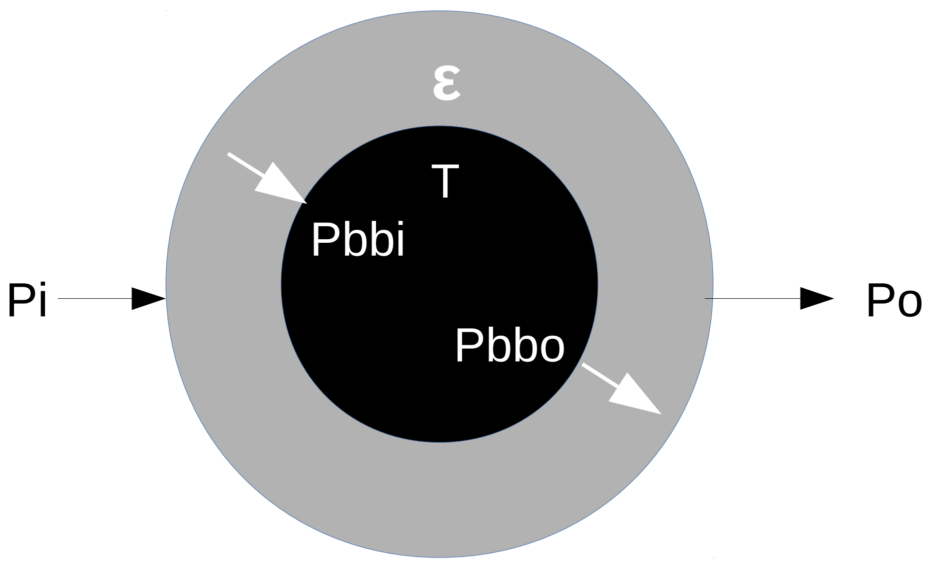
P is the emitted power flux density, T is the temperature, ε is the emissivity and σ is the Stefan Boltzmann Constant whose value is about 5.67E-8 W/m^2 per degree K^4. The immutable constant and the T^4 dependence of W/m^2 are derived from more fundamental physics, both are independent of ε or whether the W/m^2 are emissions or incident energy because in the steady state, emissions and the incident energy are balanced, both absolutely and incrementally, where forcing is just incremental incident energy.

For a black body in the steady state, Conservation of Energy dictates that the energy emitted as P must be replaced, otherwise it will cool until P is equal to the incident power. When the input increases or decreases by 1 W/m^2, upon convergence to a new steady state, P will also increase or decrease by 1 W/m^2 resulting in an emissions sensitivity of 1 W/m^2 of output emissions per W/m^2 of input power. Obfuscating an intrinsically linear emissions sensitivity, the IPCC uses an approximately linear temperature sensitivity metric as the change in T arising from forcing. This approximation is unnecessary as the effect of incremental W/m^2 on T can be calculated exactly as the derivative of the Stefan-Boltzmann Law as shown in equation 2).

2) $dT/dP = 1/(4\varepsilon\sigma T^3)$

The sensitivity of all matter in thermal equilibrium to changes in the incident power is a function of $1/T^3$ which decreases as T increases. For an ideal black body, ε is 1 and for non ideal radiators it's between 0 and 1, none the less, the $1/T^3$ relationship is also immutable and independent of ε. Clearly, the Earth isn't an ideal BB radiator and the only other possibility supported by the laws of physics is that it's a non ideal radiator. These can be quantified as gray body radiators and while they're not ideal, their bulk average behavior can still be precisely quantified by an equivalent average emissivity.

Consider a gray body radiator in equilibrium as illustrated below. The first order physical model is an ideal black body with a semi-transparent layer between it and its environment.



Steady State Condition

Pi = Po

Pbbi = Pbbo = σT^4

Po = εPbbo = εσT^4

Pbbi = Pi/ε

Pbbo are the emissions corresponding to T which are attenuated by a factor of ε before being emitted as Po, yet to sustain T, the black body must be receiving enough Pbbi to offset Pbbo. Since Pi, must be equal to Po, Pi must be amplified to the required Pbbi in order for T to be sustained as the equilibrium temperature. If the attenuation of emissions is ε, then the required amplification of the forcing is 1/ε.

Both amplification and attenuation arise from the same absorption and/or reflection of black body emissions by the graying layer. Some or all is returned to the black body manifesting the amplification by offsetting emissions in excess of the incident power while the rest is added to what's not intercepted manifesting the net attenuation. The sensitivity of this gray body radiator is also given by equation 2). Observe how this mimics the bulk macroscopic radiant behavior of the Earth whose equivalent average emissivity is about 0.62 corresponding to an amplification factor of about 1.62.

The well known physics of this model are not the least bit controversial. Even the IPCC acknowledges that the sensitivity calculated by equation 2) is valid. Where they went off the rails was considering it to be the zero feedback sensitivity which is then amplified by nebulous positive feedback in order to override the derivative of the Stefan-Boltzmann Law. Meanwhile, they ignore the fact that no one Joule is any more powerful than any other at warming the surface or maintaining its temperature.

The amplification factor of $1/\varepsilon$ must apply equally to all W/m^2 of solar input, including the next one and represents the final amplification by the system after all feedback like effects, positive, negative, known and unknown have already had their complete, steady state effect. The IPCC obfuscates this by magnifying the apparent feedback required by referring to 255K as the zero feedback temperature when without clouds or ice feedback, it would be closer to 270K owing to the lower albedo.

A black body radiator at 255K does have about the same 0.3C per W/m^2 sensitivity as a gray body radiator at 288K whose emissivity is 0.62, but only the later has any physical significance relative to Earth. The reason is that 255K isn't the temperature of any radiating matter, much less the average temperature of all the radiating matter, nor is it the temperature of the surface before feedback, it's just the temperature of an ideal black body that would emit what the Earth does. Meanwhile, 288K is the actual average surface temperature after all feedbacks have had their complete steady state influence on all of the solar forcing, and to be absolutely clear, feedback can't tell Joules apart either.

Introducing massive positive feedback that only affects the next W/m^2 is the Achilles heel of the IPCC's position. Climate science broke in 1984 when James Hansen et all applied feedback analysis to the climate. After referring to Bode's linear feedback amplifier analysis, the exact words were 'it follows that', which was followed by the wrong equation and no work showing how it came about turning the rest of the paper into unsupportable physics defying junk.

This ill conceived concept of massive amplification by positive feedback was the holy grail hypothesis establishing plausibility for a climate sensitivity large enough to justify the formation of the IPCC. Confirmation bias embraced it and called it 'settled' long before it could be verified, even if it was true. The IPCC further distanced the sensitivity from the physics by restating it as the temperature change arising from doubling CO_2 which arose by assuming it was equivalent to about 3.7 W/m^2 more solar forcing keeping CO_2 concentrations constant.

Along the way to AR1, Michael Schlesinger noticed some of Hansen's errors and published a paper in an obscure DOD journal to fix the most obvious ones, add some new ones, and get it published in time for the first IPCC assessment report. Equation 3) is the corrected equation that Schlesinger derived, but that didn't actually apply either.

3) $g = 1/(1 - f)$

The mistake in Schlesinger's inadequately reviewed and highly convoluted derivation was confusing the feedback factor with the feedback fraction which are only the same when the open loop gain is 1. Equation 3) can be more easily derived from the well known gain expression shown as equation 4) by replacing the open loop gain, G, with 1 and solving for the closed loop gain, g, which is the implicit sensitivity.

4) $1/g = 1/G - f$

Schlesinger presumed a non unit open loop gain, G, that amplified and then converted W/m^2 of input forcing into an output in degrees. The derivation broke when calculating the feedback term by incorrectly considering f in equation 4) to be f/G, turning the temperature feedback coefficients and the resulting g/G ratio he called the sensitivity, into complete nonsense. By taking G out of the loop, he implicitly set the open loop gain to 1 while insisting it can't be 1 because that doesn't convert W/m^2 into a temperature. The flawed derivation supported the flawed assumption and confirmation bias led to accepting both as valid. The bottom line is that any open loop gain turning W/m^2 into degrees K, incrementally or otherwise, isn't compliant with the feedback analysis being applied.

Further invalidating Hansen's and Schlesinger's analysis is that both ignored the only two preconditions for applying Bode's linear feedback amplifier analysis which are strict linearity and the existence of an implicit power supply. Schlesinger confirmed his position was that approximate linearity around the mean satisfied the first and that the average not accounted for by the incremental analysis satisfied the other. He was wrong on both counts and this second pair of self consistent errors easily got past per review. I showed him the specific error of conflating the feedback fraction with the feedback factor that resulted in canceling G, but he passed away before he could either explain or admit a mistake. As far as I know, the only surviving reviewer of the Schlesinger paper is Mike MacCracken whose response to this error is to claim that it's not an error. Given his role as a liaison between the IPCC and the DNC, this was not unexpected. More recently, Gerard Roe rehashed the Schlesinger paper and made the same mistake in the same derivation. The conceptual mistake is considering that feedback can amplify the gain, while the gain itself must have an origin independent of the feedback.

Strict linearity means a constant gain is applied to all possible input values from 0 to the maximum possible input. If 1 unit of input produces 10 units of output, 2 units of input will produce 20 units of output. Ignoring the implicit power supply is equivalent to connecting both the power cord and audio input of a stereo amplifier to the audio output of an I-pod, furthermore; if an audio amplifier exhibited approximate linearity in the way assumed by how feedback analysis was applied to the climate, what comes out of the speakers would be so distorted, it would be unrecognizable.

The simplifying assumption of an implicit power supply removes the requirement to conserve energy between the input and output of the open loop gain block. The climate models output emissions corresponding to a change in T originate from the input forcing and any related feedback, none of which originates from an implicit power supply. The average forcing and feedback power not accounted for by the incremental analysis is already accounted for by the average temperature that's also not accounted for.

Venus is not an example confirming the feedback model. The problems are that Venus isn't even close to a proxy for Earth, moreover; the presumed cause by runaway feedback requires the missing power supply. A better explanation is that its clouds are a thermodynamic system independent of the solid surface and they alone are in direct equilibrium with the Sun. The solid surface is ultimately heated by radiation from the clouds where the surface temperature is set by the PVT profile of the atmosphere establishing a requirement for storing energy between the clouds and the solid surface in order to be in equilibrium with those clouds. It's the same reason why the interiors of gas giants are hot, except on a smaller scale and with a tangible solid surface.

The gas giant model doesn't work for Earth because its clouds are tightly coupled to the oceans via the hydro cycle and the matter in direct thermal equilibrium with the Sun is the top layer of those oceans and bits of land that poke through and not the cloud layer. In addition, Earth's atmosphere is chaotically semi-transparent to both solar energy and surface emissions while the Venusian atmosphere is permanently opaque to both owing to its runaway cloud coverage.

The Earth doesn't deviate from the physics because of things like latent heat, other non radiant heat transfers and clouds. Those who say so can't articulate what additional effects these things have on the average radiant behavior other than the net effect they're already having. Trenberth complicated the issue by conflating the return of non radiant energy to the surface with the return of radiant energy absorbed by GHG's and clouds and called the combination 'back radiation' when much of it isn't even in the form of radiant energy. He fails to make it clear that the return of energy lost by latent heat and thermals was buried in this term.

The incremental nature of the feedback model combined with an output expressed in degrees hides many flaws. A nominal sensitivity of 0.8C per W/m^2 sounds plausible, but the equivalent emissions sensitivity of 4.4 W/m^2 of surface emissions per W/m^2 of forcing doesn't when you take into account that the Earth's average surface emissions sensitivity is only 1.62 W/m^2 of surface emissions per W/m^2 of forcing and that no one Joule can do any more or less work than any other.   If the IPCC was correct, each of the 240 W/m^2 of solar forcing must also produce 4.4 W/m^2 of surface emissions. If they did, the surface would be emitting an energy flux corresponding to an average temperature in excess of 90C, which it's not, thus falsifying the IPCC's nominal sensitivity.

If the gray body model applies to Earth's climate system, the entire range of sensitivity is falsified. Geometry dictates how the graying layer redistributes what it attenuates between the environment and returning it to the black body.   Since it absorbs energy from the black body across half the area it emits from, about half is re-emitted into the environment and the remaining half is returned to the black body.   As a result, the maximum possible emissions sensitivity is 2 W/m^2 of surface emissions per W/m^2 of forcing, yet the IPCC's lower limit is equivalent to 2.2 W/m^2 of surface emissions per W/m^2 of forcing and already exceeds the theoretical maximum supported by this model. The upper limit occurs when the graying layer absorbs 100% of what the black body emits which is otherwise considered the runaway case. If 1 W/m^2 of forcing results in 2 W/m^2 more emissions from the black body and all is absorbed, then half is emitted into space to offset the forcing, the other half is added to the forcing to offset the 2 W/m^2 of new emissions and balance is achieved.

Consider that GHG's and clouds absorb about 300 W/m^2 of the 390 W/m^2 emitted by the Earth's surface, allowing only 90 W/m^2 to leave the planet while the radiant balance requires 240 W/m^2. The missing 150 W/m^2 must originate from the atmosphere which is half of what it absorbed. The remaining half is returned to the surface and added to the solar input power offsetting the 390 W/m^2 emitted by the surface. If the atmosphere absorbed a larger fraction of surface emissions, then balance requires more than half be sent into space and less returned to the surface. If the atmosphere returned all it absorbed back to the surface, it would only be able to absorb about 150 W/m^2 which is far less than can be supported by the physics.

Here's where another flawed latent heat argument comes in where the claim is that some of the missing 150 W/m^2 comes from latent heat entering the atmosphere. Whether this is true or not doesn't matter from balance or sensitivity considerations since the return of all latent heat to the surface is already accounted for in the back radiation term and for the surface to be in balance, there's no latent heat energy available to be sent into space.

The incident energy absorbed by the atmosphere is also misrepresented. This energy is absorbed almost exclusively by the water in clouds. This water is tightly coupled to the surface waters via the hydro cycle. With a nominal period of days to weeks, the effects of solar energy absorbed by clouds on the surface has already affected monthly and longer term average surface temperatures. While the water in clouds radiates, to be considered in a steady state thermal equilibrium, it must absorb the same as it emits.

The physics of a gray body radiator are undeniably sound, but to verify that the model applies to the Earth's climate, its many non obvious predictions can be tested. If the bulk planet behaves like a gray body, the average emissivity must be independent of the temperature and the local solar insolation resulting in the same average value from pole to pole. This is a non obvious prediction since given the chaotic nature of the climate, the likelihood of this being the case by chance is exceedingly low.

Equation 1) can be applied directly to the relationship between the surface temperature and the planets emissions, but not to the relationship between the solar power input and the surface temperature. The reason is the finite time it takes for Pi to affect the surface temperature and that Pi will always be ahead of Po. The bulk behavior of the planet must still obey the laws of physics and since the input path from the solar power to the surface temperature can't be the same gray body relationship as the output path from the surface temperature to the planets emissions, the only other conforming physics would be the case where the next W/m^2 of forcing results in 1 W/m^2 more surface emissions. This isn't possible as an absolute relationship, so if true, it must be true incrementally which requires biasing the incident power by what's coming from the atmosphere before converting the result to an equivalent temperature. The 3 equations describing the input and output paths of this model are shown as equations 5a), 5b) and 5c).

5a) $Ps = \sigma To^4$
5b) $Po = \varepsilon Ps$
5c) $Pi + Ps*\alpha/2 = \sigma Ti^4$

To is the temperature satisfying the output path, Ti is the temperature satisfying the input path, Pi is the incident power, Po is the planets emissions, Ps are the surface emissions corresponding to To, ε is the effective emissivity and α is the fraction of Ps absorbed by clouds and GHG's, half of which is returned to the surface and added to Pi to quantify a physics conforming input path.

In the steady state, Ti = To and Pi = Po. Solving for the steady state condition, equations 5a), 5b) and 5c) simplify to equation 6).

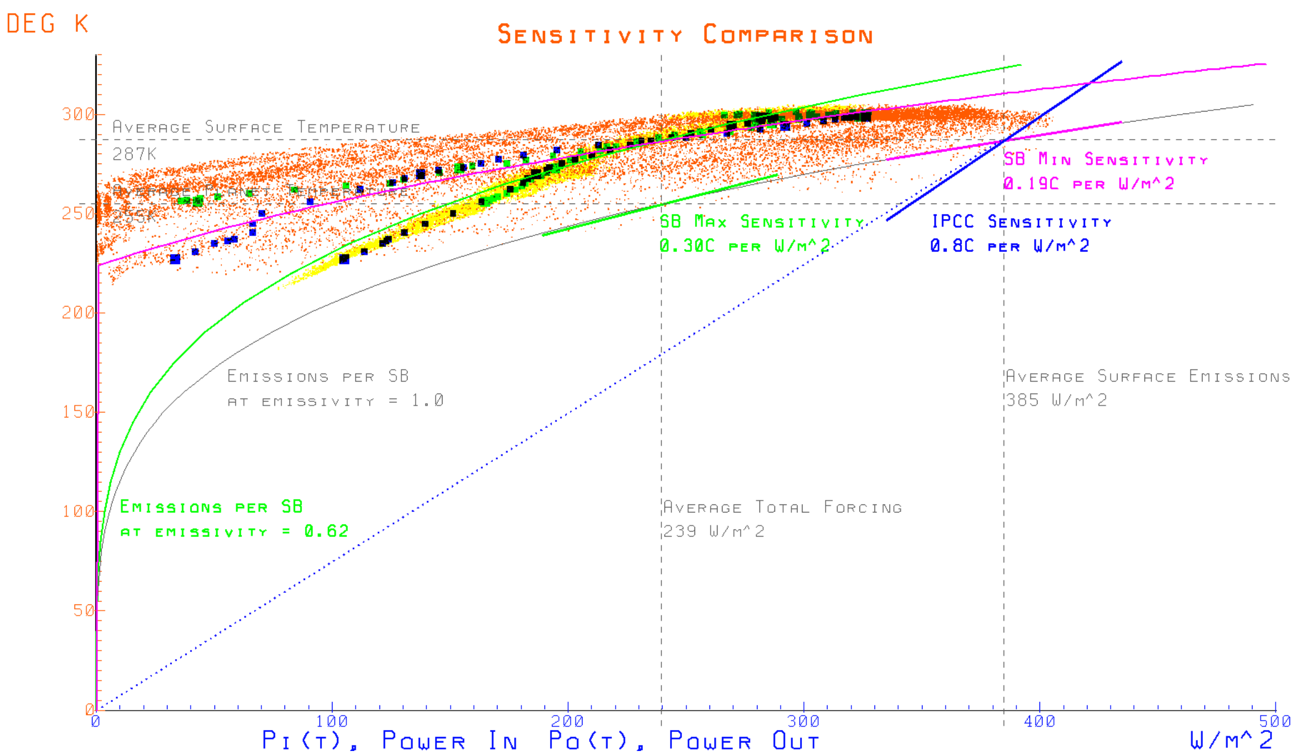
6) $\varepsilon = 1 - \alpha/2$

This leads to another non obvious prediction of the gray body Earth model which is that to achieve the required constant emissivity, the average fraction of surface emissions absorbed by the atmosphere must also be constant and independent of the temperature or forcing.

Once more, conventional wisdom would seem to preclude a constant average fraction of absorption, thus precluding a constant emissivity. If constant absorption is the goal, then changing CO_2 concentrations would be compensated for, which defies the IPCC’s narrative. A potential reason used to dispute constant absorption is that clouds dynamically modify both α and ε while the fraction of the planet covered by clouds is a free variable relative to the balance which can be achieved for any amount of clouds, thus constant absorption isn’t likely because it isn’t necessary for balance.

This leads to the most non obvious prediction of them all, which is that if a constant emissivity is to be achieved, clouds must adapt locally to obtain a constant fraction of absorption in response to local conditions including their own effects on the albedo.

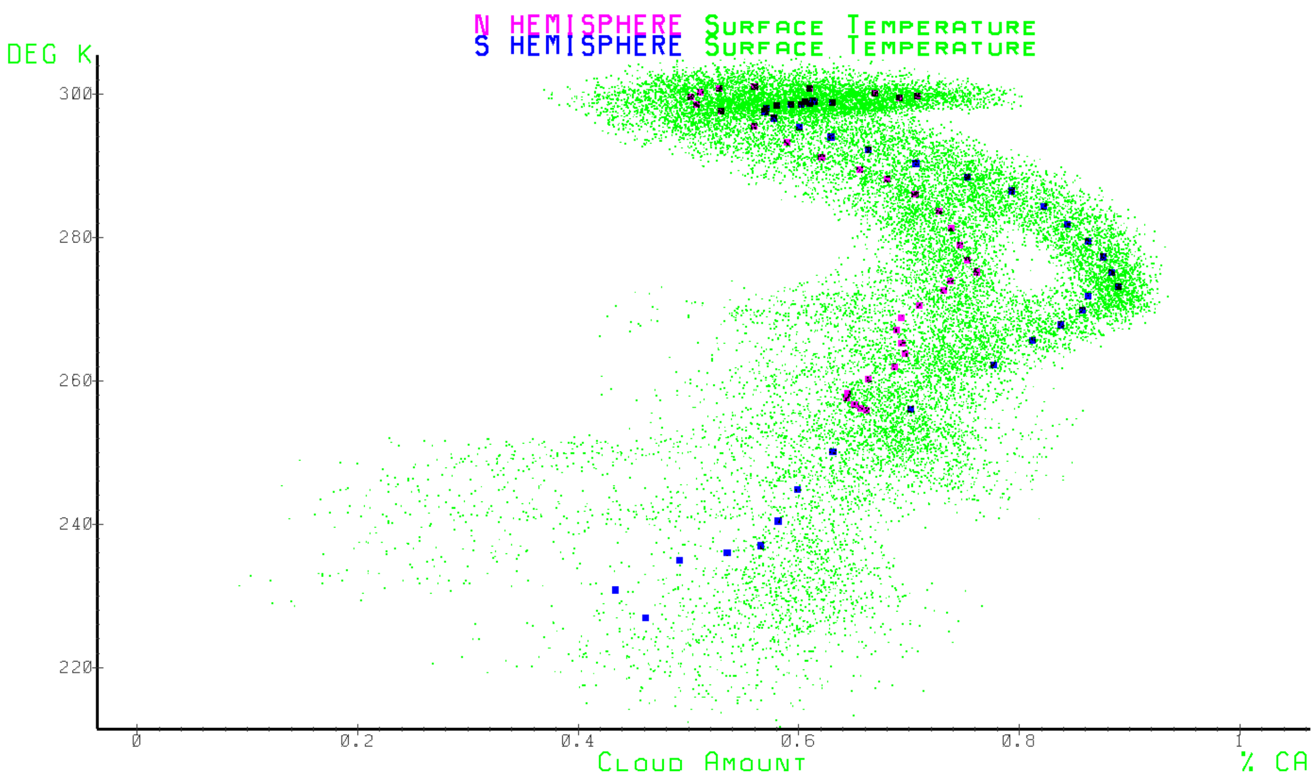
Satellite data supplied by GISS can test all of these predictions. The first plot shows measured data against what’s predicted by equations 5a), 5b) and 5c).



The small red dots are one month of data for each 2.5 degree slice of latitude from pole to pole along the input path plotting the average surface temperature, T, along the Y axis against the post reflection solar input power, Pi, along the X axis. The small yellow dots plot T along the Y axis against Po along the X axis. The larger dots centered within the yellow and red dots are the averages for each slice of latitude across all 3 decades of the available satellite record. The green line and the magenta line plot the relationships predicted by the gray body model based on a best fit for ε and α as constrained by equation 6). The black line illustrates how an ideal black body behaves and the blue line shows the relationship predicted by the IPCC's nominal sensitivity.

The match of the data to the first order predicted behavior of a gray body radiator is quite good, so this repeatable test confirms that the model is consistent with the data averages and the longer the integration time of the average, the better the fit. In addition, where the measured and predicted input and output responses intersect is the known average steady state surface temperature. The predicted response can be improved away from the mean by accounting for second order effects, like the ocean temperature saturation that occurs at about 300K and the slice specific surface emissions absorbed, rather than the average across all slices.

To complete the tests of its predictions, plot the monthly average cloud coverage against the temperature, once again for each 2.5 degree slice of the planet from pole to pole.



This shows a very interesting result. While the emissivity is a strong function of the cloud amount and is the same in both hemispheres, the cloud coverage required to meet that goal isn't. Only Po isn't trivially obtained from the data whose calculation is a complex function dependent on the reported surface temperatures, cloud temperatures, GHG concentrations, amount of clouds, their optical depth and multi-layer radiant models of the atmosphere yet the resulting relationship to the surface temperature defies the chaos with less deviation around its mean emissivity than any other relationship between any other pair of variables. If a goal beyond COE is driving the system, this surely is it.

Observe that in the first plot, the green and blue dots representing the slices of each hemisphere mostly overlap as black dots while the differences between hemispheres as a function of temperature seen in the cloud coverage is clear. This is confirmation that the clouds are adapting to meet the goal of a constant emissivity by maintaining a constant fraction of absorption in response to local conditions. In addition, it should be observed that cloud cover adapts to changes in surface reflection at 273K from melted ice and snow and to the exponential increase in evaporation starting at about 300K.

All of the tests of the gray body model confirm its applicability while first principles physics falsifies the IPCC's feedback model in many ways. The gray body model of the Earth isn't just an unconfirmed hypothesis, it's a well tested theory that's the consequence of an unrecognized physical law which is that both the local and bulk average behaviors of any thermodynamic system must obey the laws of physics.

It's intriguing that while the Earth's surface emissions sensitivity could vary between 1 and 2 W/m^2, it converges to a value of 1.62 W/m^2 per W/m^2 of forcing that seems independent of any other factor, except that it's within 1% of the golden mean. Whether this is a coincidence or not is uncertain, although the golden mean does appear in the steady state solutions of other chaotically self organized systems. If it's the goal and not a coincidence, then there are no free variables left to fudge, the climate system averages become absolutely deterministic and the IPCC/UNFCCC looses all hope of a continued existence. This top down requirement could also be applied to significantly reduce the divergence problems associated with bottom up weather and climate forecasting.

A challenge for any scientist who's uncertain about the gray body model is to apply the laws of physics in some other way that fits the data better and then explain why the clouds do as they do. If you feel that you must support the claims of the IPCC, you must also explain how to get around Conservation of Energy so that the next W/m^2 can be so much more powerful than the average W/m^2 as required to enable any theoretical emissions sensitivity larger than 2 W/m^2 of surface emissions per W/m^2 of forcing. The feedback model runaway condition is infinite emissions per W/m^2 of forcing and if you can't support 2 W/m^2, you'll never support an infinite effect and when a model can't predict how the climate is behaving now, it will never predict the future.