What Happened to Climate Science?

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Abstract

Climate science is the most controversial science of our day precipitating a politicized social conflict with the fate of the planet and trillions of dollars at stake. The climate science summarized in IPCC reports assert catastrophic effects from mankind's CO2 emissions while the skeptics assure us that the minor effect on the climate is of no concern and the most notable effect is to help feed the world by increasing agricultural productivity. There are many reasons why this controversy arose, why it persists and why each side is so obstinately committed to their point of view. The top five are presented here along with a science driven solution with the potential to resolve this crisis that's harming the reputation of science as the objective arbiter of the scientific truth.

Introduction

Climate science is the most controversial science of the modern age. What makes it so divisive is that there's absolutely no common ground between sides leaving no room for compromise and the certainty that only one side can be right. Both sides agree that incremental GHG emissions have a finite effect on the climate, but differ widely on the magnitude of this effect.

The IPCC Assessment Reports summarize the main stream view which quantifies forcing as being equivalent to an instantaneous change in the post albedo solar input power and that doubling CO2 is equivalent to 3.7 W/m^2 of forcing. They assert a climate sensitivity of 0.8C +/- 0.4C per W/m^2 of forcing which leads to a predicted surface temperature increase of 3.7 * 0.8 = 3C +/- 1.5C when CO2 is doubled. The sensitivity range asserted by the skeptics is about 0.2C +/- 0.1C per W/m^2 resulting in a temperature rise of only 0.8C +/- 0.3C when CO2 is doubled. The IPCC lower bound of 1.5C is greater than the skeptics upper bound of 1.1C illustrating the stark difference between an effect that's potentially catastrophic and needs serious attention and one whose most profound effect feeds the world by increasing agricultural productivity.

Even more surprising is that while data can be selected, processed and interpreted to support either side, trivially applying thermodynamic laws to the uncontroversial measured averages of the surface temperature and incident solar power contradicts a high sensitivity. Those who side with the IPCC insist that the climate is more complicated than a surface trivially obeying physical laws which leads to uncompromisingly opposed positions staked out by intelligent people on both sides which to resolve requires extending climate research beyond just understanding how the climate works to include why this controversy stubbornly persists.

How the Climate Works

An executive summary of the climate system starts with the definition of an equivalent temperature, which is the temperature corresponding to a specific power density emitted as an ideal Planck distribution of photons from a black body with unit emissivity and in accordance with the Stefan-Boltzmann Law. Planet emissions are strictly photons and their average power density of 239 W/m^2 corresponds to an equivalent temperature of 255K. The equivalent temperature of the equivalent surface is 287K based on its average measured radiant emissions of 385 W/m^2, where this equivalent surface is also idealized, yet closely correspond to the actual surface and its temperature as measured by surface thermometers. The conclusive result is that the average W/m^2 of solar input not reflected away results in about 1.6 W/m^2 of photon emissions from the surface after all known and unknown influences, including feedbacks, have had their effect. This represents a significant warming effect which if not for GHG's and clouds, each W/m^2 of forcing would result in only 1 W/m^2 of surface emissions and the surface temperature would only be 255K. Although, without the negative feedback influence from cloud reflectivity, the post albedo input power would be closer to 290 W/m^2 and the resulting temperature would be 267K.

The Stefan-Boltzmann Law dictates a T^4 dependency between temperature and W/m^2 of emissions implying that a sensitivity expressed as degrees per W/m^2 is only meaningful at one temperature. Relative to the sensitivity of the surface to forcing, this is the average surface temperature, moreover; each incremental W/m^2 of forcing must have a smaller effect on the temperature than the previous one and thus have a smaller effect than the average of all prior W/m^2 of forcing. This makes the average

1.6 W/m^2 of surface emissions per W/m^2 of forcing, corresponding to a sensitivity of 0.3C per W/m^2 at the average surface temperature of 287K, a conservative upper bound on the sensitivity. This conflicting result from first principles physics indicates there's something unusual about the extraordinary claims made by the IPCC.

The water in clouds is tightly coupled to the water in the oceans via evaporation and precipitation, thus the solar power absorbed by atmospheric water can be conflated with that absorbed by the oceans to facilitate a simplified equivalent model of the climate system as an ideal gray body where all incoming power contributes to its surface temperature and whose emissivity relative to space is reduced by an atmosphere. This idealized system has an emissivity of 0.62 (1/1.6) where the reduced emissivity warms the surface by slowing down the transmission of surface emissions to space via narrow band absorption by greenhouse gases and broad band absorption by the water in clouds. Cloud absorption and the GHG action of water vapor are dependent on the surface temperature and converge as required for equilibrium while GHG's like CO2, O3 and CH4 have a static effect.

An atmosphere that slows down surface emissions warms the surface because it has a finite capacity to store energy and in the Long Term Equilibrium steady state, the average rate of surface photon energy absorbed by the atmosphere, *Pa*, must be equal to the average rate of energy leaving it. Power enters from the surface and can either escape to space or be returned back to the surface. The power escaping to space makes up the difference between the surface emissions not absorbed by the atmosphere and the emissions required to offset the incoming solar power, while the power returned to the surface facilitates surface warming as the difference between the incoming solar power and the emissions of the surface at its elevated temperature. Geometric considerations of the ideal system require the power leaving each of the top and bottom of the atmosphere to be equal to half of *Pa*. If latent heat or other energy transported by matter affects LTE, the lapse rate matters or there are any other deviations from ideal, the amount of additional power required to escape to space will not be equal to that required to return to the surface and/or their sum will not be equal to *Pa*. This can be compensated for in the balance equations with offsets although the data suggests the required offsets are close to, if not exactly, zero. This implies that most, if not all, of the energy transported by matter that enters the atmosphere will be returned to the surface in some form and that relative to the effect incremental CO2 has on LTE, this energy is statistically irrelevant.

If CO2 is doubled and its effect is equivalent to 3.7 W/m^2 of forcing, the emissivity of the equivalent gray body decreases from 0.62 to about 0.61. If the main stream is correct, doubling CO2 must decrease the emissivity to about 0.595. Line by line atmospheric simulations show that the absorption of surface photons by the standard atmosphere increases by about 3.7 W/m^2 when CO2 is doubled, which in fact, is equivalent to only 1.65 W/m^2 of forcing as only half of incremental *Pa* is ultimately returned to the surface and the effective emissivity decreases from 0.62 to 0.615. This additional factor of two error caused by defining forcing in a way that equates incremental absorption to incremental solar input need not even be considered to show how CO2 emissions are climatologically benign, since the effect of 3.7 W/m^2 of forcing is demonstrably small enough to be of little or no concern.

Why Climate Science Doesn't Work

There's no single factor driving the difference between points of view which contributes to the difficulty in unwinding the conflict. Many reasons have been identified and the five most important ones are listed.

Reason 1: Expressing the sensitivity as Degrees per W/m^2

Specifying a climate sensitivity to forcing with dimensions is technically correct even though the proper term is the dimensionless ratio of output to input called gain. The problem is that the units chosen obfuscate the linearity between forcing and surface emissions by linearizing the T^4 dependency of surface emissions and temperature by qualifying it as approximately linear over a narrow range which is also both technically correct as it misleads.

The main stream sensitivity of 0.8C per W/m^2 seems plausible enough until viewed as the ratio of the change in output (incremental surface emissions) and the incremental input to the system (forcing). The average surface temperature is about 287K. Increasing this by 0.8C increases surface emissions by 4.3 W/m^2, which ultimately must be replaced or the surface cools, thus 4.3 is the dimensionless ratio between the incremental output and the the incremental input, quantifying the incremental gain that's equivalent to the main stream sensitivity of 0.8C per W/m^2.

The relationship between forcing and surface emissions is quite linear and if each of the 239 W/m^2 of solar forcing increased surface emissions by 4.3 W/m^2, the average surface temperature would be close to the boiling point of water. The average W/m^2 of forcing from the Sun results in only 1.6 W/m^2 of surface emissions and the effect on temperature from an incremental W/m^2 of forcing must be less than the average of all that preceded. In order to justify 4.3 W/m^2 of new surface emissions from only 1 W/m^2 of forcing, the origin and quantification of the incremental power emitted by the surface above and beyond 1.6 W/m^2 must be explained. This has not been explained in any IPCC assessment nor by anyone associated with main stream climate science.

Those who side with the consensus and even many skeptics will cry foul and claim that the climate is more complicated than this and the complications are the reason for the controversy. They are correct, but not in the way many think, which leads to the next two reasons why the controversy persists.

Reason 2: Conflating photons with energy transported by matter

This is the source of a perceived complication because more than just photons enter the atmosphere from the surface which again is both technically correct and misleading. Most of this is the latent heat of evaporation transported by water and a small amount is from convection transported by air. A conceptual reason for distinguishing between the forms of transport is that only matter has a temperature and photons can only indicate the temperature of distant matter. Physical reasons are that whatever effects the energy transported by matter has, the average surface temperature and its consequential emission of photons already accounts for them, the matter itself is unconditionally conserved and the evaporation of water from the surface and its condensing into clouds drives a global heat engine performing the work of weather.

A hurricane demonstrates the properties of this heat engine as a localized, maximally efficient, self contained version of the global system. The Second Law of Thermodynamics tells us that a heat engine can not warm its source of heat, which for the engine performing the work of weather, is the surface. This law is confirmed by the cooler water found in the wake of a hurricane. The unavoidable consequence is that any energy transported by atmospheric water can only decrease the sensitivity by making the surface cooler than it would be otherwise. This conflicts with the main stream requirement that the non electromagnetic sources of power entering the atmosphere from the surface must dramatically increase the sensitivity.

The data further demonstrates why the two must be separated. The amount of the roughly 76% of surface photon emissions absorbed by GHG's and clouds (.76*385 = 293 W/m^2) that must be returned to the surface for LTE (385-239 = 146 W/m^2) and the amount that must escape into space for LTE (239-(385-293) = 147 W/m^2) are the same within experimental error and their sum (147+146=293 W/m^2) is equal to the amount absorbed. The 76% average fraction absorbed can be derived from the average absorption by clouds, E=0.7, the average fraction of the surface covered by clouds, P=0.67 and the average absorption by GHG's in the cloudlesss atmosphere, A=0.55. The equation used to calculate the total fraction of surface power absorbed is then (1-P)*A + P*(1-E)*A + P*E = 0.76. P and E come from the ISCCP data set while A comes from line by line 3-d simulations of the atmosphere. The results confirm that only radiant power influences the radiant balance of the planet.

Reason 3: Relying on positive feedback

The next complication comes from asserting that positive feedback can amplify a tiny effect into something far larger resulting in an incremental sensitivity larger than the absolute sensitivity thus enabling the amplification of 1 W/m^2 up to 4.3 W/m^2. While this is also technically correct, it doesn't apply to the climate system. Not withstanding the requirement that the incremental gain must be less than 1.6, the theory supporting climate system feedback derives from Bode, who developed control theory for analyzing vacuum tube amplifiers. Bode's analysis assumes an active amplifier that measures the input (forcing) and feedback to determine how much power to deliver to the output from an external power supply. There's no external power supply in the climate system and the input and feedback are consumed to produce output while some fraction of the output is consumed to provide feedback. These Conservation of Energy constraints have never been accounted for by main stream climate science and is why both a high sensitivity and scary, but otherwise impossible, run away GHG effects can be supported.

To stem the inevitable 'Venus as proof of concept' claims, consider that Venus is not the result of a run away GHG effect, but of a run away cloud effect. Unlike Earth, the Venusian clouds completely envelop the planet and are not thermally coupled to the solid surface below through evaporation and precipitation. Venusian clouds comprise a unique thermal system in equilibrium with the Sun independent of the solid surface. Its solid surface is in equilibrium with this cloud layer and its temperature is dictated by the PVT profile of the gravity shaped CO2 ocean separating it from the clouds, just as the temperature of the solid surface of Earth beneath its oceans is a function of the gravity shaped profile of the water above and that the temperature profile of a gas giant is similarly a lapse rate dictated by gravity.

Reason 4: A conflict of interest at the IPCC

Science should be self correcting, especially since the high sensitivity required to support Catastrophic Anthropogenic Global Warming is redundantly contradicted by first principles physics, so why does consensus climate science so definitively assert otherwise?

The reason is the IPCC, which was spawned by the UN and predicated on the assumption that man made climate change is inevitably catastrophic. Their initial charter stated as much while they offered a mitigation strategy to transfer wealth from the developed world to the developing world as climate change reparations. The UN has always been looking for ways to justify global re-distributive economics and catastrophic climate change caused by man is the perfect reason whose support can be garnered with fear and whose opposition can be readily demonized.

Whether by default or by design, the IPCC became the arbiter of what defines consensus climate science by what it publishes in its reports. The resulting conflict of interest has applied a strong bias over decades of establishing what should be accepted as correct climate science by systematically omitting or discounting anything or anyone that undermines their reason to exist while acknowledging virtually anything purported to support their preconceived position regardless of technical merit. The result is an unstable pile of sloppy science and improvable hypotheses supported by speculative interpretations of sparse data which is destined to collapse as the self correctional forces that inevitably do act upon science remove critical foundation supports. Three of these support pillars were identified earlier and removing any one is sufficient to precipitate the collapse of IPCC climate science.

Reason 5: Partisan politics picked sides

There are many other contributing factors, including big money for research and green projects, a biased peer review process, the pitfalls of homogenizing sparse data, misapplied terminology, misinterpreting ice core data and more, but the most insidious reason is that partisan politics chose sides and the party that represents the political views of most academic scientists and the media initially chose wrong due to an emotional reaction to speculative claims of impending doom. They are now blind to the truth owing to the political consequences of being so incredibly wrong for so long, especially since many on the left believe their position on climate change is among their most supportable positions. Combined with the bias from the IPCC, the result has been a socially engineered false reality that many otherwise intelligent people are scared, duped or coerced into accepting.

Many will take offense with the idea that social engineering, inadvertently or otherwise, has so thoroughly distorted their understanding of climate science, especially those who expect their scientific background to immunize them from this kind of manipulation. Unfortunately, political ideologies provide a powerful unconscious bias which few can resist.

When politics chooses sides of any controversial issue, the first casualty is objectivity and is why politics, like religion, must never have a role in defining science. The political left aggressively promotes substantial man made climate change for many reasons, most having nothing to do with science and most opposing positions held by the right. These include the feel good idea of saving mankind from itself, support for economically nonviable green agendas, opposing oil company interests, support for re-distributive economics and mitigating the guilt of success by punishing the pursuit of success that drives progress.

An important hallmark of any scientific truth is that it will be embraced regardless of political bias. A testable prediction of the corruption of climate science by politics is that whether or not someone agrees with main stream climate science will be highly correlated to whether their politics leans left or right and the data overwhelmingly supports this prediction.

Can Climate Science Be Fixed?

Climate science can be fixed by elevating the laws of physics above politics. Unfortunately, this can't happen organically until politics is excised from climate science, which given how entrenched it is, seems impossible. Shutting down the IPCC would be the best first step, as it was founded on an incorrect assumption based on bad information, but it would require unprecedented conscientiousness by many politicians to disband such a well entrenched politically motivated bureaucracy.

The scientific case for a sensitivity far below the claimed lower bound of 0.4C per W/m^2 is indisputable, yet IPCC driven climate science fails to acknowledge this or even reference relevant work supporting a low sensitivity. If the reality of physics doesn't prevail over the IPCC's conflict of interest we are doomed to digress as a society, as their solutions are more often worse for our civilization than the imaginary problems they're supposed to mitigate, many of which we're already squandering valuable resources to pursue.

Climate science is in dire need of a Reformation. This can happen in one of two ways. Either a prominent main stream climate scientist musters the courage to step up and say 'Wait a minute, it's really not as bad as we think', or an indisputable, alternative consensus arises that scientists on both sides can embrace. An honest discussion about the underlying physics would be a good first step and this might actually be possible.

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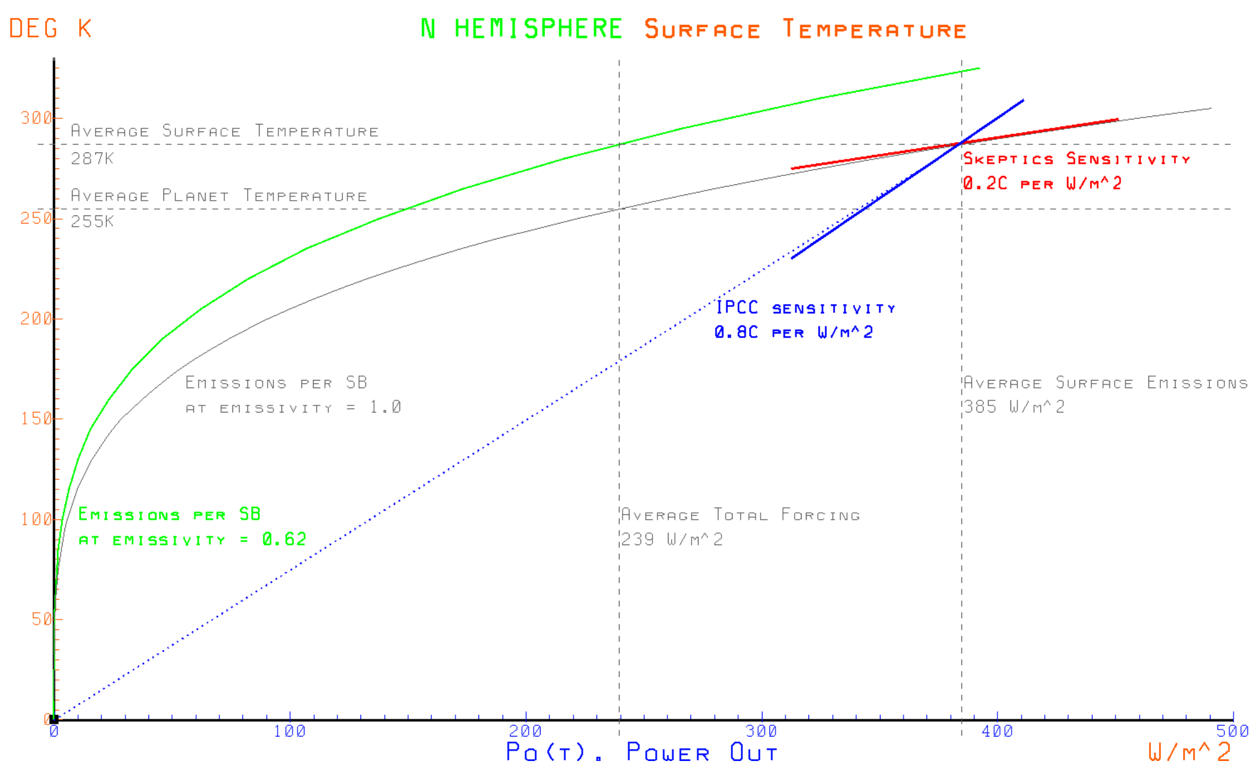
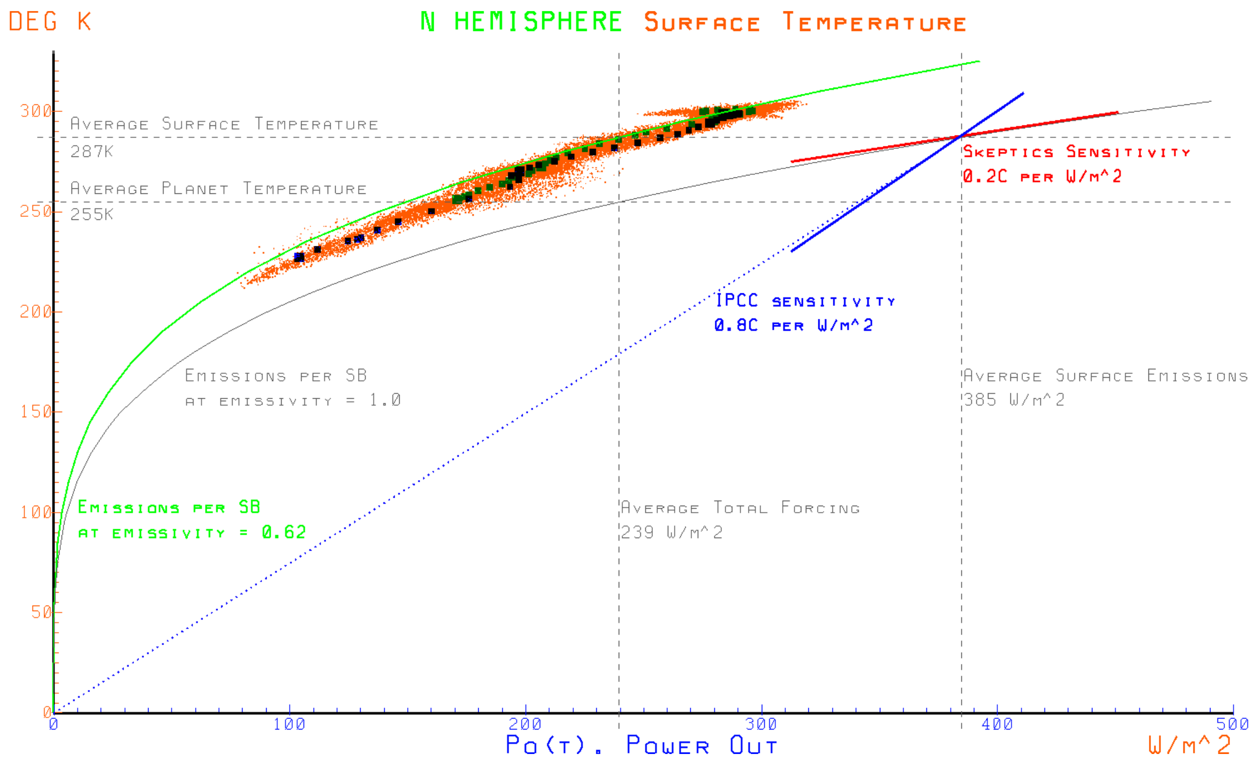
Supplemental Material
Graphical Representation of the Difference

This plot of shows graphically how the IPCC sensitivity in blue differs from the skeptics sensitivity in red in the context of the Stefan-Boltzmann Law shown in gray. The sensitivity claimed by the skeptics corresponds closely to the slope of the gray curve at the average surface temperature and is about 0.2C per W/m^2 while that claimed by the IPCC is 0.8C per W/m^2 and is even steeper than the slope of the line linearizing power vs. temperature through the origin (dotted blue). The green line shows the relationship for the 0.62 emissivity of an ideal gray body at the average surface temperature.



Supporting Data

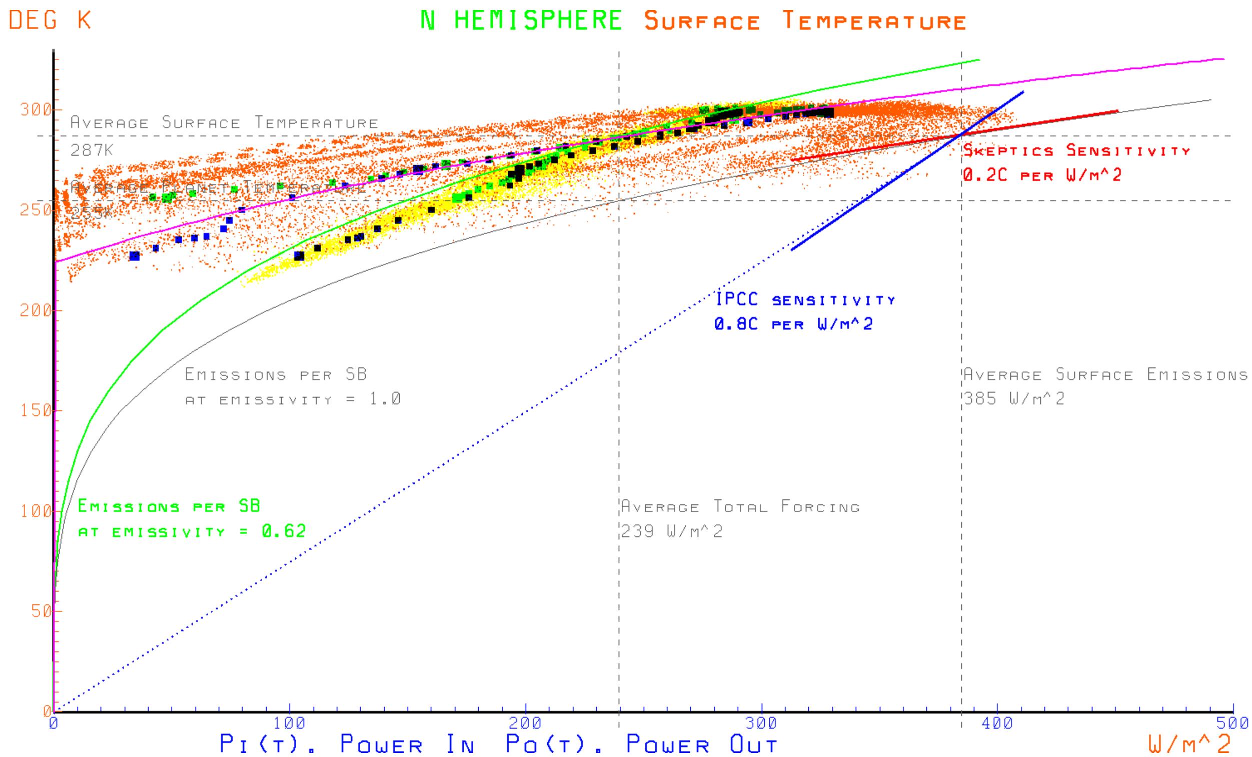
These findings depend on a linear relationship between the input power and surface emissions leading to a Stefan-Boltzmann relationship between input power and surface temperature. In the steady state, the output power, *Po*, will be equal to the input power so plotting the output power as a function of surface temperature will be a proxy for the relationship between the more variable total forcing, *Pi*, and surface temperature. When the data is superimposed on the expected results from the ideal gray body model, it aligns almost exactly.



Each of the 23K small orange dots represents the intersection of the average surface temperature and average planet emissions for one month of data and one 2.5 degree slice of latitude where each dot is the average of up to many millions of individual measurements. The larger dots (blue for the N hemisphere slices and green for the S hemisphere) are the average of all samples for each 2.5 degree slice of latitude which accumulates the results from many billions of individual remotely sensed measurements. The purpose of aggregating along 2.5 degree slices of latitude is that the relevant difference between adjacent slices is the average post albedo input power it receives, hence it reveals the response to incremental forcing per the IPCC definition. The data comes from the ISCCP weather satellite aggregation provided by GISS. The long term averages are nearly exactly represented by the ideal gray body and even the monthly averages correspond closely to the idealized model. This is clear evidence that the ideal gray body is a very accurate representative of the climates LTE behavior.

More Data

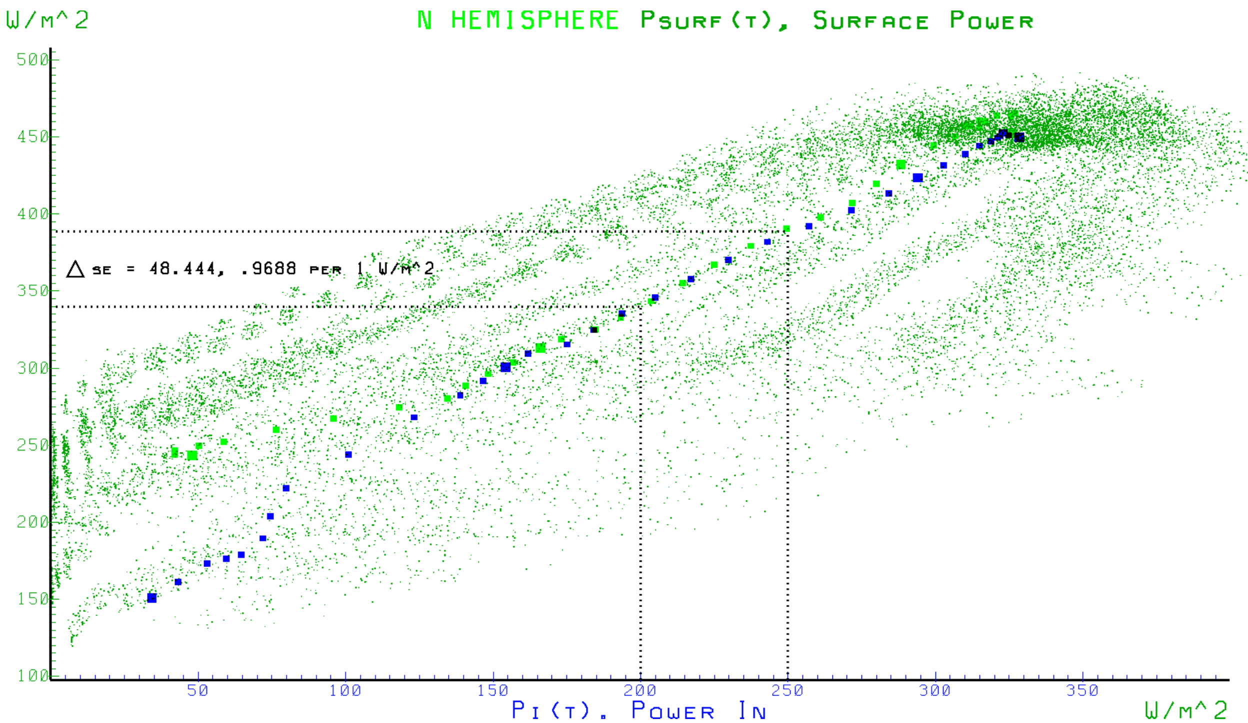
More evidence arises when the theoretical response of the surface temperature to incident solar power is plotted against the actual data. In this next plot, the surface temperature relationship to the output power is shown in yellow while that to the input power is shown in orange. The magenta line is the theoretical response of the surface to incremental input and is centered around the average planet response. This theoretical response has the same slope at 239 W/m^2 of input power as the surface has at 385 W/m^2 of output emissions and again is a very close match to the data. Notice how much more variable the distribution of surface emissions to input power is relative to output emissions.

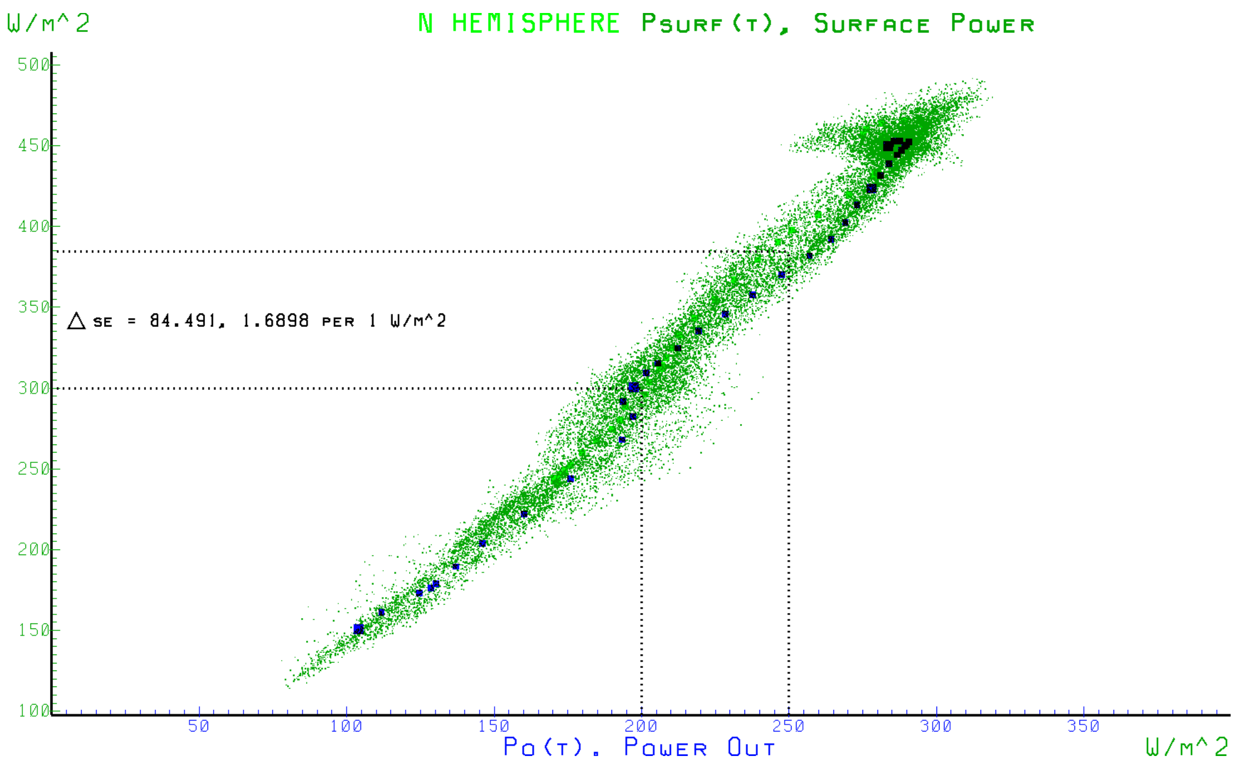


While the system always goes in the direction that increases entropy, the closer to ideal (or optimum) a system is, the slower entropy increases. Given the high complexity of the interactions within the system, there are enough degrees of freedom that the system can arrive at an solution with the lowest increase in entropy which drives the aggregate response of the system towards ideal. The slight tilt in the distribution of orange dots, relative to the magenta line is the result of a net transfer of energy from the tropics (dots towards the right) and the poles (dots towards the left), although the averages still seem to line up with predictions.

Even More Data

For completeness, these plots demonstrate the linearity in the power domain. The Y axis is the surface emissions, rather than the surface temperature and the X axises are the power in and out of the planet.





The Analytical Model

An analytical model of the climate can be constructed from the equation,

1) $Pi = Po + dE/dt$

where *Pi* is the post albedo power arriving from the Sun, *Po* is the power emitted by the planet, *E* is the total solar energy stored by the planet and *dE/dt* is the rate of energy entering and leaving the planets store of solar energy. *Po* can be defined as,

2) $Po = E/\tau$

where τ is the amount of time it would take to exhaust *E* at the rate *Po*. Substituting equation 2) in equation 1) results in,

3) $Pi = E/\tau + dE/dt$

This is easily recognized as the form of the LTI that describes a low pass filter whose response is well known and well quantified. The time constant, τ, can be determined from the low pass filter transfer function and is on the order of less than 12 months for Northern hemisphere and less than 24 months for the Southern hemisphere. This differs from the main stream estimates of the time constants which must be on the order of decades in order to support the consensus view.

The climate system differs from the low pass filter whose τ is generally a constant since the climate system τ is an inverse function of surface temperature raised to the 3rd power and decreases as the temperature increases. However, over a narrow region around LTE, the average τ can be considered constant. This is a more proper linear approximation than suggested by the consensus.

Po can also be represented as,

4) $Po = \varepsilon * Ps$

where *Ps* is the surface emissions, ε is the effective emissivity of the planet and equal to *Ps/Po*. The emissivity can also be expressed as a function of GHG concentrations where half of what is absorbed by the atmosphere is returned to the surface to warm it. This provides a purely analytical approach to calculating the sensitivity in terms of the measurable and/or computable properties of average cloud coverage and the absorption of surface emissions by clouds and GHG's.

Since *Pi == Po*, the gain, or *Ps/Pi* is equal to $1/\varepsilon$. Given that Pi is equal to $Psun*(1-\alpha)$, where α is the albedo, the complete system is characterized by a closed loop system gain of $(1-\alpha)/\varepsilon$. The most complete model accounts for albedo changes, which as the result of 3.7 W/m^2 of forcing is relatively small and if anything, small net negative net feedback from weather reduces the sensitivity. The model whose results are presented next is a simplified one that keeps albedo constant.

Results from a simple computer model

Here are the results from a simple model that given either the net emissivity of the planet or the net absorption of surface emissions by the atmosphere can calculate the steady state by determining the value of the other required for LTE, that is, when *Pi == Po (o = 1.0)*, assuming constant albedo. The net emissivity is 'e' (*Ps/Pi*) and the net absorption by the atmosphere is 'a' (*Pa* = a**Ps*).

Nominal steady state:
  e = 0.62000, a = 0.76000, o = 1.00000, s = 1.61290, T=287.14K, dT= 0.000
Results after 3.7 W/m^2 of incremental absorption:
  e = 0.61520, a = 0.76960, o = 1.00000, s = 1.62549, T=287.70K, dT= 0.559
Results after 7.4 W/m^2 of incremental absorption
  e = 0.61045, a = 0.77910, o = 1.00000, s = 1.63814, T=288.26K, dT= 1.117
Results after 3.7 W/m^2 of incremental post albedo solar input
  e = 0.62000, a = 0.76000, o = 1.00000, s = 1.61290, T=288.25K, dT= 1.105
Slew a and e +/- 5% around nominal values, note how o varies around 1.0
  e = 0.58900, a = 0.76000, o = 0.95000, s = 1.61290, T=287.14K, dT= 0.000
  e = 0.62000, a = 0.76000, o = 1.00000, s = 1.61290, T=287.14K, dT= 0.000
  e = 0.65100, a = 0.76000, o = 1.05000, s = 1.61290, T=287.14K, dT= 0.000
  e = 0.62000, a = 0.72200, o = 0.97027, s = 1.56495, T=284.98K, dT=-2.158
  e = 0.62000, a = 0.76000, o = 1.00000, s = 1.61290, T=287.14K, dT= 0.000
  e = 0.62000, a = 0.79800, o = 1.03161, s = 1.66389, T=289.39K, dT= 2.243
Tests limits of a and e
  e = 0.99995, a = 0.00010, o = 1.00000, s = 1.00005, T=254.80K, dT=-32.341
  e = 0.50005, a = 0.99990, o = 1.00000, s = 1.99980, T=303.00K, dT=15.857
  e = 0.50000, a = 1.00000, o = 1.00000, s = 2.00000, T=303.01K, dT=15.865
  e = 0.99990, a = 0.00020, o = 1.00000, s = 1.00010, T=254.80K, dT=-32.338
Shows how runaway GHG is impossible since a must be <= 1.0
  e = 0.02000, a = 1.96000, o = 1.00000, s = 50.00000, T=677.55K, dT=390.403
This is the a and e required for a 3C rise
  e = 0.59476, a = 0.81049, o = 1.00000, s = 1.68136, T=290.14K, dT= 3.000

Code Snippet

```
/*
 * Given arbitrary a and e (both between 0 and 1.0) return the difference
 * between the power arriving and that leaving. Modify a and/or e to converge
 * to LTE, which is defined when (o – 1.0) becomes zero.
 */
static double calc(double a, double e) {
    double o = 1.0 * e;     // output emissions for 1 W/m^2 of input
    double s = 1.0;         // surface input
    double t = 1.0 * a;     // new power absorbed by the atmosphere
    extern double THRESH, X;// THRESH (nominally 1E-9) and X (nominally ½)
    while (t > THRESH) {
      t = X * t; // X of what enters the atmosphere is returned to the surface
      s += t;    // surface input (and output) increases by t
      o += t * e;// e of this ends up leaving the planet while
      t = t * a; // a of this is again absorbed by the atmosphere
    }
    return o - 1.0;
}
```

If you set X to 1, that is, assume that all of the power absorbed by the atmosphere is returned to the surface, the calculated equilibrium states at o = 1.0 become,

e = 0.24000, a = 0.76000, o = 1.00000, s = 4.16667, T=364.04K, dT=76.893
e = 0.62000, a = 0.38000, o = 1.00000, s = 1.61290, T=287.14K, dT= 0.000

where the first case is the required e for the measured a and the second case is the required a for the measured e. Note that the first case reports a sensitivity close to the 4.3 claimed by the IPCC. Obviously, this isn't correct because for the sensitivity to be this high, the net emissivity must be much lower than we observe and the surface temperature much hotter, in fact, close to the boiling point of water. It's possible that this kind of error led to an excessively high sensitivity, but the results were definitely not cross checked against reality.

The code to calculate the required e from an arbitrary a is below. Similar code can calculate the required a from an arbitrary e.

```
static void convergeE(double a) {
    double e = 0.5;
    double t = .02;
    double o = 1.0;
    int i = 0;

    while (o > THRESH) {
      o = calc(a, e);
      if (o > 0.0) {
          e -= e * t;
          i |= 1;
      } else if (o < 0.0) {
          e += e * t;
          i |= 2;
          o = -o;
      }
      if (i == 3) {
          t /= 2.0;
          i = 0;
      }
    }
}
```