An Alternative Pedagogical Global Mean Energy Budget Model Which is Inconsistent with Existing Ones

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Abstract

A novel global mean energy budget model is presented which is based upon thermodynamic and empirical facts, and is found to be mutually exclusive to and hence incompatible with common existing global mean energy budgets. This incompatibility indicates that global energy budget models are better presented by being more consistent with thermodynamic and empirical facts.

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1 INTRODUCTION

It is natural that what is presented to students of science at the textbook, classroom, and general pedagogical levels one day translates to what is foundational in future research output at the professional institutional and peer-review literature levels. Thus, a well-known global energy budget is found in "Earth's Annual Global Mean Energy Budget" (Kiehl & Trenberth 1997), whose Figure 7 is reproduced in this text in Figure 1 (with original caption).

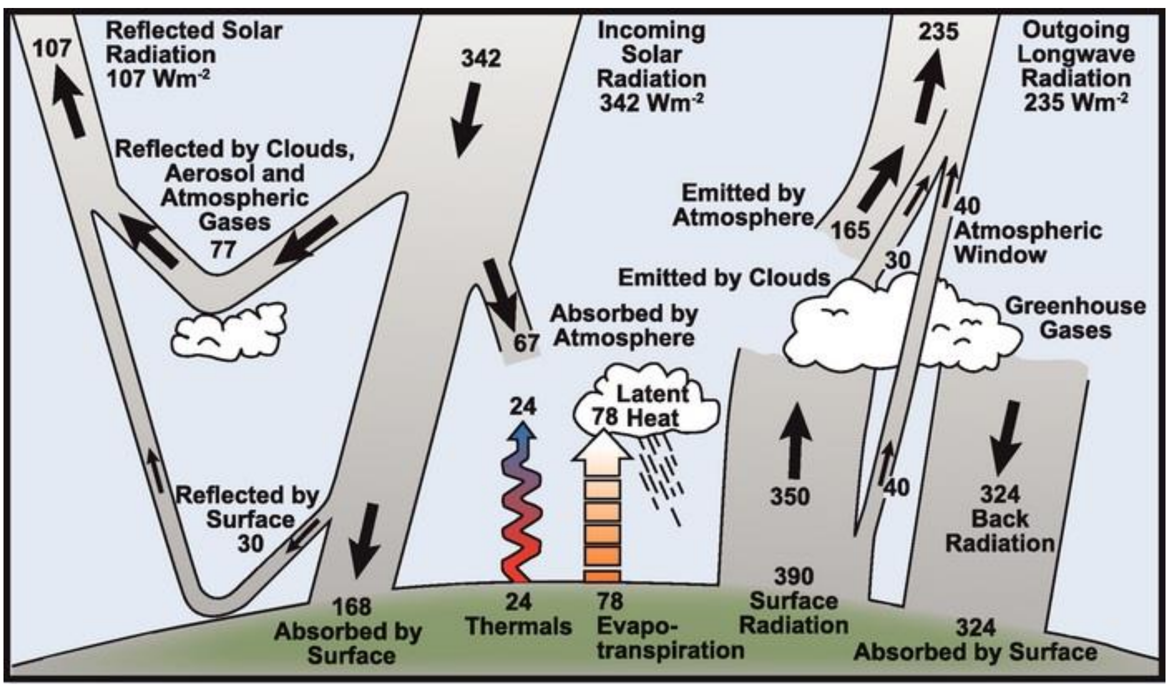

Figure 1: FIG. 7. The earth's annual global mean energy budget based on the present study. Units are Wm^{-2}.

This model is consistent with other treatments found at the textbook and classroom level regarding the climate greenhouse effect, for example from Harvard University in Figure 2, and also from Pennsylvania State University in Figure 3.

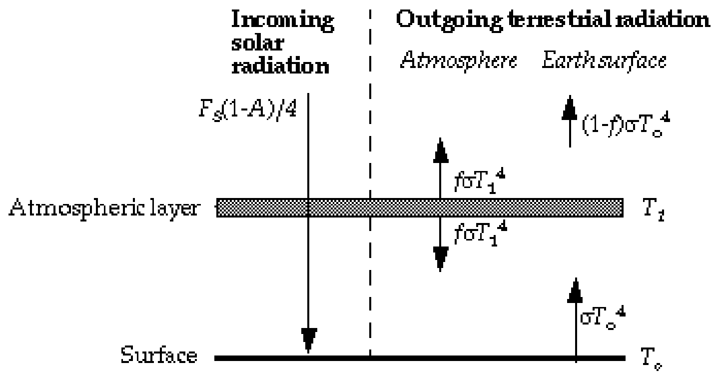

Figure 2: Found at

http://acmg.seas.harvard.edu/people/faculty/djj/book/bookchap7.html

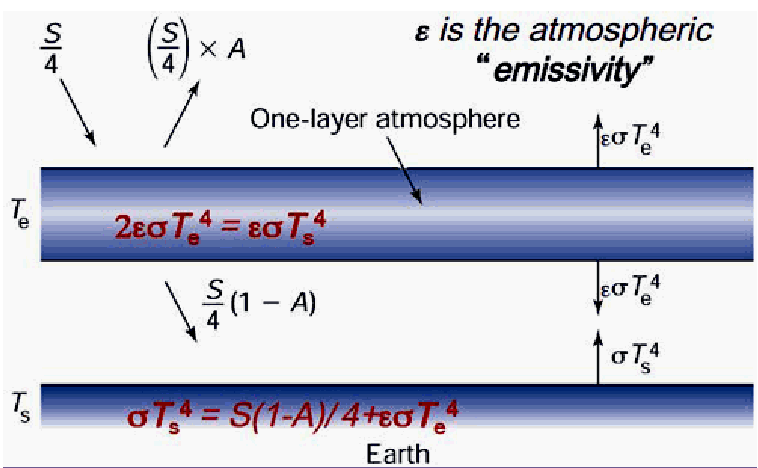

Figure 3: Found at https://www.e-education.psu.edu/meteo469/node/198

Other references to equivalent diagrams and explanations are ubiquitous, and the author was instructed with the same model during undergraduate training in astrophysics.

One main point of consistency between these three figures is that solar flux is averaged over the surface of the Earth, that is, the cross-section of intercept of solar flux by Earth’s disk is averaged over the sphere of the Earth, giving the division by four as the ratio of a disk area to that of a sphere’s area with the same radius, such as to average the disk-intercept over the entire sphere. This is noted as the one-fourth divisor in Figures 2 & 3 of the solar input, which numerically is the 341 Wm^{-2} as in Figure 1.

Another point of consistency is the cycling of energy flux within the atmosphere, labeled as “Back Radiation” in Figure 1 and as depicted with surface-directed arrows in Figures 2 & 3. This is known generally as “the greenhouse effect”, although real greenhouses actually function by limiting convective cooling.

The general concept of a global energy budget is to conserve energy given total inputs and outputs of the system, where the input and output energies manifest from disparate phenomena although having a net causal-link between them. That is, the energy output by the

Earth originates in the energy input by sunlight to the Earth, assuming negligible geothermal contribution, however there is largely a circuitous and complex link between solar input energy and terrestrial output energy, the circuitous link being the climate itself. We are interested in tabulating the energy flows through those circuits, for example. In this paper and the alternative model to be presented we focus primarily upon modeling the input and output to those circuits, and the scope of this work is not intended to exceed the introductory instructional realm.

2 DISCUSSION

An alternative global mean energy budget model is presented in Figure 4 which differs in that it does not average sunshine over the whole surface of the Earth as an input. This model is meant to be very simple for the current discussion and so does not depict internal energy flows within the atmosphere, and we shall discuss only some pertinent gross differences instead. We call the energy budget model in Figure 4 a *thermodynamic* energy budget, to highlight that we wish to base the new energy budget model on thermodynamic principles (as well as empirical ones). The model satisfies the requirements of conservation of energy and of tabulating energy flows into and out of the Earth system, but it performs this in an empirically-realistic fashion which leads to fundamental and mutually-exclusive differences to the traditional model budget in the way that the climate is thought to respond to sunlight.

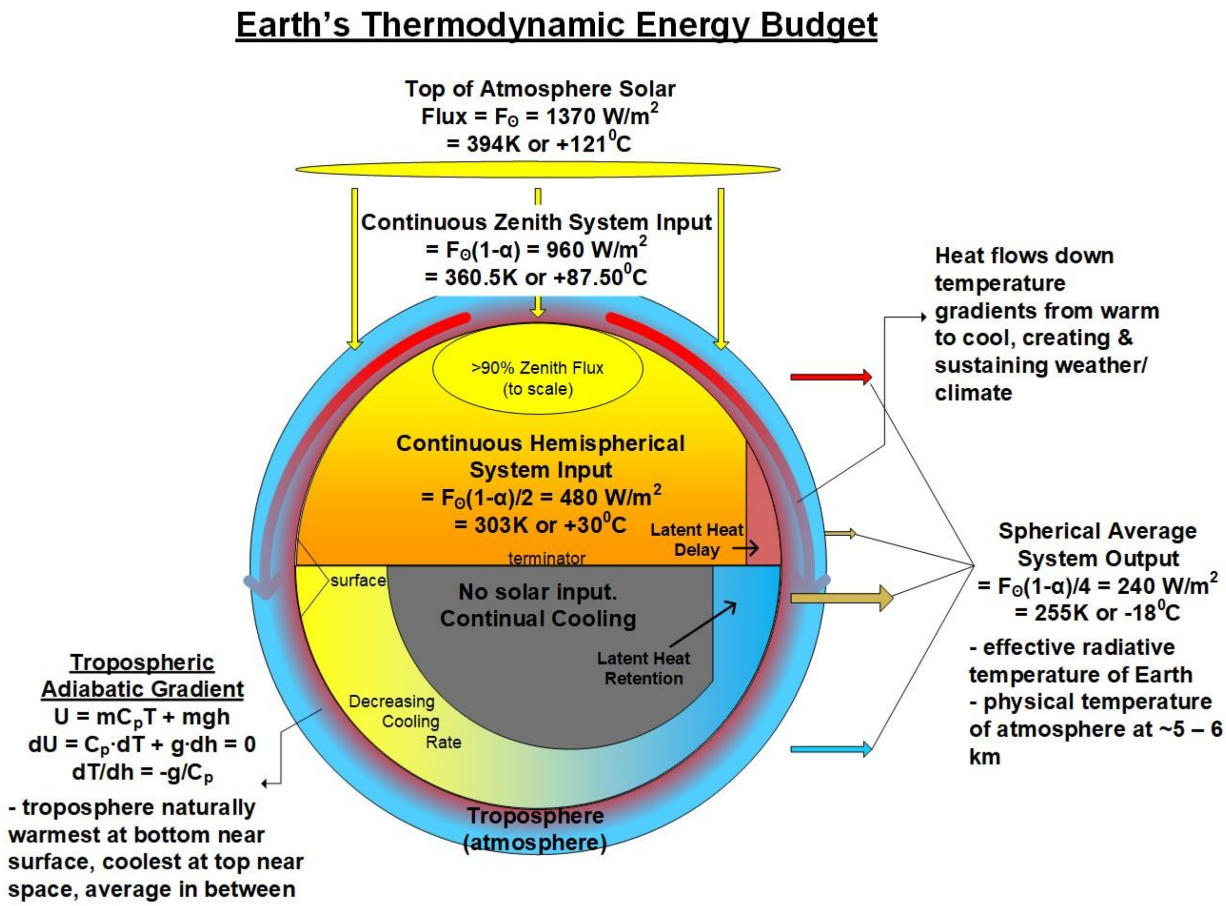

Figure 4: An alternative *thermodynamic* global mean energy budget.

For example, instead of averaging the incoming solar input evenly over the entire sphere of Earth approximated as a flat plane, the average solar input is instead represented as falling over only a hemisphere and with an intensity distribution which would be determined as the cosine of the solar zenith angle. That is, at any one time, and hence at all times and hence also as an average, solar input falls on a hemisphere only. Certainly, the surface of the Earth is rotating beneath this hemispherical input, but at any time the input is only over a hemisphere and has the expected geometrical intensity distribution.

This difference has important consequences. In the existing global energy budget, with solar flux being diluted over a total surface area it never actually spreads upon (the entire spherical surface area), solar flux is thus reduced to 168 Wm^{-2} (per Figure 1) which is an equivalent temperature forcing via the Stefan-Boltzmann Law on a blackbody of 233K (-40C, -40F). In other words, whole-surface-averaged solar flux is numerically quite feeble, and we would not be led to expect a climate to be generated by the Sun at such a low heating potential supplied by the Sun. On the other hand, the thermodynamic global energy budget supplies solar flux over only a hemisphere which sunlight ever falls upon, giving an average forcing of 480 Wm^{-2} or temperature forcing of +303K (+30C, 86F), but which maximizes around the zenith at 960 Wm^{-2} or 360K (87C, 188F). And so, solar flux is capable of performing and producing very different physical responses in matter between these two energy budgets, particularly in the examples of, say, being able to melt ice, or the ability to generate cumulonimbus clouds, and all of the other basic climatological phenomena we are familiar with which the direct action of Sunlight creates and sustains, etc. Indeed, the climate may be largely summarized as the physical responses of gas, liquid, etc., to the flow of solar heat down the temperature gradients present in the material of the troposphere and surface.

Following on this point it is relevant to reference the properties of heat flow, for example:

"If a physical process increases the total entropy of the universe, that process cannot happen in reverse since this would violate the second law of thermodynamics. Processes that create new entropy are therefore said to be irreversible. […]

"Perhaps the most important type of thermodynamic process is the flow of heat from a hot object to a cold one. We saw […] that this process occurs because the total multiplicity of the combined system thereby increases; hence the total entropy increases also, and heat flow is always irreversible. […]

"Most of the process we observe in life involve large entropy increases are therefore highly irreversible: sunlight warming the Earth […]." – Thermal Physics (pg. 82) (Schroeder 2000)

Other references to heat and the nature of heat flow are ubiquitous. The point being here that the standard global energy budget model depicts 324 Wm^{-2} of "Back Radiation" flowing to the

Earth surface from the atmosphere, a quantity nearly two-times larger than the solar input of 168 Wm^{-2}. This implies that the atmosphere heats the surface with a far greater power than the Sun does, despite the atmosphere generally presenting a temperature-reducing effect upon the surface via convection of the cooler gas upon the warmer sunlight-heated surface. However, since the origin of energy and specifically heat is the sunlight and its initial absorption into terrestrial matter, then it is implied that heat energy originally from the Sun has a second and a third go-around at heating the surface. And this multiple go-around process of "Back Radiation" has the peculiarity that it is from the cooler atmosphere acting upon the warmer surface, given that general relationship. On the other hand, the alternative *thermodynamic* global energy budget presented in this paper would require only a unidirectional flow of heat down the temperature gradients, which is consistent with thermodynamic physics. That is, incoming sunshine of high intensity flux is capable of directly producing climatological effects as a response to heat flow from the Sun, and this flow should step down in intensity as heat flows down temperature gradients through the system as manifest climate, without requiring reversibility of heat flow.

At this point we have sufficient preliminary analysis to tabulate a list of basic differences between the standard global energy budget and the alternative one presented in this paper. See Table 1.

Table 1: Comparison of the standard global energy budget to that of the alternative thermodynamic energy budget presented in this paper

Global Energy Budget	Standard Model	Thermodynamic Model
Solar Input Geometry:	Evenly over entire spherical surface represented as a flat plane	Over single hemisphere as a function of solar zenith angle
Heat Flow:	Reversible/recyclable	Unidirectional
Climate:	As a secondary consequence of heat recycling	As a direct consequence of solar heat flow
Solar flux:	Insufficient to create a climate without heat recycling	Sufficient to create a climate directly
Empirically:	Fictional	Observable
Thermodynamically:	Inconsistent with Theory	Consistent with Theory

As one can see from Table 1, although the standard model and the thermodynamic model in this paper both conserve total energy to the outside of the system, they are mutually exclusive at the boundary of the system itself. The input and output of equal total energies occur over different surface areas, and this difference has an effect upon the intensity (flux) and thus the heating potential of sunlight mathematically depicted in such models. That is: does the Sun largely have no direct influence upon generating the climate (with a feeble -40C heating input), or, is the climate the result of solar heat flow?

What makes for a better pedagogical model for understanding the basic features and origin of Earth’s climate and temperatures actually experienced? In the thermodynamic model presented in Figure 4 with sunlight falling upon the Earth in a realistic fashion, one would immediately identify that the climate is the result of solar heat flow through the troposphere. That is, without going into the details of the internal minutia, one can at least identify the high-temperature heating potential of sunlight and conclude that the climate must be the result of solar heat transfer through the troposphere and surface, with heat flowing down temperature gradients as we are directed to abide by fundamental thermodynamic principles. On the other hand, with the traditional energy budget, one cannot cursorily examine it and be led to the idea that the solar input is responsible for creating the climate; rather, it becomes apparent that the climate is largely the result of a fashion of heat recycling of a feeble solar input amplified into a more intense flux of “Back Radiation”.

Thus, we have mutually exclusive statements about the nature of reality, from two models which seemingly should both satisfactorily represent reality. The existing model is presumably a good representation of reality given that it is peer-reviewed and it is widely cited in climate research, while the alternative thermodynamic model makes for a good representation of reality because it represents the Earth and energy flow into it as it physically empirically exists and is consistent with thermodynamic theory, etc. However, both models cannot both be correct, given that they indicate mutually-exclusive processes. The existing model has utility in simplicity, and approximation is the pabulum of mathematical physics, but perhaps there is a transition point at which quantitative approximation divorces from qualitive similarity. At the expense of an only slightly more complex diagram, but still well within the grasp of undergraduate sciences, the Earth and energy flow into it can be presented in a quantitatively and qualitatively realistic fashion.

Another valuable feature of the new model is that it incorporates a demonstration of the adiabatic temperature gradient, whereas the traditional pedagogical depiction does not incorporate this fundamental property of any gaseous atmosphere situated within a central gravitational field. That is, the adiabatic thermodynamics establishes a distribution of temperature in the atmosphere of warmest at the bottom, and coolest at the top (in the troposphere that is, where ideal gas laws apply), and thus given the mathematical definition of an average, one acknowledges that the average state of the atmosphere cannot be found at an extremity of its distribution. This subsequently has relevance to the average or effective radiative temperature of the Earth as a whole thermodynamic ensemble, which is also depicted, and demonstrates the thermodynamic difference in the intensity of the quantitative radiant flux between solar input and terrestrial output.

3 CONCLUSION

An alternative global mean energy budget based upon thermodynamic and empirical facts was presented which depicts the energy flow into the Earth system from the Sun in a realistic fashion. This led to differences from the common mean global energy budget which are mutually exclusive in nature, which indicate that the traditional depiction is inconsistent with empirical and thermodynamic facts. Given the natural and demonstrated translation between pedagogy and research output, it is thus relevant, valuable, and scientific, to value such differences and the exploration of them, founded as they are in both empirical and thermodynamic fact.

4 Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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