

A Discrepancy in the Interpretation and Use of Radiative Forcing

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Abstract

The radiative forcing (RF) concept is defined in the Intergovernmental Panel for Climate Change (IPCC) reports as “a net change in the energy balance of the Earth system due to some imposed climate perturbations, relative to 1750.” For convenience, the energy is expressed in watts per square meter of Earth’s surface area, averaged over a particular period of time. However, this definition and usage of RF does not appear to be universally adhered to. Climate literature often overlooks IPCC definition and treats RF as an instantaneous power supply instead of energy. This causes a substantial apparent energy surplus in the climate system and creates a need to explain how this energy is accommodated by the Earth. In this work, the IPCC definition of radiative forcing is revisited and compared with the present definition and usage of the concept by climatologists and artificial-intelligence systems, and a discrepancy in the interpretation and usage of the concept appears to exist. Radiative Forcing is found to be overwhelmingly considered an instantaneous power supply of solar heat flux, rather than energy exchanged with climate as initially intended. This apparently inadvertent evolution of the concept transfers more theoretical heat than actual to the climate, which has profound implications for the state of climate reports, climate policy decisions, and society as a whole. It is therefore the objective of this manuscript to highlight the discrepancy in the interpretation of radiative forcing.

Keywords: IPCC Reports; Ocean Heat Content; Radiative Forcing; Theoretical Model

Significance statement

This paper suggests that the interpretation of the radiative forcing concept may have inadvertently evolved, from energy exchange over a period of time into an instantaneous power supply of solar heat to the climate system. This may have serious implications at the societal, scientific, and policy decision making levels, as it suggests a greater theoretical heat surplus in

the climate system than actually exists, potentially masking the real causes of climate severity.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2013), Section 8.1, defines Radiative Forcing (RF) as *"the net change in the energy balance of the Earth system due to some imposed perturbation, relative to 1750, usually expressed in watts per square meter averaged over a particular period of time and quantifies the energy imbalance that occurs when the imposed change takes place."* Similarly, Chapter 7, Section 7.3 and Box 7.1 of the IPCC Sixth Assessment Report, Foster et al. (2021), quantifies the effective radiative forcing (ERF) as *"the energy gained or lost by the Earth system following an imposed perturbation, ERF is the top of the atmosphere (TOA) energy budget change resulting from the perturbation."*

Energy is "static," measured in joules (J), and power is a "dynamic" flux, measured in watts (J s^{-1}), where, s, is the time in seconds. Although, it may be confusing to express RF energy in watts, it is technically acceptable as long as a period of forcing time is specified. The period of time is treated as an active mathematical modifier, embedding duration into the core parameter, and the structural definition shifts from an instantaneous power state into a cumulative measure of net energy exchanged over that period. Watt-hours are examples that provide a practical way to express the product of power and time as energy.

If, however, the period of time is inadvertently forgotten, radiative forcing expressed in watts per square meter (W m^{-2}) becomes a dynamic flux of solar energy, a power term, and a considerable theoretical heat surplus is introduced into the climate system.

Many climatologists interpret radiative forcing as a power term, for example Kleidon et al. (2023). The Editorial Board that published this paper compares radiative forcing 2.7 W m^{-2} with global energy consumption of 0.04 W m^{-2} in 2021 by dividing the energy consumption for 2021 ($5.95 \times 10^{20} \text{ J}$) by the total surface area of the Earth and the number of seconds in one year. Clearly, the Editorial Board interprets radiative forcing as an instantaneous power supply term. In addition, artificial-intelligence systems have been asked whether radiative forcing, used in the climate literature, is a power term or an energy term, and the answer was generally that it is a power term. The models included ChatGPT, Gemini, and Ask AI.

This manuscript evaluates the current interpretation and usage of radiative forcing in relation to its original conceptual definition by IPCC and its implications for the energy budget and the state of climate change.

2. Background information

A good description of the radiative forcing concept is presented in Chapter 8 of IPCC (2013). It represents energy exchanged with the climate resulting from an energy imbalance at the top of the atmosphere due to variations in greenhouse gases. The climate radiation balance can be reduced to a simple equation correlating radiative forcing with global mean surface temperature, $dT = \lambda \text{ RF}$, where dT is variation in global mean surface temperature and λ is the climate sensitivity. If greenhouse gas concentrations increase with time, the resulting rise in radiative forcing, RF, may be determined, thus allowing the calculation of surface temperature

rise and the Earth's energy budget. Most of the heat imbalance accumulates in the ocean surface and contributes to the melting of glaciers. Clearly, the interpretation of radiative forcing is fundamental to understanding the magnitude of climate change and its evolution with time.

For example, based on (IPCC, 2013), Chapter 8, Section 8.5.2: Quote" the anthropogenic forcing over the period 1951–2011 is more than 1.5 W m^{-2} . The language clearly indicates that radiative forcing is a time integrated quantity. However, and for nearly the same period of time, 1955–2010, Levitus et al. (2012) shows an increase in the ocean heat content by 0.27 W m^{-2} , which is a lot smaller than IPCC radiative forcing. The paper, Levitus et al. (2012), is cited in Chapter 3, Box 3.1, of IPCC (2013), and the increase in ocean heat content, or energy imbalance, is referred to by IPCC as heating rate instead of radiative forcing. Clearly, there is a distinction in IPCC language between radiative forcing and power supply. The power supply obtained by Levitus et al. (2012), 0.27 W m^{-2} , is a lot less than that used by Kleidon et al. (2023), 2.70 W m^{-2} , which raises a question about the inconsistency of RF value used by climatologists.

Furthermore, should IPCC radiative forcing data be extended to 2000, then between 1950 and 2000, the radiative forcing was nearly 1.77 W m^{-2} . Assuming the IPCC's original definition of radiative forcing is adhered to, the ocean heat content would increase by nearly 28.40 ZJ (one zeta joule, $1 \text{ ZJ} = 1.0 \times 10^{21} \text{ J}$). However, Gulev et al. (2021) show that ocean heat content increased by nearly 400 ZJ during that period. And between 2000 and 2020, the increase was nearly 250 ZJ. This is, of course, an incredibly large amount of heat introduced into the ocean that must be balanced by an equally large radiative forcing.

This work examines potential discrepancy between the IPCC definition of radiative forcing and deviations in its usage from that definition. The manuscript includes theory, sample calculations, and discussion and conclusion.

3. Theory and analysis

From Chapter 8 (IPCC, 2013), Sections 8.1 and 8.1.1: Quote "*Radiative Forcing, RF, is the net change in the energy balance of the Earth system due to some imposed perturbation, relative to 1750. It is usually expressed in watts per square meter averaged over a particular period of time and quantifies the energy imbalance that occurs when the imposed change takes place.*"

Chapter 7, Section 7.3 and Box 7.1 of the IPCC Sixth Assessment Report, Foster et al. (2021), are quoted as follows: "*Effective radiative forcing (ERF) quantifies the energy gained or lost by the Earth system following an imposed perturbation (for instance in GHG's, aerosols or solar irradiance). As such it is a fundamental driver of changes in the Earth's top of the atmosphere (TOA) energy budget. ERF is the TOA energy budget change resulting from the perturbation.*"

Based on these IPCC definitions, radiative forcing as energy budget represents the net (cumulative) energy imbalance at the top of the atmosphere, measured in joules (J) for an arbitrary period of time t . If the energy budget is the function $E(t)$ with time, then $\Delta E(t)$ is the net energy budget in joules over a particular period of time. By definition, this net energy imbalance is equal to zero in 1750. Assume this year, 1750, to be equal to the zero reference time t , then $E(t)$ is a curve in the energy (E)-time (t) plane that intersects $t=0$. The time, t , will be assumed to measure the number of years from the referenced 1750.

By definition, the radiative forcing, RF, mathematical expression follows:

$$RF(J)=\Delta E(t)=\int dE(t)/dt \times dt \quad (1)$$

Where RF is the radiative forcing measured in joules and, t, is the time in years. The energy flux $dE(t)/dt$ is in $J \text{ year}^{-1}$. For consistency with IPCC definition and methodology, RF will be expressed in $W \text{ m}^{-2}$

$$RF(W \text{ m}^{-2})=(1/AT) \int dE(t)/dt \times dt \quad (2)$$

Where, A and T are the surface area of the earth and time in one year, measured in m^2 and seconds, respectively.

The shape of $E(t)$ with time is generally a curve, but mostly linear, especially in the early years of greenhouse gas emissions. For simplicity, linearity will be examined. Equation (2) gives

$$RF(W \text{ m}^{-2})=(1/AT) \text{Tang}(\alpha) \times t=(1/AT) E(t)/t \times t=E(t)/(AT) \quad (3)$$

Where $\text{Tang}(\alpha)$ is the slope of the energy line that passes through the origin at $t=0$.

4. Sample calculations

Between 1950 and 2000, radiative forcing increased by nearly 1.77 W m^{-2} as discussed in the background section. Using Eq. (3), the following applies for that period of time

$$E(t)=RF(W \text{ m}^{-2}) \times (AT) \quad (4)$$

$$E(1950-2000)=1.77 \text{ AT}=1.77 \times 5.1 \times 10^{14} \times 3.15 \times 10^7=2.84 \times 10^{22} \text{ J (28.4 ZJ).}$$

$$(1 \text{ ZJ}=1.0 \times 10^{21} \text{ J})$$

The Executive Summary of chapter 7 of the IPCC's Sixth Assessment Report (AR6), Forster et al. (2021), concluded that the anthropogenic radiative forcing between 1750 and 2019 was $2.72 [1.96 \text{ to } 3.48] \text{ W m}^{-2}$. Using Eq. (4), the corresponding cumulative energy transferred to the Earth's surface through 2019 follows:

$$E(2019)=2.72 \times 5.1 \times 10^{14} \times 3.15 \times 10^7=3.37 \times 10^{22} \text{ J (43.7 ZJ).}$$

Surface temperature rise may be calculated by using Eq. 17 of Swedan (2023), quoted as follows:

$$dT_S = (dQ_S/2) \times W_S / (\Gamma \times C_{PA}) \quad (5)$$

Where

dT_S =Sea surface temperature rise, °C.

dQ_S =Heat transferred to the surface of the Earth, J.

W_S =Air humidity at saturation with sea water, $0.012 \text{ kg water per kg dry air}$, dimensionless.

C_{PA} =Specific heat of air, $1000 \text{ J kg}^{-1} \text{ }^\circ\text{C}^{-1}$.

Γ =Annual precipitation, $4.86 \times 10^{17} \text{ kg yr}^{-1}$."

Using this equation, Eq. (5), and 28.4 ZJ of heat to the Earth's surface, sea surface temperature rise between 1950 and 2000 is nearly $0.35 \text{ }^\circ\text{C}$, which agrees with observations.

However, the theoretical heat, 400 ZJ , to the ocean between 1950 and 2000 discussed in the background section, would increase surface temperature by $4.94 \text{ }^\circ\text{C}$, which is not observed. Similarly, 250 ZJ to the ocean between 2000 and 2020 would raise surface temperature by $3.09 \text{ }^\circ\text{C}$. The temperature of the entire surface ocean mixed layer would increase by at least 1.41 and $0.88 \text{ }^\circ\text{C}$, respectively. None of these surface temperature increases have been observed.

According to Kleidon et al. (2023), radiative forcing is a power term having a present value of 2.7 W m^{-2} . Therefore, the annual energy supply is nearly $4.34 \times 10^{22} \text{ J}$. This would raise the

temperatures of the entire surface ocean mixed layer and sea surface by at least 0.15 °C and 0.54 °C, respectively, every year, which are not observed.

5. Discussion and conclusions

This manuscript focuses specifically on the interpretation and use of the radiative forcing concept and its implications for energy accounting in the climate system. It is intended to interpret this concept in accordance with its definition by the IPCC. Radiative forcing interpretation or application in any way does not affect thermodynamic approaches to climate processes; these approaches are independent of the concept of radiative forcing.

Heat transferred to the Earth's surface by radiative forcing remains at the surface because there are virtually no viable heat-transfer phenomena to remove the heat or a substantial part of it. Seawater thermal conductivity is too small, and heat conduction from the surface ocean mixed layer into the deeper ocean below is negligible. It would take thousands of years for even a relatively minuscule amount of heat to be transferred from the surface to the deep ocean. The source of the observed warming of the abyssal brine adhering to the ocean floor (Purkey and Johnson, 2010) is Earth's internal heat. Because the flow of this abyssal brine is decreasing with time (Srokosz and Bryden, 2015; Swedan, 2020), its temperature is increasing in order to remove the same amount of Earth's internal heat.

Any radiative-forcing heat at Earth's surface cannot be removed by surface evaporation to balance the energy budget because surface evaporation is constant. It is dictated by astronomical parameters that do not change with climate. The same applies for radiative-forcing heat radiation. Any heat cannot be radiated to outer space either, as doing so would inherently imply the application of the Stefan-Boltzmann equation twice—once to calculate the downward greenhouse forcing, and a second time to handle the surface response, which would represent a violation of thermodynamic independence.

The thermohaline circulation cannot convect heat accumulated in the Earth's surface into the deep ocean. At the surface, the thermohaline brine must cool to a temperature equal to or lower than that of the deep ocean so that it can sink by gravity, typically at high latitudes. Therefore, no surface heat can be removed by thermohaline circulation mixing. The same is true for wind and tidal forces.

In short, climate heat exchanged with the Earth's surface remains at the surface. It can only melt glaciers and raise surface water temperature. A supply of 400 ZJ from greenhouse gases between 1950 and 2000 would have, therefore, raised the surface temperature by 4.94 °C, which is not observed in the record. This substantial theoretical amount of heat can only be explained or balanced by treating radiative forcing as an energy flux, or power supply, rather than as a static energy term. However, should radiative forcing be interpreted as energy in accordance with IPCC definition, the heat to the ocean would be nearly 28.4 ZJ instead, and surface temperature rise approaches 0.35 °C, which is in agreement with observations. This raises questions such as the validity of energy conservation and whether IPCC's initial interpretation of radiative forcing has inadvertently drifted over the years, from a static energy term for a given period of time to an instantaneous flux of power supply.

As shown in the sample calculations, the calculated total energy accumulation at the surface between 1750 and 2019 using IPCC definition of radiative forcing is 3.37×10^{22} J (43.7 ZJ),

which is nearly equal to energy consumption by humanity during the industrial years (Swedan, 2023). This energy consumption is ultimately discharged as waste heat to the surroundings. Therefore, radiative forcing, interpreted as defined by IPCC, and anthropogenic waste heat are nearly equal. Bian (2020) reveals that anthropogenic waste heat is the dominating root cause of the current global warming, which is generally in agreement with Swedan (2023).

Using radiative forcing as a power supply on the other hand induces a substantial theoretical heat surplus that cannot be balanced or accommodated in the Earth system. This may require the introduction of unproven scientific theories and heat-transfer processes that overshadow the quest to identify the real causes of surface warming, climatic extremes, and how to mitigate them. The adverse impact of using incorrect interpretation of radiative forcing goes well beyond its scientific implications and extends into the economy and society. Climate-related policies, as well as societal fear and anxiety, are some of the outcomes of inadvertent massive theoretical heat storage in the climate system.

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The Author acknowledges that this manuscript is entirely authentic and genuine and the entire work has been prepared by the author. This manuscript is not currently being considered for publication by other journals. No data has been fabricated or manipulated. All data are accessible online using the links provided in the references section. Furthermore, the Author has no conflict of interest as a result of this publication. This publication is funded by the Author.

7. Data availability

No new data. The data is readily available online by the links provided under references.

8. Competing Interest

The author declares no competing interests with respect to the research, authorship, and publication of this manuscript.

9. Author contribution

The author, Nabil Swedan, prepared the entire text.

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