



Global Warming Thermodynamics

—Thermodynamic Simulation and Analysis of Global Warming Indicators

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Abstract

Historical data since 1880 shows that no correlation exists between air temperature anomalies and atmospheric CO₂ concentrations. However, that strong pseudo-correlation from 1965 does exist implies that there could be a strong correlation between the warming and waste heat because the latter and CO₂ are concurrent by-products of fossil fuel combustion. Global warming is a basic thermodynamic problem driven by huge amount of waste heat from human activities that is about 80% of globally consumed energy. This article presents a climate change thermodynamic model of a quaternary system consisting of air, land, oceans, and ices to investigate the warming phenomena through a thermodynamic approach. Unique, definitive relationships exist between warming or sea level rise and the amount of waste heat allocated to each of the components according to their respective specific heat capacities. Simulation results of past temperature changes in air, land, and seawaters as well as sea level rise are very well consistent with observed anomalies and sea level rise measurements. The results suggest that waste heat dominates global warming. This approach can also be used to forecast future warming. Additionally, the climate system experienced a transition from a cold to a warm era around 1980, before that time the system was “heat” hungry. Reducing thermal emissions, increasing energy conversion efficiency, and recovering and reusing waste heat are important measures to effectively mitigate climate change.

Subject Areas

Atmospheric Sciences

Keywords

Climate Change Thermodynamic Model, Global Warming, Ice Melting, Sea Level Rise, Simulations, Temperature Changes, Waste Heat

1. Introduction

Global warming, or climate change, and extreme weather events threaten sustainability. They occur more evidently at accelerated rates recently, and our knowledge about them is still very limited.

1.1. GHG-Based Theory Unable to Well Explain Global Warming/Climate Change

It is stated that about 90 percent of the infrared heat reflected upwards by the earth's surface after absorbing sunlight is then absorbed by atmospheric greenhouse gases (GHGs) and radiated back to the earth's surface [1]. This is referred to as "heat trapping" or greenhouse effect. Human activities have increased atmospheric GHGs by over 48% since industrialization, which is believed to expand the greenhouse effect. It is also stated that "there's a better than 95 percent probability that human-produced greenhouse gases such as carbon dioxide, methane and nitrous oxide have caused much of the observed increase in Earth's temperatures over the past 50-plus years" [1]. From these, it seems that GHGs are the culprit and solar energy is the only energy source that GHGs trap and reflect back to the earth's surface in the form of infrared radiation, leading to the warming, but neglects the fact that waste heat (including residual heat) enters the environment from human activities in the context.

Although the mainstream perceives that GHGs should be held accountable for the warming based on the assumption that they form a "blanket" covering the earth, exerting greenhouse effect and preventing heat radiations from escaping to outer space, thus triggering global warming, this doesn't seem to be supported by the facts: 1) GHGs only share about 0.04%, a very trace amount, in the atmosphere; 2) GHGs have different specific gravities (air = 1, CO₂ = 1.5189, CH₄ = 0.5537, N₂O = 1.530, O₂ = 1.1044 [2]), randomly distribute in the atmosphere spatially with CO₂ and N₂O mostly staying at the ground level, meaning that they cannot form a "blanket" at a certain level with such a trace quantity; 3) absorbing and reflecting infrared radiations and other wavelengths of light are not the unique characteristics of GHGs, everything with absolute temperature over zero degree can absorb and emit radiations at certain wavelengths. Therefore, other compositions in the atmosphere can also absorb and reflect radiations. Additionally, GHGs should also absorb certain wavelengths of solar radiations. They then emit and reflect radiations equally upwards and downwards because of their statistically symmetrical distribution in the atmosphere, thus the solar energy reaching the earth's surface should be reduced after GHGs absorb its infrared, causing a cooling effect eventually, if the theory were valid *i.e.*, GHGs trap and reflect heat.

Further, if GHGs were responsible for the warming, they would articulate quantitatively the warmth in surface air, in land surface and sea surface as well as the sea level rise, *i.e.*, a unique relation Δt_{gw} (or ΔL_s) = $f(C_{ghg})$ could exist between the atmospheric GHG concentration (C_{ghg}) and the global (air, land, ocean)

warming (Δt_{gw}) as well as sea level rise (ΔL_s). However, the fact is that no single model can well simulate the air temperature changes, thus assembling all “satisfactory” models’ simulations together, and taking their mean become an approach, although such an approach doesn’t make common scientific sense (because if variables x and y correlate, theoretically only one relationship $y = f(x)$ exists), the simulated results still cannot align well with the observations (refer to Figure 9.8 in Reference [3]). Quantitatively explaining the temperature changes in land surface and sea surface as well as sea level rise faces more challenges.

On the other hand, exploring the relation between CO₂ concentration and the surface air temperature anomalies finds that no correlation exists based on the datasets from [4] [5] as shown in **Figure 1**, which exhibits the CO₂ concentration (in ppm) and annual mean air temperature anomalies from 1880 to 2011.

The time span between 1880 and 2011 can be divided into four periods according to the changes in annual mean anomalies: 1) 1880-1909 anomalies decreasing period; 2) 1910-1944 anomalies slight increasing period, 3) 1945-1964 anomalies very slow increasing period and 4) 1965-2011 anomalies rapid increasing period as shown in the embed small figures on top of **Figure 1**. Clearly, the air temperature anomalies and atmospheric CO₂ concentration don’t correlate. However, a strong pseudo-relation does exist in the last period since 1965. This finding is similar to Gosselin’s analysis [6]. Therefore, it is unlikely that there is a single cause-effect between CO₂ (also GHGs) and the global warming, and even just from the pseudo-relation during the last period since 1965 to draw that CO₂ has incurred the warming is farfetched because CO₂ is a concurrent by-product with waste heat from the increased fossil fuel combustions. Adversely, CO₂ and waste heat should correlate well (their relationship will be explored later). The strong pseudo-relation between annual mean anomalies and CO₂ since 1965 implies that waste heat may correlate to the air anomalies and may be the real contributor to the temperature changes, or the global warming.

The GHG-based climate change theory has been facing strong challenges, although a large number of models have been developed.

In addition, water vapor is a far more concentrated gas than GHGs in the atmosphere, it retains or traps much more heat than GHGs due to its greater specific heat capacity (SHC). Water on the earth and its vapor in the atmosphere largely regulate the temperature of the environment we live in.

The climate system consists of four components: air, land, oceans, and ice. In the previous study [7] [8], though sea ices are taken into consideration by retrieving their melted quantity from reported sea level rise, it is better to accurately contemplate sea level rise reversely from ice melting.

Global warming is a basic thermodynamic phenomenon. Waste heat from human activities can induce direct warming and ice melting. There should be unique determinative relations between the waste heat and the warming in the air, land, oceans, and ices melting as well as the sea level rise.

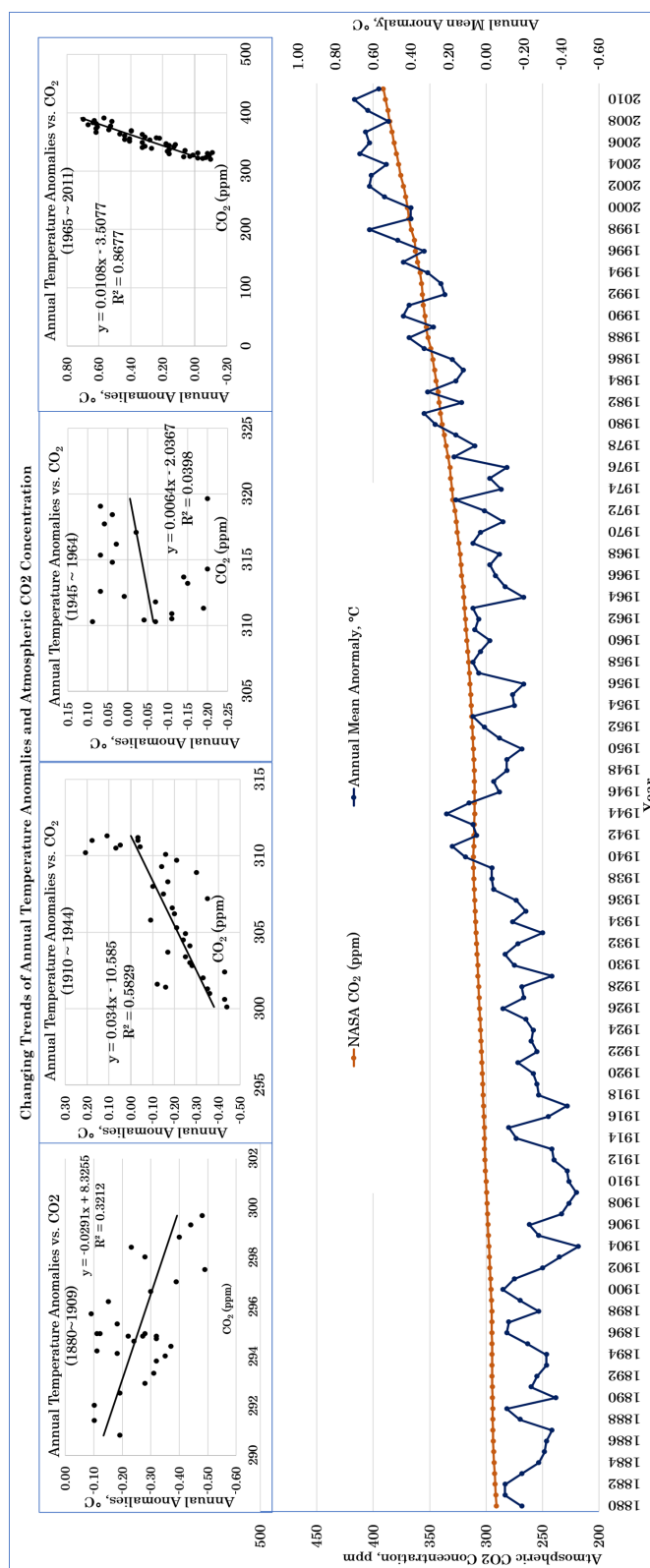


Figure 1. Changes of CO₂ concentrations [4] and annual surface air temperature anomalies (*i.e.*, land-ocean) [5] from 1880 to 2011. In different periods, their correlations are shown in the top small embed figures from which it is clear that no definitive correlation exists. In the early three periods, correlations are very weak, while from 1965 the correlation is strong.

1.2. Energy Conservation and Waste Heat from Human Activities

According to the Law of Conservation of Energy or the First Law of Thermodynamics, energy can be transformed from one form to another or others (e.g., coal through combustion to heat, electricity, and chemical energy contained in new products), but cannot be created nor destroyed. It is obvious that while being used, part of the energy is inevitably transformed into a non-useful form as residual or waste energy that dissipates into the environment.

Usually, we only consider how and how much energy is used, but are less concerned about where the energy goes eventually. In fact, in every energy application, it experiences a form transformation: from one form to another or others. For example, when burning coal to boil water, the energy released from combusting coal is converted to: 1) heat energy that heats up and boils the water, 2) heat energy that heats up the boiler case that eventually escapes into the environment and 3) the energy that disperses into the environment along with flue gas and water vapor. Among these three parts, the last two are obviously a kind of waste heat (or waste energy) that is useless. Even for the first part, the heat energy retained in the hot water is eventually released into the environment too as residual heat, whether it is used for heating or for drinking. Thus, all these three parts enter the climate system, and are referred to as waste heat.

Similarity exists in burning natural gas in the furnace, running air conditioners, cooking/baking, etc. in residential and commercial sectors from which the amount of waste heat is almost the same as the amount of energy consumed [7] [8].

In transportation, only a small part of consumed energy is used to move loads and vehicles themselves for useful work, whereas the rest is dispersed into environment through friction (which is then converted to heat) and sensible waste heat from radiator, hot hood, and tail gas, etc. It's estimated that about 75% of the used fossil fuel energy in transportation is dispersed into the environment as waste heat [7] [8].

In industries, the energy consumed is converted to several forms such as electricity, chemical energy retained in products and heat in addition to waste heat.

The widely used concept of energy efficiency cannot tell exactly how much energy is ultimately converted to useful work or retained in products, it only indicates how much of the input energy can be produced out during a process. For example, when boiling drinking water using a modern kettle with an efficiency of 90% (obviously it is very efficient), 90% of the consumed energy is used to heat the water. However, it is unclear how much energy will be still contained in the boiled water at its final state. Few people realize that almost all of this very 90% of the consumed energy is also released into the environment eventually, in addition to the 10% already entered the environment even during the boiling process. Cooking is another similar example. Thus, a new concept to describe how much of the consumed energy is really converted to useful work or energy retained in products is necessary, which is referred to as energy's effective con-

version efficiency (EECE) [7] [8]. It is the EECE that can clearly tell how much consumed energy is dissipated to the environment during a process.

As analyses shown in [7] [8], in the residential and commercial sectors, almost all the energy consumed is eventually dissipated into the environment. In transportation, only about 25% of the consumed fossil fuels is converted to useful work by considering the different levels of technologies across the world, and the rest, *i.e.*, 75%, is wasted into the environment through friction and sensible heat. In industries, it is assumed that the entire EECE is about 30% across all sectors.

According to BP [9], industries consume about 51% of the global energy, residential and commercial 29% and transport 20% (these shares may vary from time to time, but the variance should be reasonably small). Thus, it is estimated that the global EECE is about 20%, which means about 80% of the energy consumed globally enters the environment as waste heat [7] [8]. This is reasonable if considering the different technology levels in the world, and even in the USA with the most advanced technologies, the waste heat is reported to be about 67% of the consumed energy because of the inefficiencies in energy application processes, equipment [10].

BP has adjusted its estimate of a standard power plant's thermal efficiency from 36% in 2000 to 40.4% in 2019 [11] [12] in the last two decades, while remaining 36% for the period of 1965-2000, to reflect the technology advancements. Nevertheless, from the perspective of global energy application, this adjustment would not affect much on the global EECE since the basics of the energy application processes have not been changed radically. Therefore, assume the EECE is 20%, although during earlier years (say, 1965 to 1979, only after that point climate change has become more recognized) a lower EECE might exist because of less advanced technologies, especially in developing countries.

Besides, countless flaring and spontaneous firing of surface coal and methane from the natural reservoirs, volcanic eruptions, forestry wildfires and various chemical fuel applications (such as space explorations, military activities, etc.) also send a huge amount of heat to the climate system, contributing to the global warming.

2. Climate Change Thermodynamics

The climate system consists of land, oceans, air, and ices. It receives energy from sun, interior earth, and moon, etc. to sustain the earth environment human lives in. The energy reaching the earth surface retains at a dynamic energy budget balance as expressed below, which provides enough energy for the entire system.

$$E_{\text{in-net}} = E_{\text{air}} + E_{\text{water}} + E_{\text{land}} + E_{\text{bio}} + E_{\text{consum}} \quad (1)$$

where,

$E_{\text{in-net}}$ is the net energy reaching the earth surface from sun (*i.e.*, solar energy), interior earth and moon (*i.e.*, tidal energy) (energies from other celestial bodies can be ignored). Generally, it's considered that solar energy reaching the earth

surface is quite stable although a small temperature change of about 0.05°C - 0.1°C has been detected due to the variance in total solar irradiance during the 11-year solar cycle [13] [14], while the energy from moon is less studied and very limitedly known, compared to the solar one, but consideredly remains stable in the past long history.

E_{air} is the energy absorbed by and stored in air;

E_{water} is the energy absorbed by and stored in waters including ices;

E_{land} is the energy absorbed by and stored in land;

E_{bio} is the bioenergy *i.e.*, energy absorbed by and stored in plants or biomass as a result of photosynthesis;

E_{consum} is the energy consumed by humans and animals, including the solar energy collected through photovoltaic process, etc.

As described in [8], it is this dynamic energy budget balance that enabled the climate system to maintain the temperatures of air, land, and seawaters relatively stable over a long period. Any extra energy entered the system from human activities such as combusting fossil fuels, using geothermal or nuclear energy will certainly shift the above energy budget balance to the right side, making the air, land, and seawaters warmer, and thawing ices. Deforestation decreases E_{bio} converted from solar energy, thus the corresponding excessive energy contributes to the warming. However, details on deforestation's effect need further studies. It also needs attention that combusting biomass releases long-term accumulated energy back to the system concentratedly, breaking the local energy budget balance, and thus contributing to the warming.

Global warming is a basic thermodynamic problem. Warming a house by using heat energy not only warms the air in the house, but also the waters in containers, the floor, and walls, etc. Similarly, the globe warms from the surface level, *i.e.*, at surface air, land surface, seawaters surface, and ices. As indicated in the earlier articles [7] [8], the huge amount of waste heat entered the climate system induces the warming, following the thermodynamic laws.

As well known, heat always rises along with the air. In the climate system heat extends towards the poles along with the vortex of air that forms around the earth surface as the earth rotates. This attracts much heat energy to the polar areas, especially the North since the north hemisphere is much more populated, more energy consumed, and consequently more waste heat dissipated than in the South. This may help understand why the "Arctic Amplification" [15], *i.e.* the evident Arctic warming happens in the last decades, where more glaciers, ice sheets and covers melt, permafrost thaws and increasing heat waves than ever before, as Walsh said "The Arctic has been warming twice as fast as the rest of the world. In some seasons, it has warmed three times faster than the rest of the globe [16].

2.1. Equivalent Climate Change Model

Equivalent Climate Change Model (ECCM) has been developed to explain the

warming phenomena, consisting of respective equivalent climate change boundary layers to simulate temperature changes in surface air, land surface, and seawaters surface [7] [8]. The results show that the simulated temperature changes are well consistent with those observed anomalies in air, land, and oceans, respectively. However, ice melting was not considered in the same way, instead, it was considered through the observed sea level rise based on NASA's assumption that one-third of the rise is from sea water warming and two-thirds are from ice melting [15] [17]. In fact, this is not an appropriate approach and cannot fully explain how ices respond to human activities and how ices melt and contribute to sea level rise.

2.2. Climate Change Thermodynamic Model

In the present study, melting of both ices (glaciers, icebergs, and ice shelves) and sea ices (*i.e.*, ice sheets and covers) is considered thermodynamically based on the SHC and latent heat of fusion. Incorporating this into the existing ECCM [7] [8] constitutes a new climate change thermodynamic model (CCTM) that includes a thermodynamically equivalent climate change surface air layer (or column), a thermodynamically equivalent climate change land surface layer, a thermodynamically equivalent climate change seawaters surface layer, and the melting of glaciers and sea ices. They absorb the waste heat from human activities according to their respective SHC.

The temperature change in surface air:

$$\Delta t_a = \frac{3\Delta H_a}{4\pi[(R_0 + h)^3 - R_0^3] \cdot \rho_a \cdot C_{pa}} \quad (2)$$

The temperature change in land surface:

$$\Delta t_l = \frac{\Delta H_l}{S_l D_l \rho_l C_{pl}} \quad (3)$$

The temperature change in seawaters surface:

$$\Delta t_w = \frac{\Delta H_w}{S_w D_w \rho_w C_{pw}} \quad (4)$$

The amount of sea ices melted due to the absorbed heat:

$$M_{si} = \frac{\Delta H_{si}}{L_{psi}} \quad (5)$$

The amount of glaciers melted due to the absorbed heat:

$$M_{gl} = \frac{\Delta H_{gl}}{L_{pgl}} \quad (6)$$

where,

- R_0 Earth radius, 6371 km
- h The depth of the surface air layer in atmosphere from the earth surface
- S_w Seawaters surface area, 361,800,000 km²

D_w	The depth of the seawaters surface layer
ρ_a	Air density under normal pressure
C_{pa}	Air SHC under normal pressure, or the isobaric heat capacity
ΔH_a	The heat absorbed in the surface air layer corresponding to the temperature change Δt_a
Δt_a	The temperature change in the surface air layer after experiencing heat change ΔH_a
ρ_w	The seawaters density
ΔH_w	The heat change in seawaters surface layer corresponding to the temperature change Δt_w
Δt_w	The temperature change in the seawaters surface layer after experiencing heat change ΔH_w
C_{pw}	Seawaters SHC under normal pressure
ρ_l	The land (soil) density
ΔH_l	The heat change in land surface layer corresponding to the temperature change Δt_l
Δt_l	The temperature change in the land surface layer after experiencing heat change ΔH_l
C_{pl}	Land (soil) SHC under normal pressure
S_l	Land area on the earth surface
D_l	Depth of land surface layer
M_{gl}	Annal amount of melted glaciers (<i>i.e.</i> , pure ice)
C_{pgl}	Glaciers (<i>i.e.</i> , pure ice) SHC under normal pressure, $2.11 \text{ kJ}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$
L_{pgl}	Glaciers (<i>i.e.</i> , pure ice) latent heat of fusion at constant pressure, $333.4 \text{ KJ}\cdot\text{Kg}^{-1}$
M_{si}	Annual amount of melted sea ices
ΔH_{si}	Annual heat amount absorbed by melted sea ices
C_{psi}	Sea ices effective SHC
L_{psi}	Effective latent heat of fusion of sea ices at constant pressure.

Glaciers, including icebergs and ice shelves floating on oceans but originated on land [18], and the landfast ice, formed from pure water, melt at zero degree Celsius (0°C), have a SHC of $2.11 \text{ kJ}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$ and latent heat of fusion of $333.4 \text{ KJ}\cdot\text{Kg}^{-1}$ [19].

2.3. Methods

As described in [7] [8], the feature of this study is using SHC to allocate heat entered the climate system from human activities to the components: air, land, oceans, sea ices and glaciers.

Sea ices (including ice sheets and covers) behave very differently than pure ice because they contain brine and salts. They melt at different temperatures than they form. Seawaters freeze at about -2.0°C [20] - -1.8°C [21] to form sea ices due to the salinity. The resulting ices trap brine that either precipitates or drains out of the ice crystal lattice [22], forming brine pockets and eventually flowing

into the oceans again. As a result, the bulk salinity in sea ices is much lower than that in seawaters (34 - 35 parts per thousand, *i.e.*, ppts). For old and matured sea ices it is estimated the salinity ranges from 4 to 12 ppts (4 ppts is widely used for bulk sea ices) although some have lower or greater values, while for new ices or those at the bottom of ice sheets (or covers) the salinity may be greater, for example, new ices can be of between 12% - 20% [23] when growing from seawaters with normal salinity of 32 - 35 ppts or greater. Further cooling during winter reduces salinity. Therefore, it is reasonable to consider that the salinity of sea ices melted during the melting season has reduced gradually from early years when more new ice was formed around the matured ones, and the amount of new ice reduces recently as the global warming proceeds.

Similar to pure ice, sea ices are resistant to melting because it needs more heat (*i.e.*, latent heat of fusion) to go through the phase transformation. Because of very limited knowledge and data on sea ices behavior and physicochemical properties, details of the formation and ablation are not very clear yet, and much less is known about how sea ices melt in the real ocean environment, however the process is very complicated. Sea ices melt at distinguishingly higher temperatures than the freezing points (-2.0 [20] - -1.8°C [21]). From Spring to Autumn seawaters and surface air over them become warmer, it is hypothesized that when the in-situ temperature in the bulk sea ices exceeds a point at which the ice - brine pocket remains at microscopic level equilibrium at the interface [19], the melting process initiates, meltwater diluting the brine solution in the pocket, enlarging the brine flux channel and accelerating the ice melting, as a result, increasing sea ices melt. Towards summer, temperature becomes higher and the melting speeds up. Sea ices can melt completely at a temperature (T_f) determined by the following equation [19],

$$T_f = m_m * S_{si} \quad (7)$$

For example, the potentially complete melting temperature is about -0.22°C when the salinity (S_{si}) is 4 ppts and enough heat energy is available. However, due to the vast volume of sea ices and relatively limited heat availability, only a part of the ices can melt before getting into winter to re-form ices.

As such, it is anticipated that no evident phase transformation (or fusion) from sea ices to seawaters can be observed, at a certain temperature, that can be expected by a certain value of latent heat of fusion, instead, a transitional process exists that merges the phase transformation into a melting process. Under such a situation, using sea ices' effective specific heat capacity (ESHC) [19] [22] is more appropriate. ESHC includes the latent heat for phase transformation (*i.e.*, fusion) that accompanies temperature change in sea ices [19]. Furthermore, the latent heat of fusion is a function of salinity and temperature [19] [22] [24].

According to Ono [24], sea ices' ESHC can be expressed as below:

$$C_{psi} = \left(0.505 + 0.0018T + 4.3115 \frac{S_{si}}{T} - 0.0008S_{si} + 0.00002TS_{si} \right) * 4.1868 \quad (8)$$

Similarly, using effective latent heat of fusion to describe sea ices heat requirement during phase transformation is advisable. Sea ices' effective latent heat of fusion can be expressed as below according to Petrich *et al.* [19]:

$$L_{psi} = L_{pgl} - C_{pgl}T + C_{pgl}m_m S_{si} - m_m L_{pgl} \frac{S_{si}}{T} \quad (9)$$

Or simply,

$$L_{psi} = 333.4 - 2.11T - 0.1142S_{si} + 18.0403 \frac{S_{si}}{T} \quad (9a)$$

where,

m_m Water's freezing point depression as a function of salinity S_{si} , -0.054 K/ppt,

S_{si} Salinity of sea ices, in parts per thousand (ppts),

T Temperature of sea ices in degrees Celsius ($^{\circ}\text{C}$), $T < 0^{\circ}\text{C}$.

Assuming the values of salinity of sea ices are as indicated in **Table 1** for this study period concerned, where they are decreasing gradually due to less formation of new sea ices, and this decrease escalates in recent decades as warming accelerates.

Meanwhile, the ESHC of sea ices at -2°C (the most conservatively highest temperature at which it is in a steady state), the melting point temperature for potentially melting completely as well as the latent heat of fusion at the melting point that are calculated from Equations (7)-(9a) are also included in **Table 1**.

For air, its SHC depends on the temperature and the moisture content, and the latter can be derived from relative humidity. Air SHC is calculated by the equation in [25] with the procedures prescribed in [8], *i.e.*, obtaining the absolute humidity from relative humidity and then water vapor's SHC at the corresponding temperature. **Table 2** shows the surface air's temperature, relative humidity, absolute humidity, water vapor's SHC and finally the air's SHC. The water vapor's SHC at 20°C is obtained by simple linear interpolation between 2°C (*i.e.*, 275 K, $1.859 \text{ KJ}\cdot\text{Kg}^{-1}\cdot\text{K}^{-1}$) and 27°C (*i.e.*, 300 K, $1.864 \text{ KJ}\cdot\text{Kg}^{-1}\cdot\text{K}^{-1}$) [26]. The global average of air relative humidity and temperatures are obtained from the respective datasets [27] and [28] on an annual basis.

For seawaters, its SHC is determined by its surface temperature that is averaged from the datasets [29] annually, and the corresponding SHC is about $4.004 \text{ KJ}\cdot\text{Kg}^{-1}\cdot\text{K}^{-1}$ at the corresponding temperature range of $13^{\circ}\text{C} - 14^{\circ}\text{C}$ [30] as shown in **Table 3**.

The land's SHC is assumed to be $0.83 \text{ KJ}\cdot\text{Kg}^{-1}\cdot\text{K}^{-1}$ from [31].

Therefore, the relative strengths of SHCs (or simply SHC shares) of air, seawaters, land, sea ices, and glaciers in the climate system are summarized in **Table 4** for the study period, which determines how much heat will be allocated to each component respectively.

3. Result Analyses and Discussions

According to BP Global [32], the global total energy consumption, global total

Table 1. Sea Ice salinity, Effective Specific Heat Capacity (SHC), Melting Point Temperature, and Latent Heat of Fusion at Melting Point.

Year	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Sea ice salinity, ppt	12	12	12	12	12	12	12	12	12	12	11	11
Sea ice ESHC @ −2°C, steady state, KJ/Kg/K	56.2112	56.2112	56.2112	56.2112	56.2112	56.2112	56.2112	56.2112	56.2112	56.2112	51.7019	51.7019
Sea ice (complete) melting point, °C	−0.649	−0.649	−0.649	−0.649	−0.649	−0.649	−0.649	−0.649	−0.649	−0.649	−0.595	−0.595
Sea ice fusion heat, KJ/Kg at melting point	334.434	334.434	334.434	334.434	334.434	334.434	334.434	334.434	334.434	334.434	334.32	334.32
Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Sea ice salinity, ppt	11	11	11	11	11	11	11	11	10	10	10	10
Sea ice ESHC @ −2°C, steady state, KJ/Kg/K	51.7019	51.7019	51.7019	51.7019	51.7019	51.7019	51.7019	51.7019	47.1926	47.1926	47.1926	47.1926
Sea ice (complete) melting point, °C	−0.595	−0.595	−0.595	−0.595	−0.595	−0.595	−0.595	−0.595	−0.541	−0.541	−0.541	−0.541
Sea ice fusion heat, KJ/Kg at melting point	334.32	334.32	334.32	334.32	334.32	334.32	334.32	334.32	334.206	334.206	334.206	334.206
Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sea ice salinity, ppt	10	9	9	9	9	9	8	8	8	8	8	7
Sea ice ESHC @ −2°C, steady state, KJ/Kg/K	47.1926	42.6832	42.6832	42.6832	42.6832	42.6832	38.1739	38.1739	38.1739	38.1739	38.1739	33.6646
Sea ice (complete) melting point, °C	−0.541	−0.487	−0.487	−0.487	−0.487	−0.487	−0.433	−0.433	−0.433	−0.433	−0.433	−0.379
Sea ice fusion heat, KJ/Kg at melting point	334.206	334.092	334.092	334.092	334.092	334.092	333.978	333.978	333.978	333.978	333.978	333.864
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Sea ice salinity, ppt	7	7	7	7	6	6	6	6	6	5	5	5
Sea ice ESHC @ −2°C, steady state, KJ/Kg/K	33.6646	33.6646	33.6646	33.6646	29.1552	29.1552	29.1552	29.1552	29.1552	24.6459	24.6459	24.6459
Sea ice (complete) melting point, °C	−0.379	−0.379	−0.379	−0.379	−0.325	−0.325	−0.325	−0.325	−0.325	−0.271	−0.271	−0.271
Sea ice fusion heat, KJ/Kg at melting point	333.864	333.864	333.864	333.864	333.75	333.75	333.75	333.75	333.75	333.636	333.636	333.636
Year	2013	2014	2015	2016	2017	2018	2019					
Sea ice salinity, ppt	5	5	4	4	4	4	4					
Sea ice ESHC @ −2°C, steady state, KJ/Kg/K	24.6459	24.6459	20.1366	20.1366	20.1366	20.1366	20.1366					
Sea ice (complete) melting point, °C	−0.271	−0.271	−0.216	−0.216	−0.216	−0.216	−0.216					
Sea ice fusion heat, KJ/Kg at melting point	333.636	333.636	333.522	333.522	333.522	333.522	333.522					

Table 2. Surface air relative and absolute humidity; temperature, density, specific heat capacities of water vapor, dry air, and surface air.

Year	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Global average of air relative humidity, % [27]	79.277	79.420	79.622	79.181	79.502	79.403	78.719	78.738	79.009	79.027	79.094	79.155	79.172	79.178
Global average of air mean temperature [28]	20.471	20.132	19.119	19.166	18.983	18.853	18.921	18.996	18.952	19.029	18.887	18.723	19.003	18.903
air density, Kg/m ³	1.202	1.204	1.208	1.208	1.208	1.209	1.209	1.208	1.208	1.208	1.209	1.209	1.208	1.209
Air absolute humidity, g/Kg	0.117	0.115	0.108	0.108	0.107	0.106	0.106	0.106	0.106	0.107	0.106	0.105	0.107	0.106
Dry air specific heat capacity, KJ/(Kg*K) [34]	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006
Water vapor specific heat capacity, KJ/(Kg*K)	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863
Surface air specific heat capacity, KJ/(Kg*K)	1.224	1.220	1.208	1.207	1.206	1.204	1.203	1.204	1.204	1.205	1.203	1.201	1.205	1.204
Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Global average of air relative humidity, % [27]	79.207	79.251	79.440	78.942	78.862	78.940	79.093	78.714	79.185	79.249	79.022	79.023	78.946	78.978
Global average of air mean temperature [28]	18.929	19.005	18.928	19.143	19.315	19.033	19.009	19.317	19.083	18.689	18.944	19.407	19.109	19.162
air density, Kg/m ³	1.209	1.208	1.209	1.208	1.207	1.208	1.208	1.207	1.208	1.210	1.208	1.207	1.208	1.208
Air absolute humidity, g/Kg	0.106	0.107	0.107	0.107	0.108	0.107	0.107	0.108	0.107	0.105	0.106	0.109	0.107	0.108
Dry air specific heat capacity, KJ/(Kg*K) [34]	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006
Water vapor specific heat capacity, KJ/(Kg*K)	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863
Surface air specific heat capacity, KJ/(Kg*K)	1.204	1.205	1.205	1.206	1.208	1.205	1.205	1.208	1.206	1.201	1.204	1.210	1.206	1.206
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Global average of air relative humidity, % [27]	79.022	79.092	79.143	79.323	79.170	79.326	79.369	79.413	78.895	78.837	78.908	78.787	79.032	79.018
Global average of air mean temperature [28]	19.077	19.222	19.107	18.803	19.247	19.553	18.760	18.649	18.611	18.722	18.834	18.665	18.737	19.034
air density, Kg/m ³	1.208	1.207	1.208	1.209	1.207	1.206	1.209	1.210	1.210	1.209	1.209	1.210	1.209	1.208
Air absolute humidity, g/Kg	0.107	0.108	0.107	0.106	0.108	0.111	0.105	0.105	0.104	0.104	0.105	0.104	0.105	0.107
Dry air specific heat capacity, KJ/(Kg*K) [34]	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006
Water vapor specific heat capacity, KJ/(Kg*K)	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863
Surface air specific heat capacity, KJ/(Kg*K)	1.205	1.207	1.206	1.203	1.208	1.212	1.202	1.201	1.199	1.201	1.202	1.200	1.201	1.205

Continued

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Global average of air relative humidity, % [27]	78.947	78.859	78.775	79.136	78.915	79.030	78.696	78.487	78.608	78.716	78.671	78.896	78.565	79.003
Global average of air mean temperature [28]	18.756	18.708	18.854	18.664	18.706	18.955	18.616	19.142	19.554	19.494	19.219	19.102	19.286	19.433
air density, Kg/m ³	1.209	1.209	1.209	1.210	1.209	1.208	1.210	1.208	1.206	1.206	1.207	1.208	1.207	1.206
Air absolute humidity, g/Kg	0.105	0.104	0.105	0.104	0.104	0.106	0.104	0.107	0.110	0.109	0.108	0.107	0.108	0.109
Dry air specific heat capacity, KJ/(Kg*K) [34]	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006
Water vapor specific heat capacity, KJ/(Kg*K)	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863	1.863
Surface air specific heat capacity, KJ/(Kg*K)	1.201	1.201	1.202	1.201	1.201	1.204	1.199	1.205	1.210	1.210	1.206	1.205	1.207	1.210

Note: Global averages of air relative humidity and air temperatures are obtained from the NOAA's respective datasets [27] [28] on annual basis.

Table 3. Sea surface temperature, seawater specific heat capacity (SHC).

Year	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Global sea surface temperature, °C [29]	13.61	13.7	13.76	13.72	13.84	13.84	13.81	13.84	13.94	13.82	13.85	13.79	13.93	13.91
Seawater SHC, KJ·Kg ⁻¹ ·K ⁻¹ [30]	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004
Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Global sea surface temperature, °C [29]	13.97	13.93	13.96	13.89	13.96	13.93	13.96	13.96	14	14.1	14.03	14.09	14.06	13.94
Seawater SHC, KJ·Kg ⁻¹ ·K ⁻¹ [30]	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Global sea surface temperature, °C [29]	13.93	13.99	14.03	14.04	14.03	14.19	14.14	14.09	14.17	14.16	14.15	14.11	14.16	14.14
Seawater SHC, KJ·Kg ⁻¹ ·K ⁻¹ [30]	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Global sea surface temperature, °C [29]	14.2	14.21	14.25	14.32	14.31	14.31	14.32	14.35	14.38	14.46	14.4	14.39	14.33	14.34
Seawater SHC, KJ·Kg ⁻¹ ·K ⁻¹ [30]	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004	4.004

Table 4. Relative shares of specific heat capacities of air, seawater, land, sea ices and glaciers (%).

Year	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Atmospheric air, %	1.90	1.90	1.88	1.88	1.87	1.87	1.87	1.87	1.87	1.87	2.01	2.01	2.01	2.01
Seawaters, %	6.22	6.22	6.22	6.22	6.22	6.22	6.22	6.22	6.22	6.22	6.69	6.69	6.69	6.69
Vegetated land, %	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.39	1.39	1.39	1.39
Glaciers, %	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.53	3.53	3.53	3.53
Sea Ice, %	87.31	87.32	87.34	87.34	87.34	87.34	87.34	87.34	87.34	87.34	86.39	86.39	86.38	86.39
Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Atmospheric air, %	2.01	2.01	2.01	2.02	2.02	2.01	2.18	2.18	2.18	2.17	2.18	2.38	2.37	2.37
Seawaters, %	6.69	6.69	6.69	6.69	6.69	6.69	7.24	7.23	7.23	7.24	7.24	7.88	7.88	7.88
Vegetated land, %	1.39	1.39	1.39	1.39	1.39	1.39	1.50	1.50	1.50	1.50	1.50	1.63	1.63	1.63
Glaciers, %	3.53	3.53	3.53	3.53	3.53	3.53	3.81	3.81	3.81	3.81	3.81	4.15	4.15	4.15
Sea Ice, %	86.39	86.38	86.38	86.38	86.38	86.38	85.28	85.27	85.27	85.28	85.28	83.96	83.97	83.97
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Atmospheric air, %	2.37	2.38	2.60	2.60	2.61	2.62	2.60	2.87	2.87	2.87	2.88	2.87	3.22	3.23
Seawaters, %	7.88	7.88	8.64	8.64	8.64	8.64	8.64	9.58	9.58	9.58	9.58	9.58	10.73	10.73
Vegetated land, %	1.63	1.63	1.79	1.79	1.79	1.79	1.79	1.99	1.99	1.99	1.99	1.99	2.23	2.22
Glaciers, %	4.15	4.15	4.55	4.56	4.55	4.55	4.56	5.05	5.05	5.05	5.05	5.05	5.66	5.66
Sea Ice, %	83.97	83.96	82.41	82.41	82.40	82.40	82.41	80.52	80.52	80.52	80.52	80.52	78.16	78.16
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Atmospheric air, %	3.22	3.22	3.22	3.66	3.66	3.67	3.66	3.67	4.28	4.28	4.26	4.26	4.27	4.28
Seawaters, %	10.73	10.73	10.73	12.21	12.21	12.21	12.21	12.21	14.15	14.15	14.15	14.16	14.15	14.15
Vegetated land, %	2.23	2.23	2.23	2.53	2.53	2.53	2.53	2.53	2.93	2.93	2.93	2.93	2.93	2.93
Glaciers, %	5.66	5.66	5.66	6.43	6.43	6.43	6.44	6.43	7.46	7.46	7.46	7.46	7.46	7.46
Sea Ice, %	78.16	78.16	78.16	75.16	75.16	75.15	75.17	75.15	71.18	71.18	71.19	71.19	71.19	71.18

non-renewable energy consumption, the energy entered the climate system as waste heat from human activities (EECE = 20% as discussed earlier), and the energy allocated to air, seawaters, land as well as sea ices and glaciers are shown in **Table 5**. The allocation is calculated based on the waste heat multiplied by the corresponding share percentage of each component's SHC as shown in **Table 4**.

It is mentioned earlier that both waste heat and CO₂ are concurrent by-products of fossil fuel burning. **Figure 2** shows their strong correlation. Clearly this correlation is much stronger (correlation coefficient $R^2 = 0.9839$) than that between the temperature anomalies and CO₂ (correlation coefficient $R^2 = 0.8677$) shown in the small figure at the top right in **Figure 1** for the same period of 1965 ~ 2011, implying that air temperature anomalies could be more reasonably due to waste heat, as opposed to increased CO₂ or GHGs. It is worth noting that the

Table 5. Energy consumption and distribution of waste heat among the components in climate system.

Year	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Global Total Energy Effective Conversion Efficiency	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Global Primary Energy Consumption, 10^{18} J	155.2	163.5	169.7	179.9	192	204.2	212.5	224	237.1	238.4	239.6	252.5	261.7	272.2
Global consumption of non-renewable energy, E+18 J	145.8	153.4	159.4	169.1	180.5	192.2	199.9	210.8	223.7	223.7	224.7	237.6	246.3	255.6
Total energy entered climate system, E+17 KJ	1.166	1.228	1.275	1.353	1.444	1.537	1.6	1.686	1.789	1.79	1.798	1.901	1.97	2.044
The surface air absorbed heat, E+15 KJ	2.218	2.326	2.392	2.537	2.705	2.875	2.989	3.154	3.347	3.35	3.614	3.816	3.967	4.112
The sea surface waters absorbed heat, E+15 KJ	7.253	7.635	7.931	8.415	8.983	9.564	9.952	10.49	11.13	11.13	12.03	12.72	13.18	13.68
The land surface absorbed heat, E+15 KJ	1.503	1.583	1.644	1.744	1.862	1.983	2.063	2.175	2.308	2.308	2.493	2.636	2.733	2.835
Sea Ice absorbed heat, E+15 KJ	101.8	107.2	111.3	118.1	126.1	134.3	139.7	147.3	156.3	156.3	155.3	164.2	170.2	176.6
Glaciers absorbed heat, E+15 KJ	3.822	4.023	4.18	4.434	4.734	5.04	5.244	5.528	5.867	5.867	6.338	6.701	6.947	7.208
Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Global Total Energy Effective Conversion Efficiency	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Global Primary Energy Consumption, 10^{18} J	281.6	279.4	278.2	276.6	281	294.3	302	308.8	319.6	331.8	338.2	342.1	344.6	346.9
Global consumption of non-renewable energy, E+18 J	264.1	261.5	259.8	257.8	261.4	273.9	281.2	287.6	298.1	309.5	315.9	319	320.9	323.1
Total energy entered climate system, E+17 KJ	2.113	2.092	2.079	2.063	2.091	2.192	2.25	2.301	2.385	2.476	2.527	2.552	2.567	2.585
The surface air absorbed heat, E+15 KJ	4.251	4.212	4.184	4.157	4.22	4.411	4.898	5.021	5.196	5.375	5.498	6.072	6.088	6.134
The sea surface waters absorbed heat, E+15 KJ	14.14	13.99	13.91	13.8	13.99	14.66	16.28	16.65	17.25	17.92	18.29	20.1	20.22	20.36
The land surface absorbed heat, E+15 KJ	2.93	2.901	2.883	2.86	2.9	3.039	3.374	3.451	3.576	3.714	3.791	4.166	4.191	4.22
Sea Ice absorbed heat, E+15 KJ	182.5	180.7	179.6	178.2	180.6	189.3	191.8	196.2	203.3	211.2	215.5	214.3	215.5	217
Glaciers absorbed heat, E+15 KJ	7.449	7.375	7.328	7.272	7.372	7.726	8.578	8.773	9.091	9.442	9.637	10.59	10.65	10.73
Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Global Total Energy Effective Conversion Efficiency	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Global Primary Energy Consumption, 10^{18} J	349.5	354.1	361.9	372.3	376	378.1	384.8	394.5	398.3	407.2	421.6	442.4	456.6	469.6
Global consumption of non-renewable energy, E+18 J	324.3	328.6	335	345	348.1	349.9	356.3	365.3	369.9	378.1	392.5	411	424	435.4

Continued

Total energy entered climate system, E+17 KJ	2.594	2.629	2.68	2.76	2.785	2.799	2.851	2.922	2.959	3.024	3.14	3.288	3.392	3.483
The surface air absorbed heat, E+15 KJ	6.152	6.244	6.979	7.167	7.262	7.325	7.4	8.396	8.49	8.685	9.028	9.436	10.92	11.25
The sea surface waters absorbed heat, E+15 KJ	20.43	20.71	23.17	23.86	24.07	24.19	24.64	27.99	28.34	28.96	30.07	31.49	36.41	37.39
The land surface absorbed heat, E+15 KJ	4.236	4.292	4.802	4.946	4.99	5.015	5.108	5.802	5.875	6.004	6.233	6.527	7.548	7.75
Sea Ice absorbed heat, E+15 KJ	217.8	220.7	220.9	227.5	229.5	230.7	234.9	235.3	238.3	243.5	252.8	264.7	265.1	272.2
Glaciers absorbed heat, E+15 KJ	10.77	10.91	12.21	12.57	12.68	12.75	12.99	14.75	14.94	15.26	15.85	16.59	19.19	19.7
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Global Total Energy Effective Conversion Efficiency	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Global Primary Energy Consumption, 10 ¹⁸ J	484.2	489.5	482	505.4	517.6	524.6	534.3	539.6	544.4	551.7	561.8	576.1	581.5	557.1
Global consumption of non-renewable energy, E+18 J	448.9	451.4	443.1	463.5	473.9	478.2	485	487.8	490.9	495.3	502.2	512.9	515	487.2
Total energy entered climate system, E+17 KJ	3.591	3.611	3.545	3.708	3.791	3.825	3.88	3.903	3.927	3.962	4.017	4.103	4.12	3.898
The surface air absorbed heat, E+15 KJ	11.56	11.62	11.42	13.58	13.88	14.04	14.19	14.34	16.8	16.94	17.13	17.49	17.58	16.67
The sea surface waters absorbed heat, E+15 KJ	38.55	38.76	38.05	45.28	46.29	46.71	47.38	47.65	55.59	56.07	56.87	58.08	58.32	55.17
The land surface absorbed heat, E+15 KJ	7.99	8.035	7.887	9.386	9.596	9.682	9.821	9.877	11.52	11.62	11.79	12.04	12.09	11.44
Sea Ice absorbed heat, E+15 KJ	280.7	282.3	277.1	278.7	285	287.5	291.6	293.3	279.5	282	286	292.1	293.3	277.4
Glaciers absorbed heat, E+15 KJ	20.31	20.43	20.05	23.86	24.4	24.61	24.97	25.11	29.29	29.55	29.97	30.61	30.73	29.07

Note: The difference between global primary energy consumption and global consumption of non-renewable energy is the amount of total renewable energy that includes solar, wind, hydro, and biomass—referred to as surface renewable energy (geothermal should not be included in the renewable energy category, but in BP's report [32] the geothermal is instead included in the renewable energy. Due to its small amount this won't affect the results).

CO₂ here comes from various sources, not just combustion. However, if only considering CO₂ from fossil fuel burning, it is anticipated that the correlation between them should be much stronger. Later, the effects of waste heat on surface air, land and seawaters surface temperature anomalies and on sea level rise will also be investigated and confirmed.

If this is true, then CO₂ from combustion could serve as an indirect and easy indicator to assess how much waste heat pumped into the system and consequently how it impacts the system.

3.1. Surface Air Temperature Changes

Air temperature changes calculated by using Equation (2), the allocated waste

heat energy entered the surface air boundary layer, the air density, and SHC in **Table 2**, are shown in **Figure 3** at different layer depths, in which NASA's annual mean of observed anomalies and 5-year moving Lowess smoothing [33] are

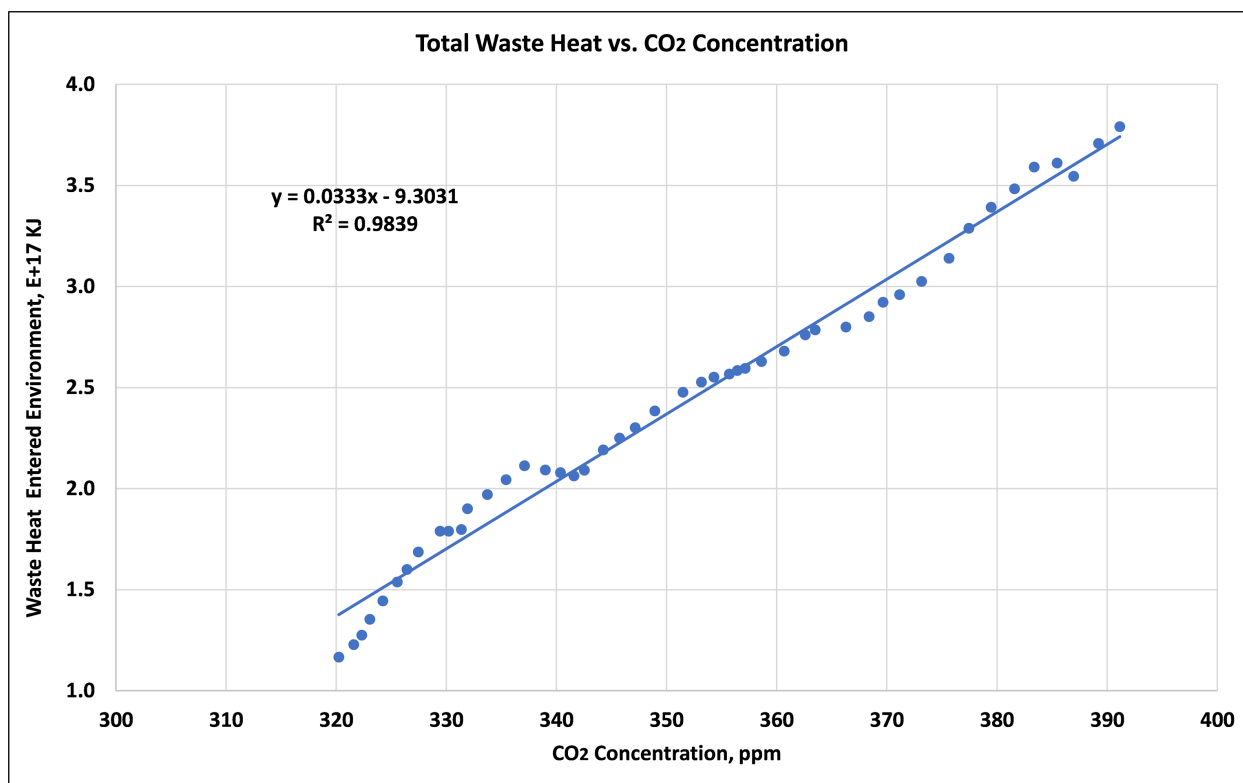


Figure 2. Correlation between waste heat entered climate system and CO₂ concentration. The amount of waste heat entered the environment is based on BP's Energy Review data [32], and CO₂ concentration is based on NASA's data [4].

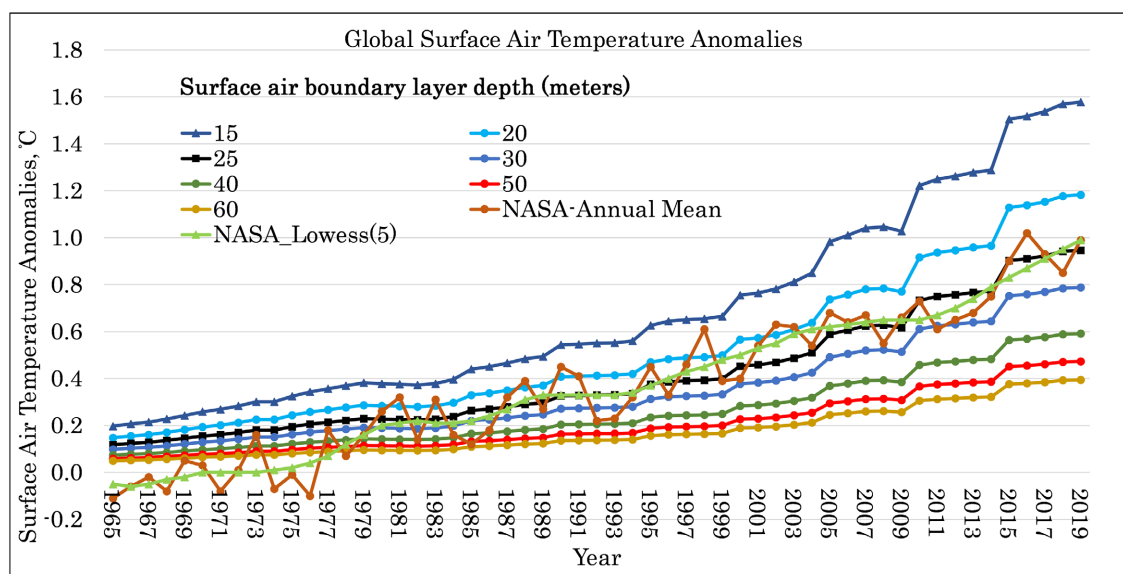


Figure 3. Simulations of global surface air temperature changes at different surface air boundary layer depths during 1965-2019. NASA's annual mean of observed anomalies (*i.e.*, NASA-Annual Mean) and 5-year moving Lowess smoothing (*i.e.*, NASA_Lowess (5)) [33] are also shown for comparison.

also exhibited.

From **Figure 3**, it is clear that in most of the time, especially the last four decades, the observed anomalies are very consistent with the calculated results at the surface air boundary layer depth between 20 - 30 meters, and the Lowess smoothing anomalies [33] are much closer to that calculated at the depth of 25 meters.

Therefore, it is reasonable to draw that a surface air column with a depth between 20 - 30 meters can be considered equivalent in simulating its warming trend, with a 25-meter depth being a representative. However, before late 1970s this is not true, observed anomalies are much less than those calculated.

Plotting the calculated results of air temperature changes at the surface air boundary layer depth of 25 meters, NASA Annual Mean and Lowess smoothing values [33] with the energy entered the surface air obtains the left in **Figure 4**, in which the corresponding trend lines are also exhibited. The black solid line on blue dots represents the strongest relation between the simulation results and the energy entered the air with a correlation coefficient of 1, which is understandable. The green triangles and dash line represent NASA's annual mean anomalies, the red squares and dot line represent Lowess 5-year smoothing values. It is noticeable that the red dot line and the green dash line are almost overlapped, with their respective correlation coefficients being 0.9361 and 0.8769 (**Figure 4**, Left), advising that the correlations between these observational values and the energy quantities are very strong. Furthermore, these trend lines of observational values are also very close to that of the simulations.

As indicated earlier, obvious differences exist between the observations and the simulations until late 1970s. Excluding these data points and only taking the rest points since 1980 is indicated at the right in **Figure 4**. It can be seen that while the simulations with the energy entered the surface air still show the strongest relation with the correlation coefficient of 1, NASA's Annual Mean

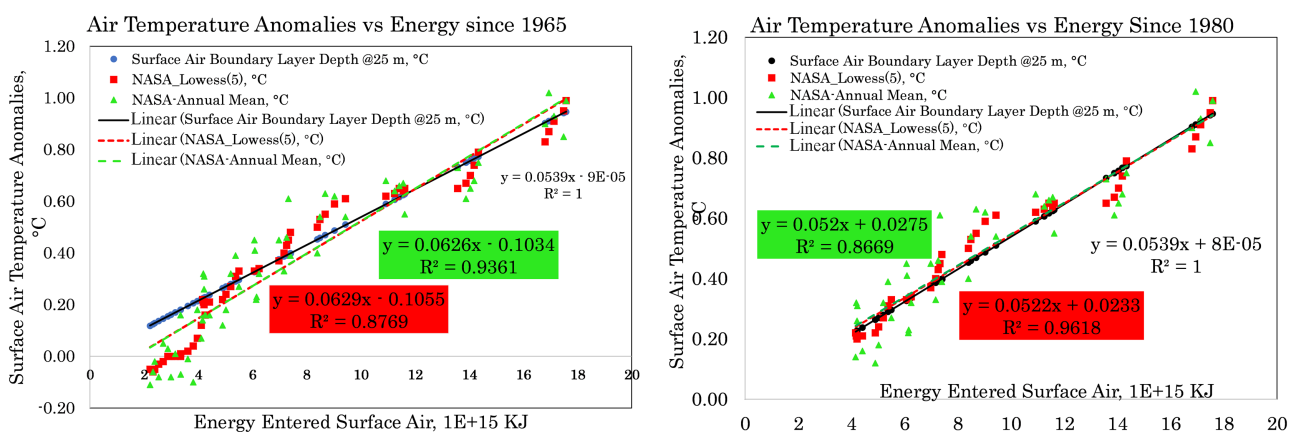


Figure 4. Correlations between surface air temperature changes (anomalies) and the energy entered the surface air layer. Blue dots and the black line show the relation between temperature changes calculated by Equation (2) and the energy entered the air with a correlation coefficient of 1; Green triangles and the green dash line represent NASA's annual mean anomalies [33]; Red squares and the red dot line represent NASA's Lowess smoothing results of the observations [33]. Left: during the period of 1965-2019; Right: during the period of 1980-2019.

and NASA's Lowess smoothing against the energy entered the air still exhibit respectively strong relations with big correlation coefficients of 0.8669 and 0.9618, and their trend lines are much closer to that of the simulations, and even they almost overlap each other, compared to those in the left figure for the period of 1965-2019. This is not by accident.

All these suggest that the temperature changes or anomalies in the surface air are strongly linked to the extra energy (*i.e.*, waste heat here) entered the air, providing direct evidence that energy beyond the earth's energy budget balance entered the surface air caused the air temperature increase. This approach can be used to predict the future surface air temperature rises.

3.2. Land Surface Temperature Changes

Simulations of land surface temperature changes by using Equation (3) and the energy entered the land in Table 5 are shown in Figure 5, in which NASA's annual mean and 5-year Lowess smoothing of observed land temperature anomalies [33] are exhibited as well.

Clearly Figure 5 shows the similar trends to surface air temperature changes as seen in Figure 3. Before late 1970s the observed anomalies deviate obviously from the simulations, with more negative anomalies; during the 1980s and 1990s the observed anomalies fluctuate between the simulations at a boundary layer depth of 0.015 and 0.15 meters, while in the last two decades the observed anomalies fall within the simulations between boundary layer depths of 0.0175 and 0.03 meters, and a depth of 0.025 meters can be a good representative since 1980.

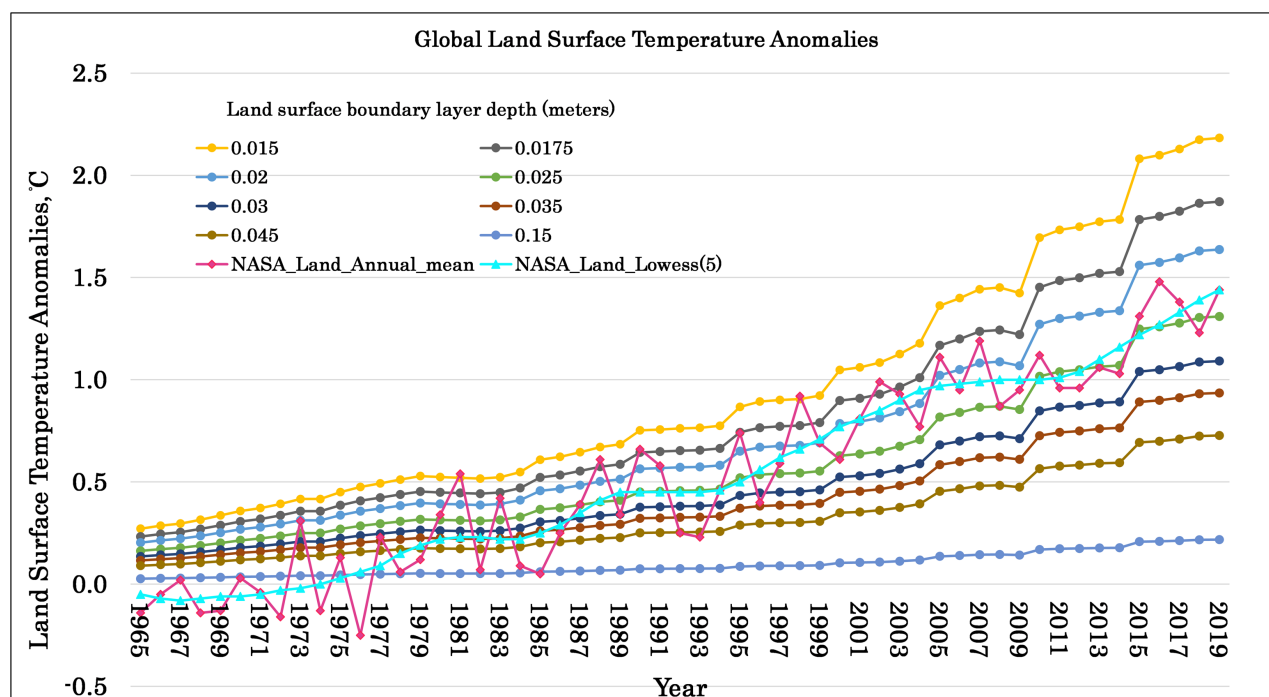


Figure 5. Simulations of global land surface temperature changes at different land surface boundary layer depths during 1965-2019. NASA's annual mean of observed anomalies (*i.e.*, NASA_Land_Annual) and 5-year moving Lowess smoothing (*i.e.*, NASA_Land_Lowess (5)) [33] are also shown for comparison.

These variations may have reflected the changes in methods and technologies of measurements as well as in natural conditions on the land surface such as vegetation covers as well as the effect of ice melting (the land is the most susceptible to any heat changes because of its smallest SHC among the components).

Plotting the simulation results at the boundary layer depth of 0.025 meters, observed anomalies (NASA_Land_Annual_mean and NASA_Land_Lowess) against the energy entered the land surface are shown in **Figure 6**: Left—the data from 1965-2019 and Right—the data from 1980-2019, revealing clearly that strong relationships exist either for the NASA_Land_Annual_mean vs the energy or the NASA_Land_Lowess vs the energy, and both have big correlation coefficients, while the simulation's correlation coefficient is 1.

Again, after excluding the data before 1980, the observational trends (NASA_Land_Annual_mean and NASA_Land_Lowess) in the right figure of **Figure 6** are much closer to the simulations than shown in the left. All these indicate that strong relationship exists between the land surface temperature change and the energy absorbed. This approach can be used to predict the future land surface temperature rises.

3.3. Sea Surface Temperature Changes

Simulations of sea surface temperature changes by using Equation (4) and the energy entered sea surface waters in **Table 5** are shown in **Figure 7**, in which NASA's annual mean and 5-year Lowess smoothing of observed sea surface temperature anomalies [33], NOAA's annual anomalies [35] are exhibited too.

Similarly, before late 1970s the observed anomalies deviate obviously from the simulations, with more negative anomalies. During 1980s and 1990s the observed anomalies fluctuate between the simulations at boundary layer depth of 0.03 and 0.1 meters, while in the last two decades the observed anomalies fall

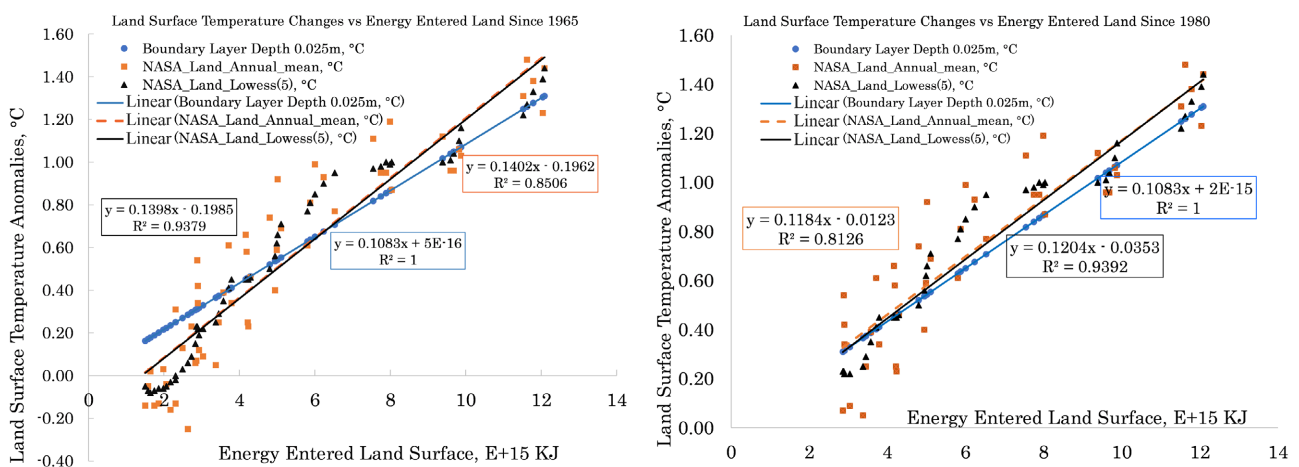


Figure 6. Correlations between land surface temperature changes (anomalies) and the energy entered the land surface layer. Blue dots and the blue solid line show the relation between temperature changes calculated by Equation (3) and the energy entered the land surface with a correlation coefficient of 1; Orange squares and the orange dash line represent NASA_Land_Annual_mean [33]; Black triangles and the black solid line represent the 5-year NASA_Land_Lowess smoothing of observations [33], respectively. Left: during the period of 1965-2019; Right: during the period of 1980-2019.

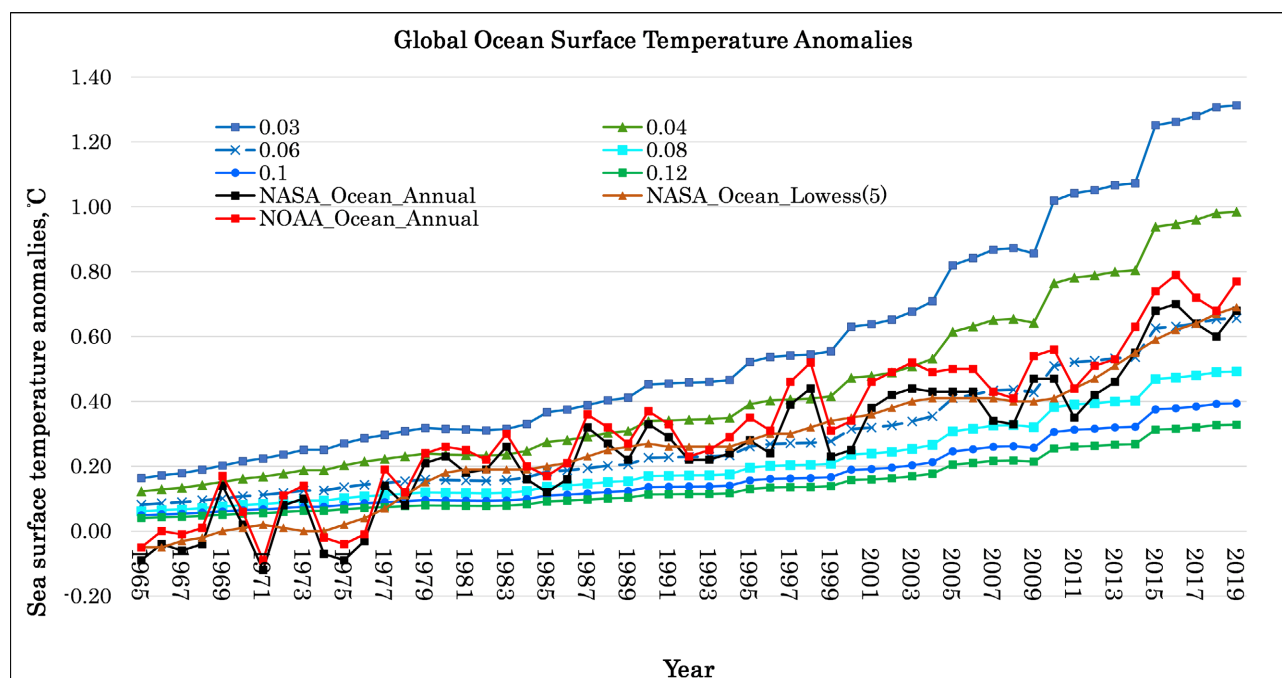


Figure 7. Simulations of global sea surface temperature changes at different sea surface boundary layer depths during 1965-2019. NASA's annual mean of observed anomalies (*i.e.*, NASA_Ocean_Annual) and 5-year moving Lowess smoothing (*i.e.*, NASA_Ocean_Lowess (5)) [33] and NOAA's annual mean anomalies (NOAA_Ocean_Annual) [35] are also shown for comparison.

within the simulations between boundary layer depth of 0.04 and 0.08 meters, and a depth of 0.06 meters can be a good representation since 1980. These variations may have reflected the changes in methods and technologies of measurements, in natural conditions of the sea surfaces such as the chemical and physical properties of surface seawaters as well as the effect of ice melting.

Plotting the simulation results at the seawaters boundary layer depth of 0.06 meters, observed anomalies (NASA_Ocean_Annual, NASA_Ocean_Lowess and NOAA_Ocean_Annual) against the energy entered the seawaters are shown in **Figure 8**: Left contains the data from 1965-2019 and Right contains data from 1980-2019, revealing clearly that strong relationships exist either for the NASA_Ocean_Annual vs the energy or the NASA_Ocean_Lowess vs the energy, or NOAA_Ocean_Annual vs the energy. All these observed anomalies trend lines have big correlation coefficients (about 0.80 or greater), and the simulation's correlation coefficient is 1.

Additionally, it is very interesting that the NOAA_Ocean_Annual trend line is almost parallel to the simulation one (*cf.* their slopes), which is important and supports that the temperature changes are due to the contribution of energy. In general, all these indicate that strong relationship exists between the sea surface temperature changes and the energy absorbed.

This approach can be used to predict the future sea surface temperature rises.

3.4. Sea Level Rise

In this study, the relationship between sea level rise and the intake energy asso-

ciated with ices melting and seawaters warming has been explored. The ices include sea ices (*i.e.*, ice sheets and covers), glaciers (including landfast ices).

Based on energy absorbed respectively by sea ices and glaciers as listed in **Table 5**, the amounts of melted sea ices and glaciers by Equations (5) and (6) are shown in **Figure 9**.

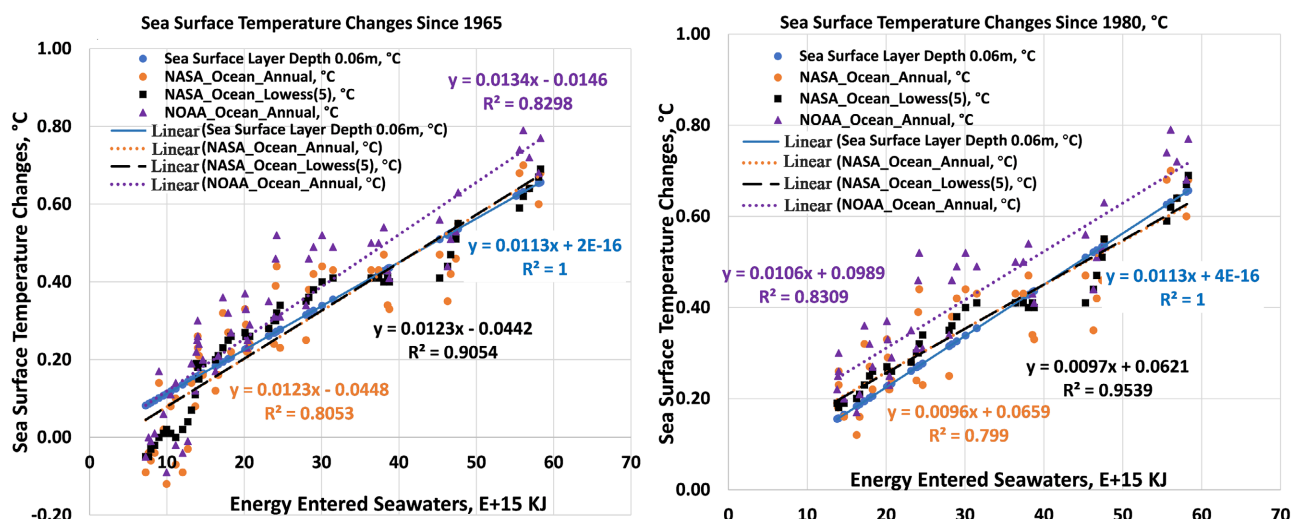


Figure 8. Correlations between sea surface temperature changes (anomalies) and the energy entered the sea surface layer. Blue dots and the blue solid line show the relation between temperature changes calculated by Equation (4) and the energy entered the sea surface with a correlation coefficient of 1; Orange dots and the orange dot line represent NASA's sea surface annual mean of observational anomalies (NASA_Ocean_Annual) [33]; Black squares and the black dash line represent the 5-year Lowess smoothing of NASA's observational anomalies (NASA_Ocean_Lowess(5)) [33]; Purple triangles and the purple dot line represent NOAA's sea surface annual mean of observational anomalies [35]. Left: during the period of 1965-2019; Right: during the period of 1980-2019.

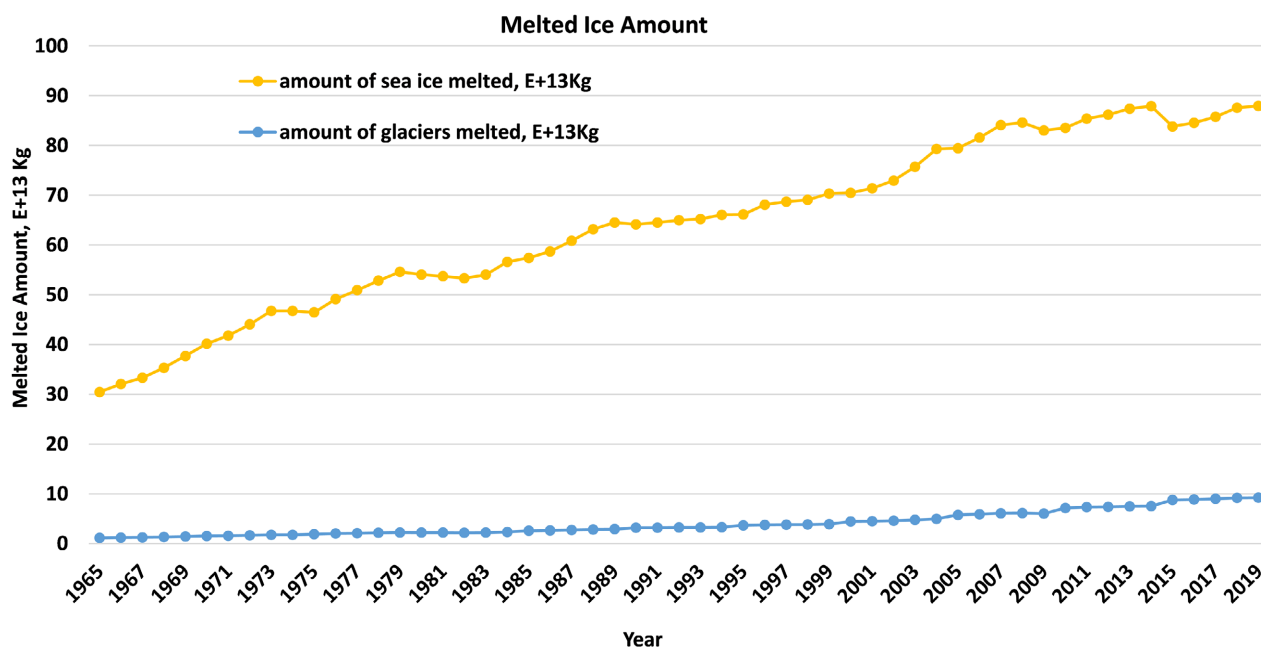


Figure 9. Melted ices amount (E+13 Kg) during 1965-2019. The top line (yellow) is the amount of melted sea ices, and the bottom one (blue) is the amount of melted glaciers.

Sea level rise consists of the following: 1) added depth from melted ices (or meltwaters), 2) added depth from meltwaters due to thermal expansion from melting point to the average of global sea surface temperatures, 3) added depth of meltwaters due to thermal expansion from seawaters warming and 4) added depth due to thermal expansion of bulk seawaters warming.

Specifically, the contribution from sea ices melting can be calculated as below:

- 1) added depth from melted sea ices;
- 2) added depth from melted sea ices due to thermal expansion from melting point (**Table 1**) to the average of global seawater surface temperature. The average seawater surface temperature during the melting season (May ~ Sept) is determined from the NCEI's ERSST V4 datasets [29] as shown in **Table 3**;
- 3) added depth from melted sea ices due to thermal expansion from the surface seawaters warming, *i.e.*, seawater surface temperature rising as discussed in the foresaid section "Sea Surface Temperature Change". The value of temperature rising is that calculated at the sea surface boundary layer depth of 0.06 meters.

The contribution from glaciers can be calculated as below:

- 1) added depth from melted glaciers;
- 2) added depth from melted glaciers due to thermal expansion from melting point (*i.e.*, 0°C) to the corresponding global average seawater surface temperature (**Table 3**). The corresponding average seawater surface temperature at the melting seasons (May ~ Sept) is determined from the NCEI's ERSST V4 datasets [29];
- 3) added depth from melted glaciers due to thermal expansion from the surface seawater warming, *i.e.*, seawater surface temperature rising as discussed in the foresaid section "Sea Surface Temperature Change". The value of temperature rising is that calculated at the seawater surface boundary layer depth of 0.06 meters.

Seawaters (including the deep waters) are subject to thermal expansion due to the cumulated entrained heat energy. According to Luann D. and Rebecca L. [36], "the 1993-2020 heat-gain rates (in oceans) were 0.37 - 0.41 Watts per square meter for depths from 0 - 700 meters, depending on which research group's analysis you consult. Meanwhile, heat gain rates were 0.15 - 0.31 Watts per square meter for depths of 700 - 2000 meters. For depths between 2000 - 6000 meters, the estimated increase was 0.06 Watts per square meter for the period from June 1992 to July 2011", the average temperature rise due to this heat gain is estimated about 3.23446×10^{-5} °C per year for the full ocean depths. Suppose this temperature rise applies to the entire period of this study and a depth of 2000 meters is taken as a representative for the entire ocean depths, seawaters' thermal expansion coefficient is 1.57×10^{-4} K⁻¹ under the pressure of 2000 decibars (in oceans one meter depth is about equivalent to 1 decibar) and 5°C at a salinity of 35 ppts [37].

The simulated global sea level rise (GSLR) that accumulates annually is shown

in **Figure 10**, where the measured global mean sea level rise (GMSL, mm) [38] is also exhibited. Clearly, they have similar trends. Since the GMSL is an accumulated record since 1880, and in 1965 its value is 86.8 mm, adjusting the GMSL by subtracting 85 mm can easily compare with the simulations which start from 1965. The adjusted GMSL (*i.e.*, GMSL-85) is also shown in **Figure 10**. Clearly at an early time the simulation is very close to the measurements, however, an increasing departure from the simulation appears with time especially in the last two decades. The potential reasons for this departure may be attributed to 1) volcanic eruptions, wildfires, coal fires [39], natural gas fires and explosions [40] [41], flares as well as various chemical fuels used in military and space explorations, etc.; 2) increase in the amount of melted multiple-year sea ices in which salinity is very low and even close to zero (0), compared to simulations with higher salinity.

Increased volcanic eruptions have been reported since 2000 [42], although the actual number may be greater and possibly remain unchanged due to inaccessibility and technological difficulties. Volcanic eruptions eject substantial energy into the climate system that can change the climate, for example, the eruption of Mount St. Helens in 1980 released 24 megatons of thermal energy, equivalent to 1600 times the size of the atomic bomb dropped on Hiroshima [43], that is about $0.1\text{E}+15$ KJ. However, huge amount of volcanic dust, etc. may also shelter solar radiations, leading to a decrease in the temperature in the system afterwards.

Additionally, wildfires occur recently more frequently and intensively such as those in California and Australia. According to Jonathan [44], the annual energy released from wildfires in Western United States is about $1.4\text{E}+15$ KJ. Although these wildfires are fueled by the biomass that is included in the earth's energy budget balance during a long growing time, the concentrated burning and

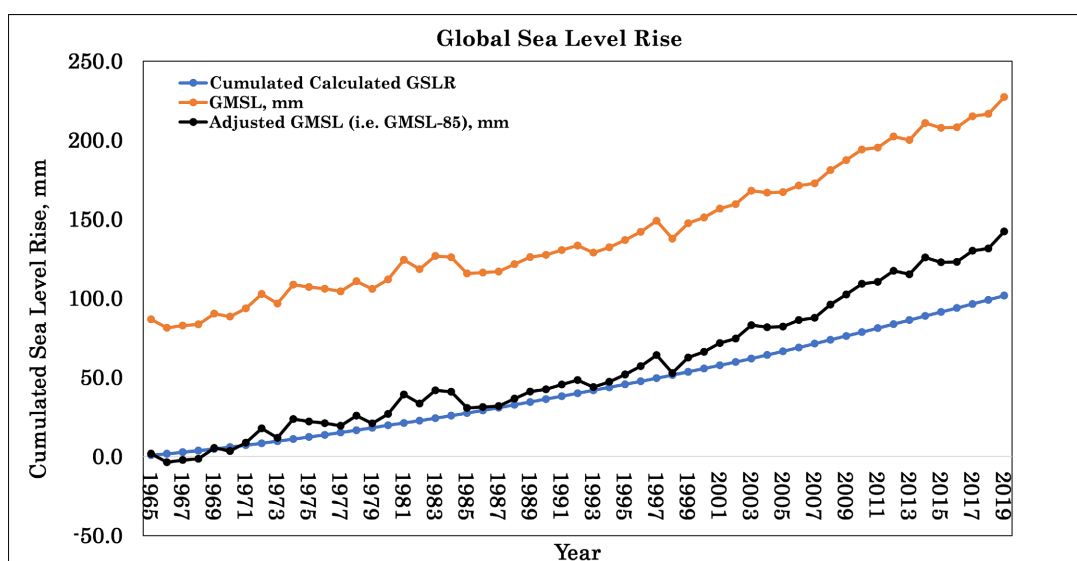


Figure 10. Cumulated simulation of sea level rise from annual melted sea ices and glaciers as well as seawaters warming, measured global mean sea level rise (*i.e.*, GMSL) [38] and adjusted GMSL (*i.e.*, Adjusted GMSL (GMSL-85)).

release of this cumulated energy in a short time will impact the system's behavior.

These compounding effects are significant on the system.

Figure 11 plots the sea level rise (both simulated sea level rise, *i.e.*, cumulated calculated GSLR and GMSL-85) against the energy associated with ice melting (*i.e.*, the sum of the energies melting sea ices and glaciers respectively). Polynomial regressions show clearly that both the measurements and the simulations have strong correlations with the energy.

According to the regression of GMSL-85 in **Figure 11**, the energy that melted ices (*i.e.*, sea ices and glaciers) in 2019 should be $339.84\text{E}+15$ KJ, compared to the allocated waste heat of $324.02\text{E}+15$ KJ, the difference of $15.82\text{E}+15$ KJ could be the extra energy coming from those forementioned energy sources. It is known that in 2019 the energy allocated to melting sea ices and glaciers is about 78.65% of total waste heat entered the climate system, thus this extra energy melting the ices corresponds to a total extra energy of $20.12\text{E}+15$ KJ. That would contribute to extra temperature rises in air, land, and oceans of about 0.021°C (depth: 25 m), 0.028°C (depth: 0.025 m) and 0.014°C (depth: 0.06 m), respectively. These correspond to adjusted simulation results of 0.97°C , 1.34°C and 0.67°C , being much closer to their corresponding observations: 0.99°C , 1.44°C and 0.68°C [33].

Furthermore, **Figure 12** shows the contributions to sea level rise of sea ices melting, glaciers melting and bulk seawaters warming on an annual basis (top) and cumulated basis (bottom) when sea ice salinity changes from 12 (1965) to 4 ppts (2019). Clearly, on an annual basis (top), the melting of sea ices is the dominant contributor to sea level rise, sharing about 90.2% - 95.6%, and glaciers contributing about 3.6% - 9.5% while bulk seawaters warming only contributes about 0.4% - 1.2%.

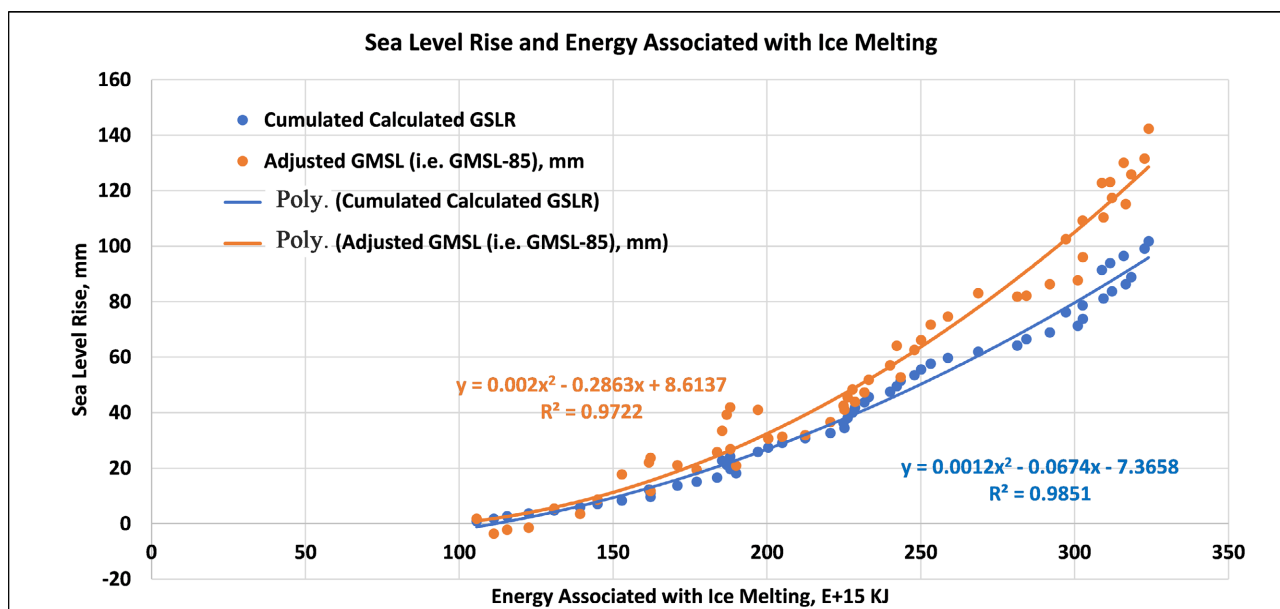


Figure 11. Relation between sea level rise and the energy associated with ice melting. Blue dots and the blue line represent the simulated results (GSLR), while orange dots and the orange line represent the measurement results less 85 mm (GMSL-85).

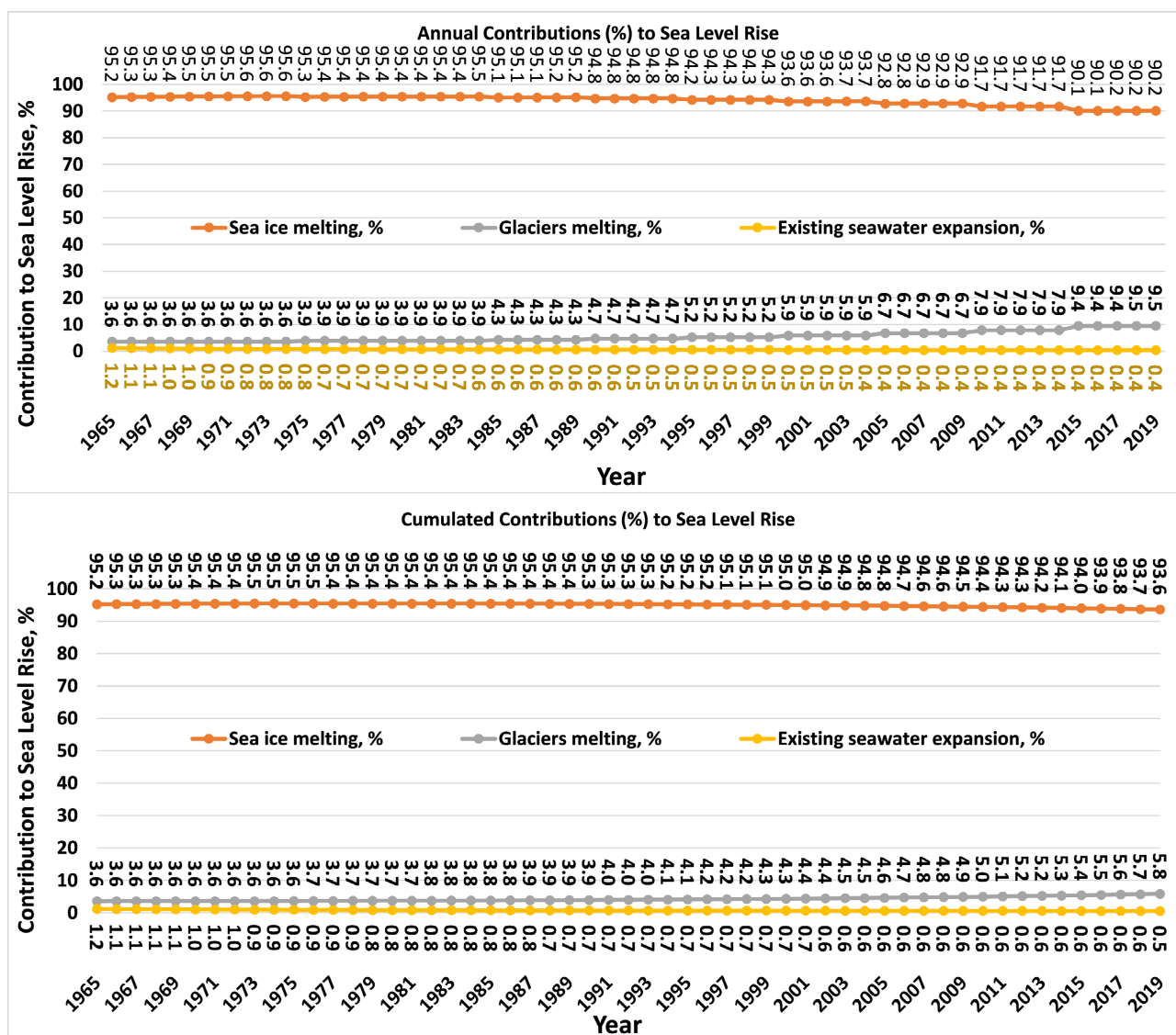


Figure 12. Contributions to sea level rise of sea ice melting, glaciers melting and bulk seawater warming on an annual and cumulated basis when sea ices salinity changes from 12 to 4 ppts from 1965 to 2019. Upper: On annual basis; Bottom: on a cumulated basis since 1965.

On the cumulated basis (bottom), the melting of sea ices still dominates the sea level rise, with its contribution ranging from 93.6% - 95.5%, glaciers melting contributes about 3.6% - 5.8% and bulk seawaters warming only shares about 0.5% - 1.2%.

We can therefore forecast future sea level rise if the salinity in sea ices and the global EECE as well as global energy consumption, etc. are known.

3.5. Miscellaneous

3.5.1. Cold Era and Warm Era

According to NOAA [45], the Earth has experienced a gradual warming since the early 1900s as indicated in **Figure 13** in which before 1900 the globe was cooling gradually from 1880. The fluctuations in temperature anomalies between

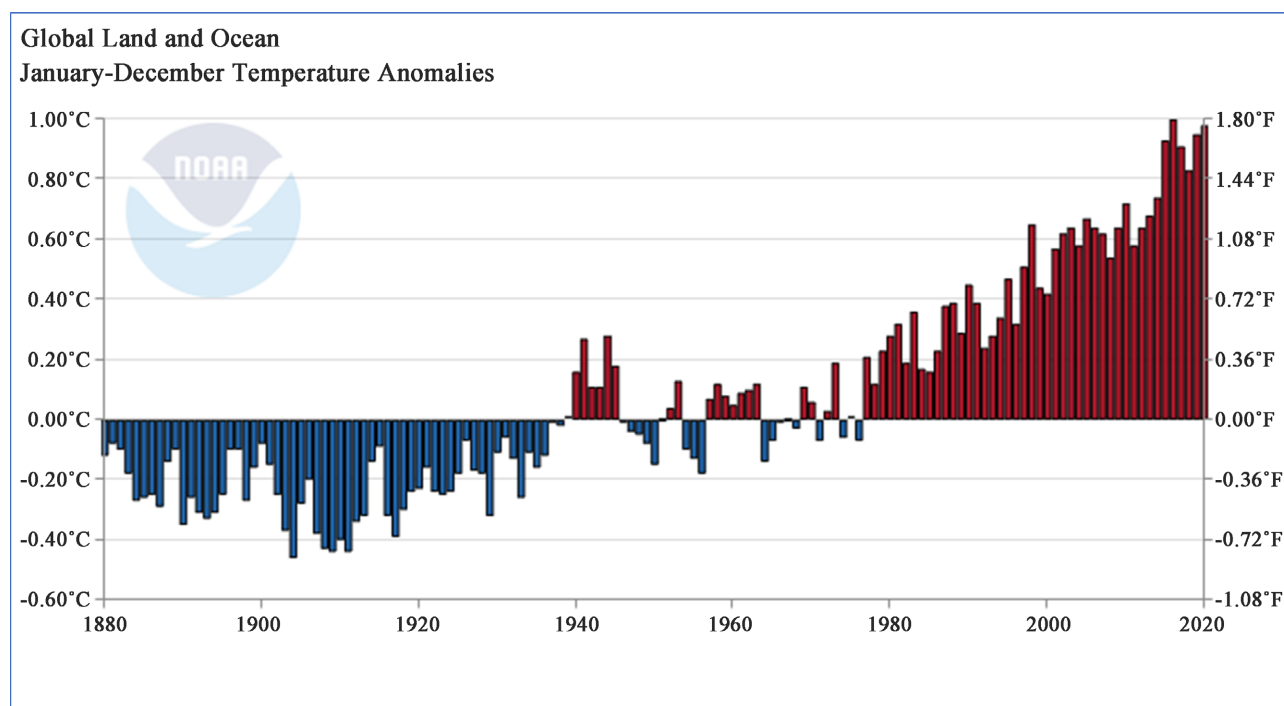


Figure 13. Global land and ocean (*i.e.*, surface air) temperature anomalies from 1880 to 2020 based on NOAA’s analyses [45]. Earth was in a gradual cooling period until the early 1900s, then turned to gradually warming although there were fluctuations in the temperature anomalies between the 1940s and late 1970s, which might be attributed to ENSO cycles: El Niño and La Niña, etc.

the early 1940s and late 1970s suggest that this is a transitional period and susceptible to any disturbance due to the ENSO cycles, *i.e.*, El Niño and La Niña, etc.

Alternatively, when looking at the heat content in oceans (**Figure 14**), a similar phenomenon is observed that before around mid-1980s the heat energy in the top half-mile depth of the oceans is negative compared to the average between 1955 and 2006 [36], which indicates that the oceans were heat energy “hungry”, *i.e.*, “aggressively” absorbing heat, and after that the oceans are “rich” in heat and storing more heat.

These suggest that the globe has experienced a change from a “cold” era to a warm one as the warming proceeds. These changes are generally consistent with the changes in sea surface temperatures as shown in **Figure 15** [29], where, similarly, the temperature was declining before 1904 and thereafter turning to an increasing trend journey, which coincides with **Figure 1**. This can be attributed to the industrialization that has consumed increasingly more fossil fuels and dissipated more waste heat into the climate system, driving the warming.

However, a time lag (several decades) exists between the two phenomena shown in **Figure 13** and **Figure 14**, which is dependent on the baseline used and due to the difference between their medium’s SHC. Although the time points at which the values of temperature anomalies and heat content turn from negative to positive are different, it is reasonable to believe that the Earth entered a warm era from around 1980.

This cold-to-warm-era transition can easily explain what we’ve seen in the

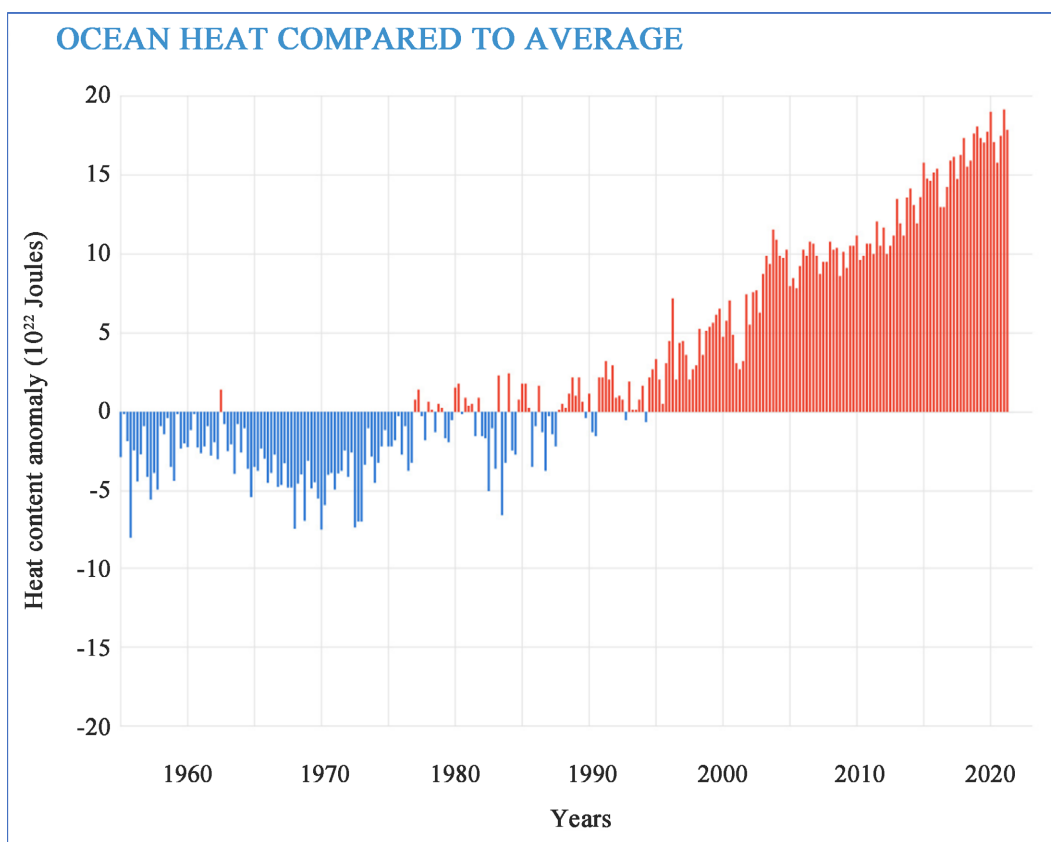


Figure 14. Global ocean heat content changes with time compared to the 1955-2006 average, more than ninety percent of the heat trapped in the climate system entered the oceans [36].



Figure 15. Sea surface temperature change from 1854 to 2020 based on NOAA's datasets of ERSST v4 [29].

simulations of temperature changes in surface air, land surface, and seawaters surface in the early years where the simulation results are always greater than the measurements. This is due to in the cold era the system (including air, land, seawaters, especially ices and possibly permafrost) needs great deal of heat to balance its energy requirement. However, we need more knowledge about the system then to better understand its behaviors.

Additionally, permafrost may also contribute to the early “abnormal” behaviors in air, land, and seawaters’ temperature anomalies by absorbing much heat before exhibiting evidence of “thawing”. As discussed above, large amount of waste heat has been cumulated towards the polar areas, especially the North because of the densified population, increased fossil fuel consumption and thus increased associated waste heat release, via the atmospheric vortexes.

3.5.2. Global Warming Forecast

Figure 16 shows the waste heat energy distribution in the climate system where the steps indicate the change of salinity in sea ices. Among the total energy that entered the climate system, about 92.8% - 96.8% entered the oceans through melting sea ices and glaciers, warming surface seawaters (this aligns well with the estimate by Luann D. and Rebecca L. [36], and **Figure 14** above), 1.9% - 4.3% absorbed by air, with the remainder (about 1.3% - 2.9%) absorbed by the land. Oceans therefore become the primary energy storage, the buffer and regulator of temperature changes in the system.

If the energy (mainly non-renewable energy) consumption, energy effective conversion efficiency and the salinity in sea ices are known, it is possible to

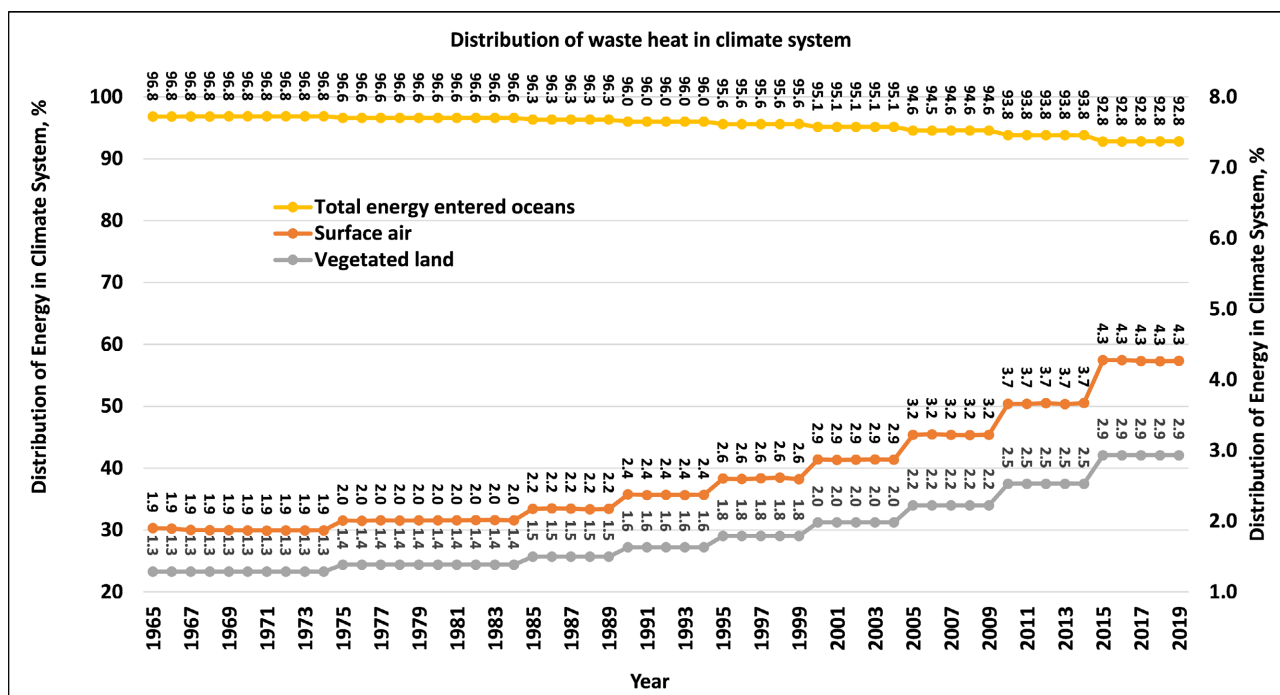


Figure 16. Waste heat energy distribution in the climate system. Energy entered surface air and land surface are shown by the secondary vertical axis, and energy entered oceans is indicated by primary vertical axis.

forecast the temperature increases in surface air, land, and oceans as well as sea level rise with very good certainty and reliability.

There are two methods that can be used for forecasting future temperature rises in air, land and oceans, and sea level rise. One is based on the thermodynamic equations as discussed earlier; and another is based on the empirical regression equations found in the corresponding regression figures above.

Using the thermodynamic equations and the 2020 global energy consumption [32], the calculated temperature rises in surface air, land, and oceans are 0.90°C, 1.24°C, 0.62°C, respectively, and the sea level rise is 104.7 mm. They are close to the observations: surface air 0.98°C, land surface 1.58°C, sea surface 0.75°C [46], sea level rise 91.3 mm [47], although differences exist that can be attributed to the extra heat energy from natural sources and chemical fuels as discussed earlier. If considering these extra energy contributions, these simulated values will be much closer to what observed. Remember that 2020 was the second warmest year in the 141-year record for air surface, and the hottest one for land surface [48] (large scale wildfires might have contributed to the hottest land surface), this may help to understand why such differences exist.

BP's 2020 Energy Outlook [49] imagines three possible scenarios *i.e.*, Rapid, NetZero and Business-as-usual (BAU), regarding how the energy economy would be transitioned in future. The energy consumptions in 2050 are estimated in Table 6 where renewables consist of wind, solar and biofuels. It is noted that the biofuels also include geothermal. The latter is a non-surface renewable energy and should be considered in the simulation, but its amount is very small, thus its impacts on the earth's energy budget balance can be negligible. Besides, the non-combusted fossils such as feedstocks for petrochemicals, etc. are excluded from this calculation.

Assuming that in 2050 the salinity in sea ices remain 4 ppts, global sea surface temperature about 14.5°C and the polar areas' sea surface temperature in the melting season is about 0.2°C, the EECE is 20% under BAU, 30% under Rapid

Table 6. Energy Outlook at 2050 (E+18 J) [49].

Scenario	Rapid	Net Zero	BAU
Total	625	625	725
Oil	89	42	172
Natural Gas	134	81	187
Coal	24	12	123
Nuclear	44	57	31
Hydro	57	62	51
Renewables (incl. biofuels)	277	370	161
Non-Combusted	44	28	53
Net Non-renewables	247	165	460

and 25% under NetZero scenarios. The forecast values of the climate change indicators (temperature risings of surface air, land surface, sea surface and sea level rise) are shown in **Table 7**. The forecast for temperature changes is performed by the two aforesaid methods: theoretical methods with Equations (2)-(4); Regression equations of simulated results and regression equations of measurements in **Figure 4**, **Figure 6**, **Figure 8** and **Figure 11**, respectively. With the endeavors and measures to be taken, the climate change indicators are remarkably suppressed under the forecast energy consumption scenarios compared to the current levels. The results produced by different methods are very close for temperatures.

With respect to sea level rise, the situation is little different as shown in **Table 7**, because decreased fossil fuels and increased surface renewables will be consumed. Using the theoretical method produces similar results under the three scenarios, which is very reliable by comparing to the current rise in sea level. Under BAU using three methods creates slightly different results, with the biggest one from Adjusted GMSL regression, while under Rapid and NetZero scenarios, the two regression methods produce much less results than those by theoretical method. Among the three methods, using Cumulated Calculated GSLR regression produces the smallest results under all three scenarios. Consequently, using the theoretical approach provided by this thermodynamic model to forecast sea level rise is highly effective and recommended. Using empirical regression methods largely underestimates concentratedly-consumed surface renewable energies' impacts

3.5.3. Challenges in Future Studies

Accurate data are very limited on global energy's effective conversion efficiency

Table 7. Forecast climate change indicators under different scenarios by different methods.

Climate Change Indicator	Forecast Method	BAU	NetZero	Rapid
Surface air temperature change at 25 m (°C)	Theoretical, Equation (2)	0.38	0.14	0.20
Surface air temperature change at 25 m (°C)	Calculated regression, Figure 4 Right	0.38	0.14	0.20
Surface air temperature change (°C)	NASA Lowess Regression, Figure 4 Right	0.39	0.15	0.22
Land surface temperature change at 0.25 m (°C)	Theoretical, Equation (3)	0.51	0.18	0.20
Land surface temperature change at 0.25 m (°C)	Calculated regression, Figure 6 Right	0.51	0.18	0.28
Land surface temperature change (°C)	NASA Lowess Regression, Figure 6 Right	0.54	0.17	0.27
Sea surface temperature change at 0.06 m (°C)	Theoretical, Equation (4)	0.26	0.09	0.14
Sea surface temperature change at 0.06 m (°C)	Calculated regression, Figure 8 Right	0.26	0.09	0.14
Sea surface temperature change (°C)	NASA Lowess Regression, Figure 8 Right	0.28	0.14	0.18
Sea surface temperature change (°C)	NOAA Regression, Figure 8 Right	0.34	0.19	0.23
Cumulated sea level rise (mm)	Theoretical	110	107	106
Cumulated sea level rise (mm)	Cumulated Calculated GSLR regression, Figure 11	103.5	1.7	19.0
Cumulated sea level rise (mm)	Adjusted GMSL Regression, Figure 11	135.4	3.0	21.5

(EECE) at various processes, sea ices salinity, melting point and thermodynamic properties of permafrost (density, SHC, melting points, etc). Therefore, collecting more accurate and reliable data will be crucial to allow accurate future modelling.

Additionally, greater attention should be paid to the relationship between extreme weather events and the heat accumulated in the environment, especially in oceans.

4. Conclusions

From these analyses, it is clear that there is no correlation between atmospheric CO₂ or GHGs and the surface air temperature anomalies, which means GHGs and global warming don't have a cause-effect relation. CO₂ (and other GHGs) and waste heat are concurrent by-products of fossil fuel combustions, they correlate strongly.

Global warming correlates strongly with the waste heat. A huge amount of waste heat from human activities provides enough energy to warm the climate system: arising temperatures of air, land, and oceans as well as melting ices (sea ices and glaciers) to raise sea level. Waste heat distributes among the components of the climate system according to their specific heat capacities, about 92.8% - 96.8% entered oceans through melting ice and warming seawaters, 1.9% - 4.3% into the air and 1.3% - 2.9% into the land. The climate system had transitioned from a cold to a warm era around 1980.

Thermodynamic simulations by means of the climate change thermodynamic model are well consistent with the observations in air, land and oceans' temperature anomalies and sea level rise, providing direct evidence that the warming is caused dominantly by the waste heat. Other extra energies entered the system also contribute to the warming. Both approaches of using thermodynamic model and using regression equations can be used for future temperature change forecasting.

Sea level rise comes from 1) meltwater, 2) meltwater thermal expansion from melting point to the average surface seawater temperature, 3) meltwater thermal expansion due to the surface seawater warming and 4) thermal expansion of seawaters by the retained heat energy. Using the thermodynamic approach to forecast future sea level rise is recommended.

Based on these, efficiently fighting global warming needs to control and reduce waste heat from human activities. Increasing energy's effective conversion efficiency (EECE), rather than only increasing energy efficiency, changing societal and personal behaviors, and reducing energy consumption through technology advancements and retrofits, as well as largely developing and prudentially planning the use of surface renewable energies are vital. Recovering and reusing waste heat from the environment will also help greatly mitigate climate change.

These findings invite the international communities to further review and

re-investigate the real root cause of the current climate change from different angles: is it GHGs or waste heat or other factors? So that the right, effective and efficient solutions can be developed.

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Conflicts of Interest

The author declares no conflicts of interest.

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